EXPERIMENT 12
BEHAVIOR OF GASES

INTRODUCTION

A large number of substances of considerable chemical interest are gases. For example, CO_2 is currently in the news because it is thought to be partly responsible for global warming. One important part of deciding whether or not this is so is to study the behavior of pure CO_2. (Another important aspect is to understand its behavior in the atmosphere—what part of the atmosphere does it reside in? How long does it remain there without reacting with some other atmospheric component or floating off into space?, etc.)

Studying the behavior of individual gases was historically a very difficult problem because one needs to isolate and contain the sample in the face of the tendency of gases to occupy the entire volume available to them. The first reliable apparatus for doing this was the pneumatic trough described by Hales (1677–1761) in 1727. (See **FIGURE 12-1**) A gas was generated by decomposing a substance in the fire.
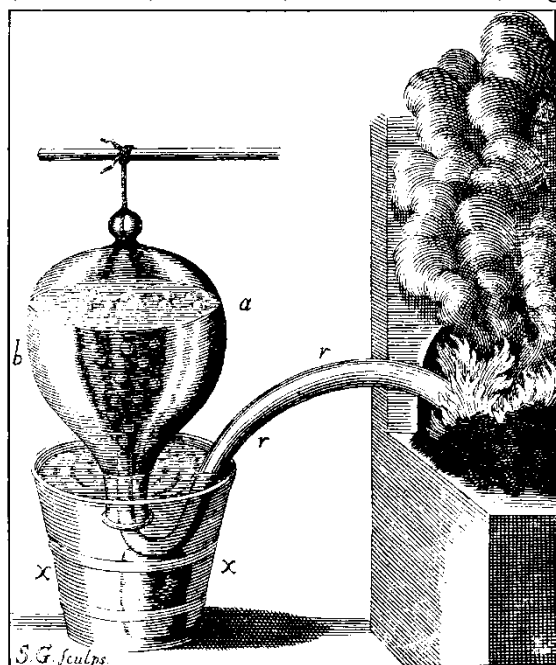
For example, one such reaction might be:

$$CaCO_3(s) \rightarrow CO_2(g) + CaO(s) \tag{12-1}$$

A gun barrel was originally used to connect the decomposition vessel to a vessel filled with water. The gas emitted passed through the barrel and exerted pressure to displace the water. After all the water was displaced, one had a pure sample of the gas (mixed with water vapor). The vessel could be capped under water and turned right side up.

Studies on many different gases revealed that their physical properties were independent of the identity of the gas, at least at ordinary pressures and temperatures. This behavior is summarized in the Ideal Gas Law:

$$\tag{12-2}$$

Figure 12-1. Hales' Pneumatic Trough Apparatus for Gas Collection.

where P = pressure, V = volume, n = number of moles of gas, R = ideal gas constant and T = temperature in Kelvins. The Ideal Gas Law was, of course, formulated from studies in which one quantity at a time was varied and the effect on some other quantity was noted. For example, Boyle (1627–1691) studied the change in volume of a sample of gas as its pressure was varied (n and T stayed constant). Amontons (1663–1705) studied how the pressure of a gas changed as the temperature was varied (n and V stayed constant). Charles (1746–1823) measured the effect on the volume of a gas as the temperature T was changed (n and P stayed constant). Dalton (1766–1844) formulated his law describing the fact that gases in a mixture behave independently of one another. For example, each gas exerts its pressure independently so that

$$P_{total} = P_1 + P_2 + P_3 + \ldots \tag{12-3}$$

where the subscripts 1, 2, 3, ... refer to the different gases in the mixture.

As a result of this behavior, we can study the physical properties of gases by using air, even though air is a mixture of gases. The purpose of this experiment is to investigate the physical properties of gases. The interesting point is how much gases do in fact conform to ideal gas behavior under conditions of low pressure and moderate temperature found in the laboratory.

In this experiment, we will explore the variation of pressure with volume (as described in Boyle's Law) and the variation of pressure with temperature (as described in Amontons' Law).

TECHNIQUE AND ANALYSIS

A. Measuring Pressure

The pressure of a confined gas sample can be measured with a manometer. This instrument consists of a U-shaped tube partially filled with mercury. When both arms of the U are open to the atmosphere, the pressure will be the same in both arms. When one arm of the manometer is attached to a closed flask containing air at atmospheric pressure, the mercury levels will remain the same in both arms, since the pressure on the mercury in the two arms is still the same (atmospheric pressure). If the pressure inside the flask is changed, the mercury levels in the manometer arms will no longer be equal. If the flask pressure is greater than atmospheric, the mercury is pushed down in the arm that is connected to the flask. If we express pressure in mm Hg, then the difference in the mercury levels, Δh (also in mm Hg), is the amount by which the pressure in the flask exceeds atmospheric pressure:

$$P_{flask} = P_{atm} + \Delta h \tag{12-4}$$

If the flask pressure is lower than atmospheric, the mercury rises in the arm connected to the flask. The difference in the mercury levels, Δh, is the amount by which the atmospheric pressure exceeds the pressure in the flask.

