NSTA 2025
Philadelphia, PA

Chemistry Essentials: Getting Started with Vernier

Experiments

Boyle's Law: Pressure-Volume Relationship in Gases

- Go Direct® Gas Pressure Sensor

Household Acids and Bases

- Go Direct pH Sensor

Determining the Concentration of a Solution: Beer's Law – Vernier Graphical Analysis® version

- Go Direct Colorimeter

Determining the Concentration of a Solution: Beer's Law – Vernier Spectral Analysis® version

- Go Direct SpectroVis® Plus Spectrophotometer

Workshop Presenter

Nüsret Hisim
nhisim@vernier.com
chemistry@vernier.com

SCAN ME

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.

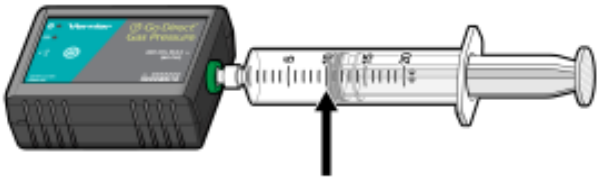

Figure 1

OBJECTIVES

- 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.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Go Direct Gas Pressure
20 mL gas syringe

PROCEDURE

1. Prepare the data-collection equipment and an air sample for data collection.

    a. Launch Graphical Analysis. Connect the Gas Pressure Sensor to your Chromebook, computer, or mobile device.

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. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
   b. Enter **Volume** as the Event Name and **mL** as the Units. Click or tap Done.

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. Click or tap Collect to 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. Click or tap Keep and enter **5.8**, the gas volume (in mL). Remember, you are adding 0.8 mL to the volume of the syringe for the total volume. Click or tap Keep Point to store this pressure-volume data pair.

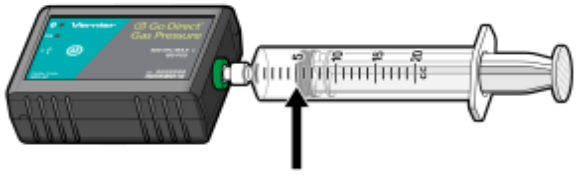

Figure 2

   d. Continue this procedure using syringe volumes of 10.0, 12.5, 15.0, 17.5, and 20.0 mL.
   e. Click or tap Stop to 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. Click or tap Graph Options, , and choose Apply Curve Fit.

b. Select Power as the curve fit and Dismiss the Curve Fit box. The curve fit statistics are displayed for the equation in the form

$$y = ax^b$$

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. Rescale the axes on your graph by clicking or tapping Graph Options, . Choose Edit Graph Options and set the x-axis to display 0 to 25 mL and the y-axis to display 0 to 300 kPa. Dismiss the Graph Options box.
e. (optional) Export, download, or print the graph with the curve fit displayed.

7. With the best-fit curve still displayed, proceed directly to the Processing the Data section.

DATA AND CALCULATIONS

Volume (mL)	Pressure (kPa)	Constant, *k* (P / V or P • V)

PROCESSING THE DATA

1. With the best-fit curve still displayed, click or tap Graph Options, , and turn on Interpolate. Dismiss the box and click the graph to interpolate. Move along the regression line until the volume value is 5.0 mL. Note the corresponding pressure value. Now move to the point where the volume value is doubled (10.0 mL). What does your data show happens to the pressure when the volume is *doubled*? Show the pressure values in your answer.

2. Using the same technique as in Question 1, what does your data show happens to the pressure if the volume is *halved* from 20.0 mL to 10.0 mL? Show the pressure values in your answer.

3. Using the same technique as in Question 1, what does your data show happens to the pressure if the volume is *tripled* from 5.0 mL to 15.0 mL? 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 *vs*. 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? Explain or show work to support your answer.

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, $k = P \cdot V$. 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, it is necessary to create a new column of data, reciprocal of volume, based on your original volume data:

   a. Click or tap More Options, ⋯, in the Volume column header in the table. Choose Add Calculated Column.
   b. Enter **1/volume** as the Name and **1/mL** as the Units.
   c. Click or tap Insert Expression and choose A/X as the expression.
   d. Enter **1** as Parameter A and select Volume as the Column.
   e. Click or tap Apply.

