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.

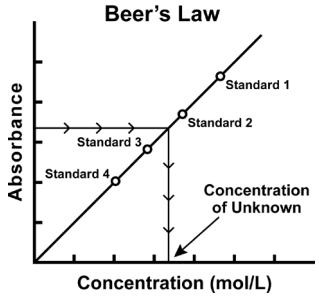

Figure 1

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
Vernier data-collection interface
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. Connect the Colorimeter to the data-collection interface, and then connect the interface to your Chromebook, computer, or mobile device. Launch Graphical Analysis.

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