$$P_{flask} + \Delta h = P_{atm} \tag{12-5}$$

and so

$$P_{flask} = P_{atm} - \Delta h \tag{12-6}$$

One problem connected with using manometers is the possibility of spilling Hg. Therefore, we will only use MeasureNet to obtain pressure readings. The pressure is measured by a transducer (pressure sensor) connected on one side to a syringe containing the gas sample and open to the atmosphere on the other. The sensor is connected to the MeasureNet station, and the measured pressure is displayed on the screen in torr (mmHg). The pressure sensor acts like an open-end manometer, so the displayed values of P correspond to the Δh values discussed above. We call these displayed values P_{sensor}.

B. Pressure-Volume Measurements

We will first study the behavior of the pressure of a sample of gas as the volume changes. The gas is contained in a syringe connected to the pressure sensor by way of a Luer fitting, as shown in **FIGURE 12-**

2. The volume is varied by changing the position of the plunger. Under these circumstances n is constant (determined by the amount of air initially trapped) and T is constant (the temperature of the laboratory).

Figure 12-2. Setup for P-V Measurements.

Although it is easy to see that we can vary the gas volume and observe changes in the measured pressure, things are not quite so straightforward as they might initially seem. In fact, this experiment provides a good illustration of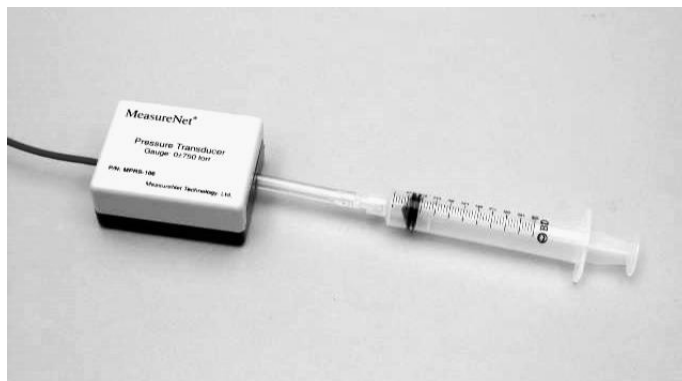 the type of situation commonly encountered in scientific investigations: it is not possible to directly measure the quantities we wish to investigate. Boyle's Law shows the relationship between the *total* volume of a gas sample and the *absolute* pressure of the gas. With the apparatus available, however, we actually measure the volume of only that portion of the gas sample contained in the syringe and the difference in pressure between the gas sample and atmospheric pressure. We must use the actually measured quantities to calculate the desired quantities.

As mentioned in Part A, the sensor measures the pressure of the gas sample relative to atmospheric pressure, so

$$P_{air} = P_{sensor} + P_{atm} \tag{12-7}$$

Since we can measure P_{atm} independently by means of a barometer, we are able to combine it with P_{sensor} values to obtain the desired values of P_{air}.

The total volume of the air sample (V_{air}) is the volume read from the syringe *plus* an additional volume we call V_{tubing}. V_{tubing} includes the volume of the tubing connecting the syringe to the pressure sensor and a small contribution in the sensor itself. Thus,

$$V_{air} = V_{syringe} + V_{tubing} \tag{12-8}$$

Although $V_{syringe}$ changes as the position of the plunger is changed, V_{tubing} does not. We have no convenient way of directly measuring V_{tubing}, so the V_{air} values cannot be directly determined. We can, however, still determine whether air behaves in the manner indicated by Boyle's Law, and, if so, determine the value of V_{tubing} in our analysis of the data.

The Ideal Gas Law, **EQUATION 12-1**, is formulated in terms of quantities pertaining to the gas sample under study. Since we are working under conditions of constant n and T, the Ideal Gas Law reduces to Boyle's Law:

$$P_{air}V_{air} = nRT = \text{constant} \tag{12-9}$$

Substituting from **EQUATION 12-8**,

$$P_{air}(V_{syringe} + V_{tubing}) = \text{constant} \tag{12-10}$$

The easiest way to determine whether the results we have obtained are consistent with **EQUATION 12-10**, and thus whether air behaves according to Boyle's Law, is to rearrange the equation into the form of an equation for a straight line, $y = mx + b$. We obtain:

$$V_{syringe} = \text{constant}\left(\frac{1}{P_{air}}\right) - V_{tubing} \tag{12-11}$$

This suggests that a plot of $V_{syringe}$ (y axis) versus $1/P_{air}$ (x axis) should be made. **If the air behaves according to Boyle's Law**, the result should be a set of points falling essentially along a straight line. The slope of the line, m, is the "constant" in **EQUATION 12-11**, and the **intercept on the $V_{syringe}$ axis,**

b (the y-intercept), is $-V_{tubing}$. This plot, therefore provides the best indication of whether air behaves according to Boyle's Law, **and, if it does,** (if the points do indeed fall along a straight line) then we obtain a value for V_{tubing} from the intercept of the line. We can use this to obtain the actual values of V_{air} so that we may further manipulate the results.