2. Plot a best-fit regression line on your graph of pressure *vs*. 1/volume:

   a. Click or tap Graph Options, ⌐, and choose Edit Graph Options.
   b. Enter **0** as the value for both the Left value for the x-axis and the Bottom value for the y-axis.
   c. Dismiss the Graph Options box. Your graph should now include the origin (0,0).
   d. Click or tap Graph Options, ⌐, and choose Apply Curve Fit.
   e. Select Linear as the curve fit and Dismiss the Curve Fit box. The linear-regression statistics 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.

   f. 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.

Household Acids and Bases

Many common household solutions contain acids and bases. Acid-base indicators, such as litmus and red cabbage juice, turn different colors in acidic and basic solutions. They can, therefore, be used to show if a solution is acidic or basic. An acid turns blue litmus paper red, and a base turns red litmus paper blue. The acidity of a solution can be expressed using the pH scale. Acidic solutions have pH values less than 7, basic solutions have pH values greater than 7, and neutral solutions have a pH value equal to 7.

In this experiment, you will use litmus and a pH Sensor to determine the pH values of household substances. After adding red cabbage juice to the same substances, you will determine the different red cabbage juice indicator colors over the entire pH range.

OBJECTIVES

- Use litmus paper and a pH Sensor to determine the pH values of household substances.
- Add cabbage juice to the same substances and determine different red cabbage juice indicator colors over the entire pH range.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Go Direct pH
Stir Station
Electrode Support
wash bottle
distilled water
sensor soaking solution
household solutions
7 small test tubes
test-tube rack
red and blue litmus paper
paper towel
stirring rod
red cabbage juice
250 mL beaker

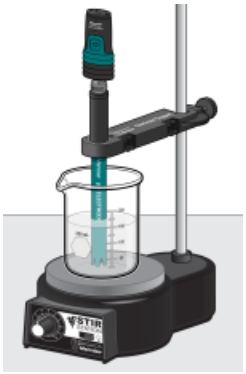

Figure 1

PROCEDURE

1. Obtain and wear goggles. **Caution**: *Do not eat or drink in the laboratory*.

Part I Litmus Tests

2. Label seven test tubes with the numbers 1–7 and place them in a test tube rack.
3. Measure 3 mL of vinegar into test tube #1. Refer to the data table and fill each of the test tubes 2–7 to about the same level with its respective solution. **DANGER**: *Treat all laboratory chemicals with caution. Prudent laboratory practices should be observed. Avoid inhaling vapors. Avoid contacting your skin and clothing with any of the solutions. Wear goggles at all times. Notify your teacher immediately in the event of an accident*.
4. Use a stirring rod to transfer one drop of vinegar to a small piece of blue litmus paper on a paper towel. Transfer one drop to a piece of red litmus paper on a paper towel. Record the results. Clean and dry the stirring rod each time.
5. Test solutions 2–7 using the same procedure. Be sure to clean and dry the stirring rod each time.

Part II Red Cabbage Juice Indicator

6. After you have finished the Part I litmus tests, add 3 mL of red cabbage juice indicator to each of the seven test tubes. Record your observations. Dispose of the test-tube contents as directed by your teacher.

Part III pH Tests

7. Prepare the pH Sensor for data collection.
   a. Launch Graphical Analysis. Connect the pH Sensor to your Chromebook, computer, or mobile device.
   b. Remove the pH Sensor from the sensor storage solution bottle by unscrewing the lid. Carefully remove the bottle, leaving the cap on the sensor body.
   c. Rinse the tip of the sensor with distilled water and place the sensor tip into a beaker containing sensor soaking solution. Use an Electrode Support to fasten the pH Sensor to a Stir Station, as shown in Figure 1.
8. Raise the pH Sensor from the sensor soaking solution and set the solution aside. Use a wash bottle filled with distilled water to thoroughly rinse the pH Sensor. Catch the rinse water in a 250 mL beaker.

9. Obtain one of the 7 solutions in the small container supplied by your teacher. Raise the solution to the pH Sensor and swirl the solution about the sensor. When the pH reading stabilizes, record the pH value.

10. Prepare the pH Sensor for reuse.
    a. Rinse it with distilled water from a wash bottle.
    b. Place the sensor into the sensor storage solution and swirl the solution about the sensor briefly.
    c. Rinse with distilled water again.
11. Determine the pH of the other solutions using the Step 9 procedure. You must clean the pH Sensor between tests using the Step 10 procedure.

