

# 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. The wavelength of light used should be one that is absorbed by the solution. The  $\text{NiSO}_4$  solution used in this experiment has a deep green color, so you will use the red LED on your Colorimeter. 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.

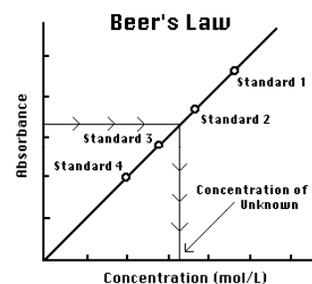


Figure 1

You will determine the concentration of an *unknown*  $\text{NiSO}_4$  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

In this experiment, you will

- Prepare  $\text{NiSO}_4$  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  $\text{NiSO}_4$  solution.

## MATERIALS

TI-Nspire handheld **or**  
 computer and TI-Nspire software  
 data-collection interface  
 Vernier Colorimeter  
 one cuvette  
 five 25 × 150 mm test tubes  
 30 mL of 0.40 M  $\text{NiSO}_4$   
 5 mL of  $\text{NiSO}_4$  unknown solution

two 10 mL pipets (or graduated cylinders)  
 two 100 mL beakers  
 pipet or pipet bulb  
 distilled water  
 test tube rack  
 stirring rod  
 tissues (preferably lint-free)

## PROCEDURE

- Obtain and wear goggles. **CAUTION:** *Be careful not to ingest any NiSO<sub>4</sub> solution or spill any on your skin. Inform your teacher immediately in the event of an accident.*
- Add about 30 mL of 0.40 M NiSO<sub>4</sub> stock solution to a 100 mL beaker. Add about 30 mL of distilled water to another 100 mL beaker.
- Label four clean, dry, test tubes 1–4 (the fifth solution is the beaker of 0.40 M NiSO<sub>4</sub>). Pipet 2, 4, 6, and 8 mL of 0.40 M NiSO<sub>4</sub> 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<sub>4</sub> 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 <sub>4</sub> (mL)	Distilled H <sub>2</sub> O (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

- 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.
- Connect the Colorimeter to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.
- Set up the data-collection mode and change the scale options for the graph.
  - Choose New Experiment from the  Experiment menu. Choose Collection Mode ► Events with Entry from the  Experiment menu. Enter **Concentration** as the Name and **mol/L** as the Units. Select OK.
  - Choose Autoscale Settings from the  Options menu. Select Autoscale from Zero as the After Collection setting. Select OK.
- Calibrate the Colorimeter.
  - Place the blank in the cuvette slot of the Colorimeter and close the lid.
  - 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.

8. You are now ready to collect absorbance-concentration data for the five standard solutions.
  - a. 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 Colorimeter. Close the lid.
  - c. When the value displayed on the screen has stabilized, click the Keep button (📌) and enter **0.080** as the concentration in mol/L. Select OK. 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 Colorimeter and close the lid. Wait for the value displayed on the screen to stabilize and click the Keep button (📌). Enter **0.16** as the concentration in mol/L. Select OK.
  - 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<sub>4</sub>. **Note:** Wait until Step 10 to test the unknown.
  - f. Stop data collection (📌).
  - g. Click the Table View tab (📊) to display the data table. 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 the Graph View tab (📈).
  - b. Choose Curve Fit ► Linear from the  Analyze menu. 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.
  - c. Record your fit equation in your data table.

**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<sub>4</sub> solution.
  - a. Click the Meter View tab (📏).
  - b. Obtain about 5 mL of the *unknown* NiSO<sub>4</sub> in another clean, dry, test tube. Record the number of the unknown in your data table.
  - c. 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.
  - d. Monitor the absorbance value. When this value has stabilized, record it in your data table.
  
11. Discard the solutions as directed by your instructor.

## DATA

Trial	Concentration (mol/L)	Absorbance
1	0.080	
2	0.16	
3	0.24	
4	0.32	
5	0.40	
6	Unknown number ____	
Linear Fit Equation: $y = mx + b$		
Concentration of unknown (mol/L)		

## PROCESSING THE DATA

- To determine the concentration of the unknown  $\text{NiSO}_4$  solution, interpolate along the regression line to convert the absorbance value of the unknown to concentration.
  - Click the Graph View tab (.
  - Choose Interpolate from the  Analyze menu.
  - Click on any point on the regression curve. Use  $\blacktriangleright$  and  $\blacktriangleleft$  to find the Linear Fit value that is closest to the absorbance reading you obtained in Step 10. The corresponding  $\text{NiSO}_4$  concentration, in mol/L, will be displayed.
  - Record the concentration value in your data table.
- (optional) Print a graph of absorbance vs. concentration, with a regression line and interpolated unknown concentration displayed.