C. Pressure-Temperature Measurements

FIGURE 12-3 shows a diagram of the apparatus for measuring pressure as a function of temperature. A filter flask with a side-arm is fitted with an air-tight rubber stopper; the arm is connected with tubing to the pressure sensor which, in turn, is connected to the MeasureNet station. The filter flask is clamped in a 250 mL beaker that is filled with water so as to immerse the flask as completely as possible. The temperature probe connected to the MeasureNet station is also immersed in the water.

Under this set of experimental conditions, the quantity of air (n) remains constant (determined by the amount of air originally trapped). The volume (V) also remains essentially constant; it is the volume of the flask, side arm, tubing and sensor available to the air. Heating or cooling the water bath changes the temperature of the air inside the flask. Time must be allowed so that heat exchange can occur to make the temperature inside the flask the same as the temperature of the water in the bath. The MeasureNet station displays both temperature and pressure values.
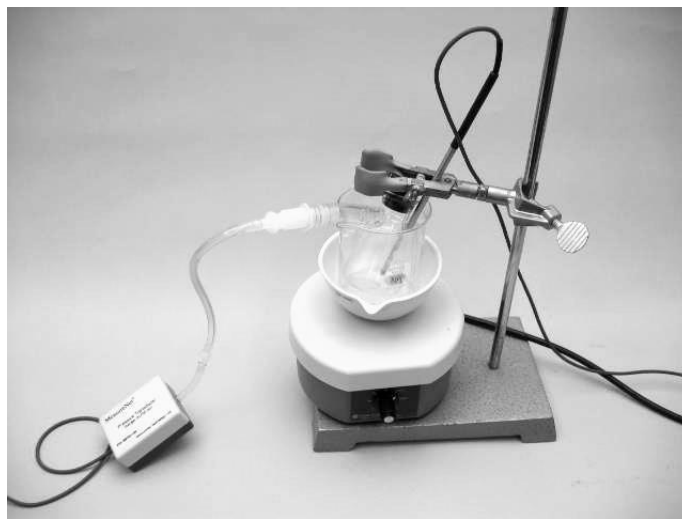

Figure 12-3. Setup for P-T Measurements.

Temperature readings are given in °C. Pressure readings are P_{sensor}, in torr, which may be combined with P_{atm} to obtain P_{air} values. The Ideal Gas Equation leads us to expect that the following behavior will be observed:

$$P_{air}V_{air} = P_{air} \cdot \text{constant}' = nRT = \text{constant}''\cdot T \tag{12-12}$$

since V_{air} and n do not change for the sample. This rearranges to Amontons' Law:

$$P_{air} = \text{constant} \cdot T \tag{12-13}$$

From **EQUATION 12-13** it is evident that P_{air} becomes 0 when the absolute temperature T (in K) goes to 0. The temperature reading from MeasureNet is t (in °C), and the relation between the two scales is given by:

$$T(K) = t(°C) + k \tag{12-14}$$

where κ is a constant. Substituting into **EQUATION 12-13**, we obtain

$$P_{air} = \text{constant} \cdot [t(°C) + \kappa] \tag{12-15}$$

Hence, a plot of P_{air} vs. the Celsius temperature t should be a straight line of slope m (= constant) and intercept b (= constant times κ). Obtaining such a straight line would confirm that the behavior of the sample of air is as described by Amontons' Law. and m and b could be used to find κ--since the y-intercept equals the slope times κ, then **κ equals the y-intercept divided by the slope.**

The constant κ can also be evaluated from the plot by extrapolating the straight line until it crosses the axis where $P_{air} = 0$, where we have:

$$0 = \text{constant} \cdot [t(°C) + \kappa] \tag{12-16}$$

At this point, then:

$$t(°C) = - k \tag{12-17}$$

Thus, the x-intercept equals the opposite of the value for κ.

Returning to **EQUATION 12-13**, we see that it could be rearranged to give:

$$\frac{P_{air}}{T} = \text{constant} \tag{12-18}$$

Hence, another way of confirming that the behavior of the gas sample is consistent with Amontons' Law would be to calculate P_{air}/T for each pair of data points. Consistency with Amontons' Law would result in an essentially constant value for P_{air}/T for all points.

EQUIPMENT NEEDED

beaker, 250 mL	20-mL syringe (Luer tip)
pressure sensor	10-mL syringe(Luer tip)
Styrofoam cup	clamp
stir plate	rubber stopper
stir bar	ring stand
glass stirring rod	temperature probe
filter flask, with adapter tubing and 3-way stopcock	

CHEMICALS NEEDED

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PROCEDURE

You are to perform this experiment in pairs; however, you may work alone if space permits.