12. When you are finished, rinse the sensor with distilled water and return it to the sensor soaking solution.

DATA TABLE

Test tube	Solution	Blue litmus	Red litmus	Red cabbage juice	pH
1	vinegar				
2	ammonia				
3	lemon juice				
4	soft drink				
5	drain cleaner				
6	detergent				
7	baking soda				

PROCESSING THE DATA

1. Which of the household solutions tested are acids? How can you tell?

2. Which of the solutions are bases? How can you tell?

3. What color(s) is red cabbage juice indicator in acids? In bases?

4. Can red cabbage juice indicator be used to determine the strength of acids and bases? Explain.

5. List advantages and disadvantages of litmus and red cabbage juice indicators.

Determining the Concentration of a Solution: Beer's Law

The primary objective of this experiment is to determine the concentration of an unknown nickel (II) sulfate solution. You will be using a colorimeter or spectrometer. The wavelength of light used should be one that is absorbed by the solution. The $NiSO_4$ solution used in this experiment has a deep green color, so colorimeter users will be instructed to use the red LED. Spectrometer users will determine an appropriate wavelength based on the absorbance spectrum of the solution. The light striking the detector is reported as *absorbance* or *percent transmittance*. A higher concentration of the colored solution absorbs more light (and transmits less) than a solution of lower concentration.

You will prepare five nickel sulfate solutions of known concentration (standard solutions). Each is transferred to a small, rectangular cuvette that is placed into the Colorimeter. The amount of light that penetrates the solution and strikes the photocell is used to compute the absorbance of each solution. When a graph of absorbance *vs.* concentration is plotted for the standard solutions, a direct relationship should result, as shown in Figure 1. The direct relationship between absorbance and concentration for a solution is known as Beer's law.

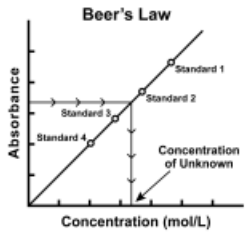

Figure 1

You will determine the concentration of an unknown $NiSO_4$ solution by measuring its absorbance. By locating the absorbance of the unknown on the vertical axis of the graph, the corresponding concentration can be found on the horizontal axis (follow the arrows in Figure 1). The concentration of the unknown can also be found using the slope of the Beer's law curve.

OBJECTIVES

- Prepare $NiSO_4$ standard solution.
- Measure the absorbance value of each standard solution.
- Find the relationship between absorbance and concentration of a solution.
- Determine the concentration of an unknown $NiSO_4$ solution.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Go Direct Colorimeter
one cuvette
five 20 × 150 mm test tubes
30 mL of 0.40 M $NiSO_4$
5 mL of $NiSO_4$ unknown solution
two 10 mL pipets (or graduated cylinders)
two 100 mL beakers
pipet pump or pipet bulb
distilled water
test tube rack
tissues (preferably lint-free)

PROCEDURE

1. Obtain and wear goggles. **Caution**: *Be careful not to ingest any* $NiSO_4$ *solution or spill any on your skin. Inform your teacher immediately in the event of an accident*.

2. Add about 30 mL of 0.40 M $NiSO_4$ stock solution to a 100 mL beaker. Add about 30 mL of distilled water to another 100 mL beaker. **DANGER**: *Nickel sulfate solution,* $NiSO_4$: *Causes skin, respiratory tract, and eye irritation. Do not breathe mist, vapors, or spray—toxic if swallowed*.

3. Label four clean, dry, test tubes 1–4 (the fifth solution is the beaker of 0.40 M $NiSO_4$). Pipet 2, 4, 6, and 8 mL of 0.40 M $NiSO_4$ solution into Test Tubes 1–4, respectively. With a second pipet, deliver 8, 6, 4, and 2 mL of distilled water into Test Tubes 1–4, respectively. *Thoroughly* mix each solution with a stirring rod. Clean and dry the stirring rod between stirrings. Keep the remaining 0.40 M $NiSO_4$ in the 100 mL beaker to use in the fifth trial. Volumes and concentrations for the trials are summarized below:

Trial number	0.40 M $NiSO_4$ (mL)	Distilled H_2O (mL)	Concentration (M)
1	2	8	0.08
2	4	6	0.16
3	6	4	0.24
4	8	2	0.32
5	~10	0	0.40