A. Logging In

In this experiment, you will save your data as you normally do. However, by logging in at your workstation prior to the collection of any data, not only will the data be stored on the network computer, but it also will be uploaded to a web data storage site. You will then be able to download the data from any remote computer with internet access, and analyze the data using spreadsheet software that is available from the data storage site.

1. In order to send and properly store your data at the website, you must first log in at your workstation. Press the MAIN MENU button. Press the function key listed for OTHER, and then the function key for LOG IN. When prompted, enter the experiment number (12) and your 4-digit student ID number that you obtained from the Chem21 website before you came to your lab room. If you are working with a lab partner, **he or she must also log in.** This can be accomplished by pressing F1 and following the procedure described above. Once you leave the laboratory, the data will only be accessible to those students who have successfully logged in.

B. Pressure vs. Volume Measurements
Setting Up the Workstation and Calibrating the Pressure Sensor

1. Press the MAIN MENU button. Press the function key listed for PRESSURE, and then the function key for PRESSURE AND VOLUME.

2. Press the function key for CALIBRATE. Enter the atmospheric pressure (your instructor will give you this information). When prompted to enter a value for tubing volume, enter '0'. (V_{tubing} hasn't been determined at this point; we enter '0' here just so the program runs properly.) Connect the pressure sensor to the workstation and follow the instructions for calibration of the pressure sensor. This procedure sets the pressure reading to zero when the difference in pressure between the two sides of the sensor is zero. **Be sure to press ENTER when a stable reading is obtained.** When you

finish, press the DISPLAY button. The workstation should now display a pressure reading of 0.0; if not, repeat the calibration.

Air Pressure Measurements

3. Obtain a 10 mL syringe equipped with a Luer fitting. Set the bottom ring seal on the plunger to the 2.0 mL mark on the syringe (as precisely as possible), then connect the syringe to the pressure sensor as show in **FIGURE 12-2. Note: the Luer fittings are threaded—they should be connected or disconnected by screwing or unscrewing, not cramming together or yanking apart.** Note the pressure reading on the workstation display. Press START/STOP to record P_{sensor} and then enter the volume reading on the syringe (for this first point, for example, $V_{syringe}$ will be 2.0 mL) when prompted, pressing ENTER when finished. Note the entries counter at the bottom of the display now reads '1'. Record the pressure and volume measurements on your report sheet.

4. Push in and hold the plunger so that the plunger reads 1.0 mL. Record and enter the pressure and volume readings as above.

5. Holding the syringe by the flanges at the top of the syringe, (do <u>not</u> grasp the barrel of the syringe) pull out the plunger until the bottom ring seal on the plunger lines up exactly with the 10.0 mL mark on the syringe. Hold the plunger steady so that the pressure remains fairly stable, then again record and enter the pressure and volume readings.

6. Repeat the experiment by randomly pushing in and pulling out the plunger until you have accumulated 15-20 pairs of pressure/volume readings. Try to space out the plunger volumes fairly evenly over the range of 1 to 10 mL. Keep in mind that the smallest markings on the syringe barrel represent 0.2 mL increments.

7. Pressing FILE OPTIONS, then SAVE, and enter **001** as the three-digit file code. This will not only save the data file onto the network computer as usual, but since you are logged in, it will also upload the data to Chem21 report page for exp. 12. Check with your TA to confirm that your data has been uploaded properly before you go on to the next portion of the experiment.

C. Pressure vs. Temperature Measurements

Calibration of the Probes

1. Press the **MAIN MENU** button, press the function key listed for **PRESSURE**, and then the function key for **PRESSURE AND TEMPERATURE**. Obtain some ice. Fill a Styrofoam cup approximately three quarters full with ice and add enough distilled water to barely cover the ice. When vigorously and thoroughly stirred, this ice/water mixture will be at 0.0°C. Press **CALIBRATE** and place the temperature probe in the ice water, using the temperature probe to continually stir it. Follow the instructions on the display for the calibration of the temperature probe, then re-calibrate the pressure sensor. Once you have calibrated the probes, press **DISPLAY**.

Setting up the Apparatus and Testing for Leaks

2. Set up an apparatus as in **FIGURE 12-4**. Obtain a 20-mL syringe equipped with a Luer fitting, and pull out the plunger to the 15-20 mL mark. Place a stopper firmly into a clean, dry 50-mL filter flask fitted with a tubing connector and adapter tubing. Connect one opening of the stopcock to the pressure sensor, and the other to the syringe. Turn the stopcock so that the arm marked **OFF** is pointed away from the syringe.

Figure 12-4. Setup to Test for Leaks in the P-T Exp.

3. Depress the syringe until the pressure reaches ~150torr and hold it, then turn the stopcock so that the arm marked **OFF** is pointed toward the syringe. Release the plunger, and monitor the pressure reading on the workstation display for about 2 minutes. The pressure should not drop by more than 0.1 torr per every 10 seconds. If it does, test for leaks at each tubing connection and around the stopper using soapy water.