4. Prepare a blank by filling an empty cuvette 3/4 full with distilled water. To correctly use a cuvette, remember:
   - All cuvettes should be wiped clean and dry on the outside with a tissue.
   - Handle cuvettes only by the top edge of the ribbed sides.
   - All solutions should be free of bubbles.
   - Always position the cuvette so the light passes through the clear sides.
5. Launch Graphical Analysis. Connect the Colorimeter to your Chromebook, computer, or mobile device.
6. Calibrate the Colorimeter.
   a. Place the blank in the cuvette slot of the Colorimeter and close the lid.
   b. Press the < or > buttons on the Colorimeter to set the wavelength to 635 nm (Red). Then calibrate by pressing the CAL button on the Colorimeter. When the LED stops flashing, the calibration is complete.
7. Set up the data-collection mode.
   a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
   b. Enter **Concentration** as the Event Name and **mol/L** as the Units. Click or tap Done.
8. You are now ready to collect absorbance-concentration data for the five standard solutions.
   a. Click or tap Collect to start data collection.
   b. Empty the water from the cuvette. Using the solution in Test Tube 1, rinse the cuvette twice with ~1 mL amounts and then fill it 3/4 full. Wipe the outside with a tissue and place it in the device. Close the lid on the Colorimeter.
   c. When the value has stabilized, click or tap Keep and enter **0.080** as the concentration in mol/L. Click or tap Keep Point. The absorbance and concentration values have now been saved for the first solution.
   d. Discard the cuvette contents as directed by your instructor. Using the solution in Test Tube 2, rinse the cuvette twice with ~1 mL amounts, and then fill it 3/4 full. Place the cuvette in the device, wait for the value displayed on the screen to stabilize, and click or tap Keep. Enter **0.16** as the concentration in mol/L. Click or tap Keep Point.
   e. Repeat the procedure for Test Tube 3 (0.24 M) and Test Tube 4 (0.32 M), as well as the stock 0.40 M $NiSO_4$. **Note**: Wait until Step 10 to test the unknown.
   f. Click or tap Stop to stop data collection.
   g. To examine the data pairs on the displayed graph, click or tap the graph. Record the absorbance and concentration data values in your data table.
9. Display a graph of absorbance *vs*. concentration with a linear regression curve.
   a. Click or tap Graph Options, , and choose Edit Graph Options.
   b. Enter **0** as the value for both the Left value for the x-axis and the Bottom value for the y-axis. Dismiss the Graph Options box.
   c. Click or tap Graph Options, , and choose Apply Curve Fit.

d. Select Linear as the curve fit and Dismiss the Curve Fit box. The linear-regression statistics for these two data columns are displayed for the equation in the form

$$y = mx + b$$

where x is concentration, y is absorbance, m is the slope, and b is the y-intercept.
Note: One indicator of the quality of your data is the size of b. It is a very small value if the regression line passes through or near the origin. The correlation coefficient, r, indicates how closely the data points match up with (or *fit*) the regression line. A value of 1.00 indicates a nearly perfect fit.

The graph should indicate a direct relationship between absorbance and concentration, a relationship known as Beer's law. The regression line should closely fit the five data points *and* pass through (or near) the origin of the graph.

10. Determine the absorbance value of the unknown $NiSO_4$ solution.
    a. Obtain about 5 mL of the *unknown* $NiSO_4$ in another clean, dry, test tube. Record the number of the unknown in your data table.
    b. Rinse the cuvette twice with the unknown solution and fill it about 3/4 full. Wipe the outside of the cuvette and place it into the device.
    c. Monitor the absorbance value. When this value has stabilized, record it in your data table.
11. Discard the solutions as directed by your instructor. Before closing Graphical Analysis, continue to the Processing the Data section.

PROCESSING THE DATA

1. To determine the concentration of the unknown $NiSO_4$ solution, interpolate along the regression line to convert the absorbance value of the unknown to concentration.
    a. Click or tap Graph Options, , and turn on Interpolate.
    b. Click or tap any point on the curve to find the absorbance value that is closest to the absorbance reading you obtained during the Procedure. Record the corresponding $NiSO_4$ concentration, in mol/L, in your data table.
2. (optional) Print a graph of absorbance *vs*. concentration, with a regression line and interpolated unknown concentration displayed.

DATA AND CALCULATIONS

Trial	Concentration (mol/L)	Absorbance
1	0.080	
2	0.16	
3	0.24	
4	0.32	
5	0.40	
6	Unknown number _____	

Concentration of unknown	mol/L

Determining the Concentration of a Solution: Beer's Law

The primary objective of this experiment is to determine the concentration of an unknown nickel (II) sulfate solution. You will be using a colorimeter or spectrometer. The wavelength of light used should be one that is absorbed by the solution. The $NiSO_4$ solution used in this experiment has a deep green color, so colorimeter users will be instructed to use the red LED. Spectrometer users will determine an appropriate wavelength based on the absorbance spectrum of the solution. The light striking the detector is reported as *absorbance* or *percent transmittance*. A higher concentration of the colored solution absorbs more light (and transmits less) than a solution of lower concentration.

You will prepare five nickel sulfate solutions of known concentration (standard solutions). Each is transferred to a small, rectangular cuvette that is placed into the Spectrometer. The amount of light that penetrates the solution and strikes the photocell is used to compute the absorbance of each solution. When a graph of absorbance *vs*. concentration is plotted for the standard solutions, a direct relationship should result, as shown in Figure 1. The direct relationship between absorbance and concentration for a solution is known as Beer's law.

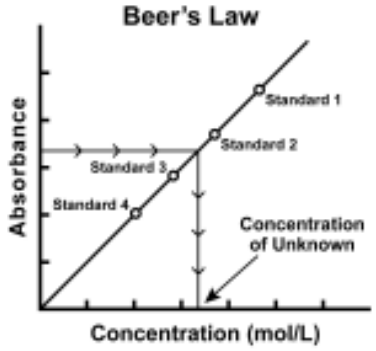

Figure 1

You will determine the concentration of an unknown $NiSO_4$ solution by measuring its absorbance. By locating the absorbance of the unknown on the vertical axis of the graph, the corresponding concentration can be found on the horizontal axis (follow the arrows in Figure 1). The concentration of the unknown can also be found using the slope of the Beer's law curve.

OBJECTIVES

- Prepare $NiSO_4$ standard solution.
- Measure the absorbance value of each standard solution.
- Find the relationship between absorbance and concentration of a solution.
- Determine the concentration of an unknown $NiSO_4$ solution.

MATERIALS

Chromebook, computer, **or** mobile device
Vernier Spectral Analysis app
Go Direct SpectroVis Plus
one cuvette
five 20 × 150 mm test tubes
30 mL of 0.40 M $NiSO_4$
5 mL of $NiSO_4$ unknown solution
two 10 mL pipets (or graduated cylinders)
two 100 mL beakers
pipet pump or pipet bulb
distilled water
test tube rack
tissues (preferably lint-free)

PROCEDURE

1. Obtain and wear goggles. **Caution**: *Be careful not to ingest any* $NiSO_4$ *solution or spill any on your skin. Inform your teacher immediately in the event of an accident*.

2. Add about 30 mL of 0.40 M $NiSO_4$ stock solution to a 100 mL beaker. Add about 30 mL of distilled water to another 100 mL beaker. **DANGER**: *Nickel sulfate solution,* $NiSO_4$: *Causes skin, respiratory tract, and eye irritation. Do not breathe mist, vapors, or spray—toxic if swallowed*.

3. Label four clean, dry, test tubes 1–4 (the fifth solution is the beaker of 0.40 M $NiSO_4$). Pipet 2, 4, 6, and 8 mL of 0.40 M $NiSO_4$ solution into Test Tubes 1–4, respectively. With a second pipet, deliver 8, 6, 4, and 2 mL of distilled water into Test Tubes 1–4, respectively. *Thoroughly* mix each solution with a stirring rod. Clean and dry the stirring rod between stirrings. Keep the remaining 0.40 M $NiSO_4$ in the 100 mL beaker to use in the fifth trial. Volumes and concentrations for the trials are summarized below:

Trial number	0.40 M $NiSO_4$ (mL)	Distilled H_2O (mL)	Concentration (M)
1	2	8	0.08
2	4	6	0.16
3	6	4	0.24
4	8	2	0.32
5	~10	0	0.40

4. Prepare a blank by filling an empty cuvette 3/4 full with distilled water. To correctly use a cuvette, remember:
   - All cuvettes should be wiped clean and dry on the outside with a tissue.
   - Handle cuvettes only by the top edge of the ribbed sides.
   - All solutions should be free of bubbles.
   - Always position the cuvette so the light passes through the clear sides.