4. Place ~175 mL of **hot** tap water in a 250 mL beaker. Measure the temperature of the water with the temperature probe—it should be ~35-40°C. If the temperature is too low, dump the water and refill the beaker from the tap, making sure the tap has been running long enough to get the water as hot as possible. Do not heat the water with the hot plate!

5. Set up the apparatus to make pressure-temperature readings as in **FIGURE 12-3**. Place an evaporating dish on top of a stir plate which is set on a ring stand, and place the 250 mL beaker containing water in the evaporating dish. Place a magnetic stir bar in the beaker, then place the 50 mL filter flask in the beaker. Place the clamp <u>over</u> the flask so that the flask is submerged in the water as completely as possible. If the beaker is not completely filled with water at this point, add some more hot water. Remove the syringe from the stopcock, and turn the stopcock arm one full rotation so that the pressure is released from the system and the arm marked **OFF** points toward the opening where the syringe was. This will ensure that your pressure readings will begin at around zero; as the experiment proceeds, the pressure reading values will decrease and eventually become negative. At this point, the pressure inside the flask is less than the atmospheric pressure; this will help minimize the effect of any small leaks remaining in the system. Insert the temperature probe through the clamp into the water so that the tip is just below the bottom of the filter flask, but above the bottom of the beaker.

Air Pressure Measurements

6. Turn on the stir plate to a low setting. It is important than you also stir the water above the flask with a stirring rod to ensure as uniform a water temperature as possible. Allow the flask to sit in the water

bath for ~5 minutes (to let the temperature of the gas inside the flask to equilibrate with the temperature of the water bath), then press the **START/STOP** button to record both the temperature and pressure electronically.

7. Repeat these measurements every 2-4 degrees down to about 10°C. **It is not necessary to make the readings at exact intervals**; it is more important that the temperature and pressure are fairly steady (remain at the same value to the nearest 0.1 unit for 5 seconds) when you enter the data. Making measurements every 2-4°C merely ensures a reasonable number of readings. The water bath can be cooled down by adding ice to the beaker one piece at a time. Be sure to stir thoroughly with the stirring rod until the ice has melted completely. Wait about thirty seconds after the ice has melted before making another reading of temperature and pressure. **Note: the pressure should change by a few torr for every 1ºC drop in temperature.** Record the temperature/pressure data points on the report sheet.

8. Save and upload your data by pressing FILES OPTIONS, SAVE, and entering **002** as the three-digit file code. Check with your TA to make sure the data has been uploaded properly.

Report Sheet: Experiment 12

Name _____   Date _____

Partner's Name _____

Atmospheric Pressure____

Pressure-Volume Data

Reading #	Pressure	Volume		Reading #	Pressure	Volume
1	_____	_____		11	_____	_____
2	_____	_____		12	_____	_____
3	_____	_____		13	_____	_____
4	_____	_____		14	_____	_____
5	_____	_____		15	_____	_____
6	_____	_____		16	_____	_____
7	_____	_____		17	_____	_____
8	_____	_____		18	_____	_____
9	_____	_____		19	_____	_____
10	_____	_____		20	_____	_____

Value for V_{tubing}:_____

Pressure-Temperature Data

Reading #	Pressure	Temperature
1	_____	_____
2	_____	_____
3	_____	_____
4	_____	_____
5	_____	_____
6	_____	_____
7	_____	_____
8	_____	_____
9	_____	_____
10	_____	_____

Value for κ: _____

A. Preparing P$_{air}$ vs. V plots—Microsoft Excel 2019 (PC version)

Go to the Chem21labs.com. After you log in, click on Download MeasureNet Files. Scroll down to experiment 12 and click on File ID: 1. The file should open up in Excel.

V$_{syringe}$ vs. 1/P$_{air}$

1.   *Important: If you see a green triangle in the corner of the cells containing your data, Excel is viewing those values as text, which will make your data plot incorrectly. Highlight all of the data, click on the orange triangle that appears, and click on 'Convert to Number'.*

2.   Select columns A through H: click on the heading for Column A (the shaded cell with the letter A), and while holding the mouse button (or mouse pad) down, drag the cursor to the heading for column H. Click on the line separating the headings for columns A and B—a line width window should pop up. Change the width of columns A through H to 14.00.

3.   While Columns A through H are highlighted, click on the Center Data icon in the Alignment section of the menu bar (the icon looks like a number of lines that are centered).

4.   Click on cell A1 and give this cell the title V(syringe),mL **(Note:** If your data was downloaded directly, you will need to unmerge this cell first). Click on cell B1 and give this cell the title P(sensor),torr. Click on cell C1 and give this cell the title P(air),torr. Click on cell D1 and give this cell the title 1/P(air),torr-1.