5. Launch Spectral Analysis. Connect the Go Direct SpectroVis Plus to your Chromebook, computer, or mobile device. Click or tap Absorbance vs. Concentration.

6. To calibrate the Spectrometer, place the blank cuvette in the Spectrometer and select Finish Calibration. **Note**: If necessary, wait for the Spectrometer to warm up before selecting Finish Calibration.

7. Determine the optimal wavelength for creating the standard curve.

   a. Remove the blank cuvette, and place the 0.40 M standard into the cuvette slot.

   b. The live graph will update with the spectrum of the sample. Click or tap the desired wavelength or enter the Wavelength. Click or tap Done.

8. You are now ready to collect absorbance-concentration data for the five standard solutions.

   a. Click or tap Collect to start data collection.

   b. Empty the 0.40 M solution from the cuvette. Using the solution in Test Tube 1, rinse the cuvette twice with ~1 mL amounts and then fill it 3/4 full. Wipe the outside with a tissue and place it in the device.

   c. When the value has stabilized, click or tap Keep and enter **0.080** as the concentration in mol/L. Click or tap Keep Point. The absorbance and concentration values have now been saved for the first solution.

   d. Discard the cuvette contents as directed by your instructor. Using the solution in Test Tube 2, rinse the cuvette twice with ~1 mL amounts, and then fill it 3/4 full. Place the cuvette in the device, wait for the value displayed on the screen to stabilize, and click or tap Keep. Enter **0.16** as the concentration in mol/L. Click or tap Keep Point.

   e. Repeat the procedure for Test Tube 3 (0.24 M) and Test Tube 4 (0.32 M), as well as the stock 0.40 M $NiSO_4$. **Note**: Wait until Step 10 to test the unknown.

   f. Click or tap Stop to stop data collection.

   g. To examine the data pairs on the displayed graph, click or tap any data point. Record the absorbance and concentration data values in your data table.

9. Display a graph of absorbance *vs*. concentration with a linear regression curve.

   a. Click or tap Graph Options, , and choose Edit Graph Options.

   b. Enter **0** as the value for both the Left value for the x-axis and the Bottom value for the y-axis. Dismiss the Graph Options box.

   c. Click or tap Graph Options, , and choose Apply Curve Fit.

   d. Select Linear as the curve fit and Dismiss the Curve Fit box. The linear-regression statistics for these two data columns are displayed for the equation in the form

$$y = mx + b$$

   where x is concentration, y is absorbance, m is the slope, and b is the y-intercept. **Note**: One indicator of the quality of your data is the size of b. It is a very small value if the regression line passes through or near the origin. The correlation coefficient, r, indicates how closely the data points match up with (or *fit*) the regression line. A value of 1.00 indicates a nearly perfect fit.

The graph should indicate a direct relationship between absorbance and concentration, a relationship known as Beer's law. The regression line should closely fit the five data points *and* pass through (or near) the origin of the graph.

10. Determine the absorbance value of the unknown $NiSO_4$ solution.
    a. Obtain about 5 mL of the *unknown* $NiSO_4$ in another clean, dry, test tube. Record the number of the unknown in your data table.
    b. Rinse the cuvette twice with the unknown solution and fill it about 3/4 full. Wipe the outside of the cuvette and place it into the device.
    c. Monitor the absorbance value. When this value has stabilized, record it in your data table.
11. Discard the solutions as directed by your instructor. Before closing Spectral Analysis, continue to the Processing the Data section.

PROCESSING THE DATA

1. To determine the concentration of the unknown $NiSO_4$ solution, interpolate along the regression line to convert the absorbance value of the unknown to concentration.
    a. Click or tap Graph Options, , and turn on Interpolate.
    b. Click or tap any point on the curve to find the absorbance value that is closest to the absorbance reading you obtained during the Procedure. Record the corresponding $NiSO_4$ concentration, in mol/L, in your data table.
2. (optional) Print a graph of absorbance *vs*. concentration, with a regression line and interpolated unknown concentration displayed.

DATA AND CALCULATIONS

Trial	Concentration (mol/L)	Absorbance
1	0.080	
2	0.16	
3	0.24	
4	0.32	
5	0.40	
6	Unknown number _____	

Concentration of unknown	mol/L