5.   Click on cell C2 and type **=B2+xxx.x**, where xxx.x represents the atmospheric pressure. (in other words, type equals sign, B2, plus sign, your atmospheric pressure.). If you forgot to write down the atmospheric pressure when in the lab room, it should be listed after Const1 on first line of the File ID: 1 file from Chem21. When you hit Enter, the C2 cell should display the total pressure of air in the flask.

6.   Click on C2 again, then click and hold on the small block at the lower right corner of the cell. Drag down column C until you are even with the last row containing data in column B. This will copy the equation you set up in C2 to all of the other cells in column C.

7.   Click on cell D2 and type **=1/C2**. This will calculate the reciprocal of P(air). Drag and copy this formula to the remaining cells in the D column.

8.   Select all of the data in column A by clicking on cell A1 and dragging down to the bottom to the data and select Copy. Click on cell E1 and paste the data into this column (we need to do this so that V$_{syringe}$ is plotted on the y-axis and 1/P$_{air}$.is plotted on the x-axis). Select all of the data in both columns D and E, **including the column titles**.

9.   Select Insert from the menu bar. From the Charts section, click on the Select Scatter Chart icon (the one with a bunch of dots), then Scatter (the icon in the top left corner. Your plot should now appear.

10.   Right click near the top right corner of the chart and select Move Chart…Choose to place your chart on a new sheet. Click 'OK', and your plot of V$_{syringe}$ vs. 1/P$_{air}$ should show up on a new sheet!

11.   Select Design from the 'Chart Tools' section of the menu bar. Click on the Add Chart Element icon on the far left of the menu bar. From the Axis Titles menu, select 'Primary Horizontal'. In the formula box (the big box at the top of the page next to the f_x icon) type in the label for the x-axis (the label should include the parameter being measured and the units, e.g. 1/P(air), torr-1), and hit Enter. From the Axis Titles menu, select 'Primary Vertical' and enter in the label for the y-axis. Again from the Add Chart Element menu, select Chart Title, making sure the title is positioned above the chart. Give the plot an appropriate title. <u>Title of plot: should include a figure number, what parameters are being measured (the y and x axes), and what sample is being investigated</u> (example: Figure 1. Plot of Volume vs. 1/Pressure for Air).

12.   Draw a best fit line through your data by selecting Trendline from the Add Chart Elements menu. Select 'More Trendline Options', make sure 'Linear' is selected for the regression type, then select 'Display equation on chart'

13.   From the equations of the trendline, determine the value of V_{tubing}. (Don't know how to find V_{tubing}? Go back to equation 12-11 in the handout or slide 5 of the prelab PowerPoint.) **Enter the value for V_{tubing}** in the box containing your line equation (don't forget that there's no such thing as a negative volume!)

Take a screen shot of this plot, or right click on the plot and use 'Save As Picture…' to save the plot as a JPEG, GIF, or PNG. Follow the instructions on the Exp. 12 report sheet on Chem21 to upload or copy the image onto the report sheet. (**Note**: you do not need to anything with the plots that appear on the report sheet. Just use the 'Next Problem' button on the side panel to bypass them.

V_{air} vs. P_{air} relationships

14.   Go back to the data worksheet by clicking the tab labeled with the data file name at the bottom of the page. Type in the following column titles:

cell F1: V(tubing)/mL; cell G1: V(air)/mL; cell H1: 1/V(air)/mL-1

15.   In cell F2 enter the value for V_{tubing}. Drag and copy to the remaining cells in column F

16.   In cell G2 type **=E2+F2**. This calculates the value for V_{air}. Drag and copy this cell to the rest of the remaining cells in the G column.

17.   In cell H2 type **=1/G2**. This gives the reciprocal value for V_{air}. Drag and copy to the remaining cells in the H column.

18.   We can change the parameters of pressure and volume on the $V_{syringe}$ vs. $1/P_{air}$ plot we already made. Go back to the plot by clicking on the Chart 1 tab at the bottom of the page. Right click on the Chart 1 tab and select Move or Copy…. Place a check in the 'Create a copy' and click on OK.

19. Right click on one of the data points on the plot and select Select Data…. Above the Legend Entries (Series) window, click on Edit; you should be able see that the x values on the plot come from the values in the D column of the worksheet ($1/P_{air}$) and the y values come from the E column ($V_{syringe}$). Replace the D's in the x value box with G's, and change the E's in the y value box to C's, then click on 'OK'. This will cause the plot to display P_{air} (y-axis) vs. V_{air} (x-axis). Note the shape of the curve. Change the columns plotted in the x and y value boxes to view the following additional plots:

Plot	x value data from column:	y value data from column:
V_{air} (y-axis)vs. P_{air} (x-axis)	C	G
$1/V_{air}$ (y-axis)vs. $1/P_{air}$ (x-axis)	D	H
P_{air} (y-axis)vs. $1/V_{air}$ (x-axis)	H	C
V_{air} (y-axis)vs. $1/P_{air}$ (x-axis)	D	G

20.   Select one of the plots that gives a straight line relationship. **Change the title and the x and y axis labels** to reflect the new plot. Because this plot shows a straight line relationship between some manipulation of P_{air} and V_{air}, it demonstrates Boyle's Law.

Take a screen shot of this plot, or right click on the plot and use 'Save As Picture…' to save the plot as a JPEG, GIF, or PNG. Follow the instructions on the Exp. 12 report sheet on Chem21 to upload or copy the image onto the report sheet.

B. Preparing P$_{air}$ vs. T plots

1.   From Chem21, open or copy the data in file ID: 2 into Excel as above.

2.   Change the width of columns A through C to 18.00.

3.   Center the data in columns A through C.

4.   Click on cell A1 and give this cell the title Temperature/deg. C. Click on cell B1 and give this cell the title P(sensor)/torr.Click on cell C1 and give this cell the title P(air)/torr.

5.   Click on cell C2 and type **=B2+xxx.x**, where xxx.x represents the atmospheric pressure. (in other words, type equals sign, B2, plus sign, your atmospheric pressure). When you hit Enter, the C2 cell should display the total pressure of air in the flask.

6.   Click on C2 again, then click and hold on the small block at the lower right corner of the cell. Drag down column C until you reach the last row containing data in column B. This will copy the equation you set up in C2 to all of the other cells.

7.   Select all of the data in column A by clicking on cell A1 and dragging down to the bottom to the data. While holding down the control button, do the same for column C. You should now have all of the data in columns A and C, **including the column titles**, highlighted.

8.   Follow steps 9-12 of the P vs. V plot instructions above to create a plot of P$_{air}$ vs. T, **including a title and axis labels**, and a best fit line with the line's equation. **Calculate the value of κ and enter the value in the box containing your line equation.** (Don't know how to find κ? Look at equations 12-14, and 12-15 in the Introduction, or slide 6 of the prelab PowerPoint.)

Take a screen shot of this plot, or right click on the plot and use 'Save As Picture…' to save the plot as a JPEG, GIF, or PNG. Follow the instructions on the Exp. 12 report sheet on Chem21 to upload or copy the image onto the report sheet.

A. Preparing P_{air} vs. V plots—Microsoft Excel 2019 (Macintosh version)

Go to the Chem21labs.com. After you log in, click on Download MeasureNet Files. Scroll down to experiment 12 and click on File ID: 1. The file should open up in Excel.

V$_{syringe}$ vs. 1/P$_{air}$

1.   *Important: If you see a green triangle in the corner of the cells containing your data, Excel is viewing those values as text, which will make your data plot incorrectly. Highlight all of the data, click on the orange triangle that appears, and click on 'Convert to Number'.*

2.   Click on cell A1 and give this cell the title V(syringe)/mL. Click on cell B1 and give this cell the title P(sensor)/torr. **Note: if your data was entered into Excel directly, you will need to unmerge cell A1 first.**

3.   Select columns A through D: click on the heading for Column A (the shaded cell with the letter A), and while holding the mouse button down, drag the mouse to the heading for column D. Click on the line separating the headings for columns A and B—a line width window should pop up. Change the width of columns A through C to 18.00.

4.   While Columns A through C are highlighted, click on the center data icon on the menu bar in the alignment section (the icon looks like a number of lines that are centered).

4.   Click on cell C1 and give this cell the title P(air)/torr. Click on cell D1 and give this cell the title 1/P(air)/torr-1.

5.   Click on cell C2 and type **=B2+xxx.x**, where xxx.x represents the atmospheric pressure. (in other words, type equals sign, B2, plus sign, your atmospheric pressure.). When you hit Enter, the C2 cell should display the total pressure of air in the flask.

6.   Click on C2 again, then click and hold on the small block at the lower right corner of the cell. Drag down column C until you are even with the last row containing data in column B. This will copy the equation you set up in C2 to all of the other cells.

7.   Click on cell D2 and type **=1/C2**. This will calculate the reciprocal of P(air). Drag and copy this formula to the remaining cells in the D column.

8.   Select all of the data in column A by clicking on cell A1 and dragging down to the bottom to the data. Right click on the highlighted data, select Copy. Right click on cell E1 and paste the data into this column (we need to do this so that V$_{syringe}$ is plotted on the y-axis and 1/P$_{air}$.is plotted on the x-axis). Select all of the data in both columns D and E, **including the column titles**.

9.   Select Charts from the menu bar. Select Scatter, then click on the Marked Scatter icon (the graph icon without any lines).Your plot should now appear.

10.   Place the cursor in the top right part of the graph (in an empty space), right click and select Move Chart. Choose to place your chart on a new sheet. Click 'OK', and your plot of V$_{syringe}$ vs. 1/P$_{air}$ should show up on a new sheet!

11.   Select Add Chart Element, then Axis Titles. Select Primary Horizontal Axis Title (title below axis)—this is the x-axis label. Give the x-axis an appropriate title (it should include the parameter being measured and the units, e.g. P(air), torr-1). Select Primary Vertical Axis Title (rotated title), and give the y-axis an appropriate title. Select Chart Title, and give the plot an appropriate title (the title should have a figure number, the parameters (y vs. x) that are being measured, and the material being investigated. For example this plot should be titled: Figure 1. Plot of V(syringe) vs. P(air) for Air.).

12.   From the Add Chart Element menu, select Trendline. Select 'Trendline Options',then select 'More Trendline Options'. Click on the boxes to select 'Display equation on chart'.

13.   From the equations of the trendline, determine the value of V_{tubing}. (Don't know how to find V_{tubing}? Go back to equation 12-11 in the handout or slide 5 of the prelab PowerPoint.) **Enter the value for V_{tubing}** in the box containing your line equation (don't forget that there's no such thing as a negative volume!)

Take a screen shot of this plot, or right click on the plot and use 'Save As Picture…' to save the plot as a JPEG, GIF, or PNG. Follow the instructions on the Exp. 12 report sheet on Chem21 to upload or copy the image onto the report sheet

V_{air} vs. P_{air} relationships

14.   Go back to the data worksheet by clicking the tab labeled Sheet1 at the bottom of the page. Type in the following column titles:

   cell F1: V(tubing)/mL

   cell G1: V(air)/mL

   cell H1: 1/V(air)/mL-1

15.   In cell F2 enter the value for V_{tubing} (don't forget that there's no such thing as a negative volume!).

16.   In cell G2 type **=E2+F\$2**. This calculates the value for V_{air}. Drag and copy this cell to the rest of the remaining cells in the G column.

17.   In cell H2 type **=1/G2**. This gives the reciprocal value for V_{air}. Drag and copy to the remaining cells in the H column.

18.   We can change the parameters of pressure and volume on the $V_{syringe}$ vs. $1/P_{air}$ plot we already made. Right click on the Chart 1 tab and select Move or Copy. Select '(move to end)', then click on Create a Copy, and hit OK.

19. Right click on one of the data points on the plot and select Select Data. You should be able see that the x values on the plot come from the values in the D column of the worksheet ($1/P_{air}$) and the y values come from the E column ($V_{syringe}$). Replace the D's in the x value box with G's, and change the E's in the y value box to C's, then click on 'OK'. This will cause the plot to display P_{air} (y-axis) vs. V_{air} (x-axis). Note the shape of the curve. Change the columns plotted in the x and y value boxes to view the following additional plots:

Plot	x value data from column:	y value data from column:
V_{air} (y-axis)vs. P_{air} (x-axis)	C	G
$1/V_{air}$ (y-axis)vs. $1/P_{air}$ (x-axis)	D	H
P_{air} (y-axis)vs. $1/V_{air}$ (x-axis)	H	C
V_{air} (y-axis)vs. $1/P_{air}$ (x-axis)	D	G

19.   Select one of the plots that gives a straight line relationship. Change the title and the x and y axis labels to reflect the new plot.

20.   Save the file as Pressure vs. Volume. This file should contain your data and two plots--$V_{syringe}$ vs. $1/P_{air}$, and the plot of P_{air} and V_{air} that gives a straight line relationship.

B. Preparing P$_{air}$ vs. T plots

1.   From the Chem21 website, open the data in'File ID: 2' link into Excel as above.

2.   Change the width of columns A through C to 18.00 (unmerge A1 if necessary).

3.   Center the data in columns A through C.

4.   Click on cell A1 and give this cell the title Temperature/deg. C. Click on cell B1 and give this cell the title P(sensor)/torr.Click on cell C1 and give this cell the title P(air)/torr.

5.   Click on cell C2 and type **=B2+xxx.x**, where xxx.x represents the atmospheric pressure. (in other words, type equals sign, B2, plus sign, your atmospheric pressure). When you hit Enter, the C2 cell should display the total pressure of air in the flask.

6.   Click on C2 again, then click and hold on the small block at the lower right corner of the cell. Drag down column C until you reach the last row containing data in column B. This will copy the equation you set up in C2 to all of the other cells.

7.   Select all of the data in column A by clicking on cell A1 and dragging down to the bottom to the data. While holding down the Command button, do the same for column C. You should now have all of the data in columns A and C, including the column titles, highlighted.

8.   Follow steps 9-12 of the P vs. V plot instructions above to create a plot of P$_{air}$ vs. T, **including a title and axis labels**, and a best fit line with the line's equation. **Calculate the value of κ and enter the value in the box containing your line equation.** (Don't know how to find κ? Look at equations 12-14, and 12-15 in the Introduction, or slide 6 of the prelab PowerPoint.)

Take a screen shot of this plot, or right click on the plot and use 'Save As Picture…' to save the plot as a JPEG, GIF, or PNG. Follow the instructions on the Exp. 12 report sheet on Chem21 to upload or copy the image onto the report sheet.