

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 the Colorimeter shown in Figure 1. In this device, red light from the LED light source will pass through the solution and strike a photocell. The NiSO_4 solution used in this experiment has a deep green color. A higher concentration of the colored solution absorbs more light (and transmits less) than a solution of lower concentration. The Colorimeter monitors the light received by the photocell as either an *absorbance* or a *percent transmittance* value.

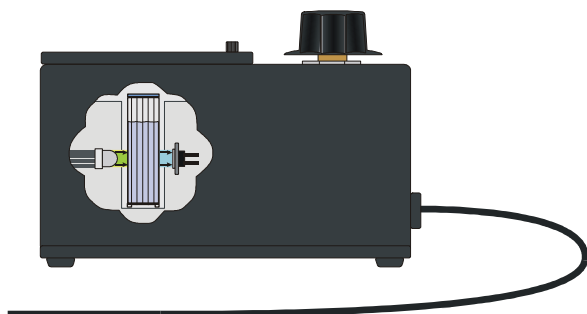


Figure 1

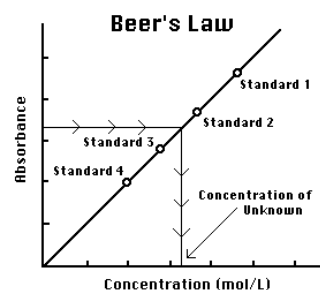


Figure 2

You are to 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 2. The direct relationship between absorbance and concentration for a solution is known as Beer's law.

The concentration of an *unknown* NiSO_4 solution is then determined by measuring its absorbance with the Colorimeter. 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 2). The concentration of the unknown can also be found using the slope of the Beer's law curve.

MATERIALS

LabPro or CBL 2 interface
TI Graphing Calculator
DataMate program
Vernier Colorimeter
one cuvette
five 20 x 150 mm test tubes
50 mL of stock solution NiSO_4
5 mL of 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

1. Obtain and wear goggles! **CAUTION:** *Be careful not to ingest any NiSO₄ solution or spill any on your skin. Inform your teacher immediately in the event of an accident.*
2. Prepare 50 mL of stock solution NiSO₄ into a 50 mL volumetric flask. Weigh out desired amount of Nickel sulfate to the nearest 0.1 mg. Calculate and report the exact molarity of the stock NiSO₄ solution with the correct number of significant figures in the table below.
3. Label four clean, dry, test tubes 1-4 (the fifth solution is the beaker of stock NiSO₄). Pipet (to the nearest 0.02 mL) 2, 4, 6, and 8 mL of stock NiSO₄ 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 stock₄ in the 100-mL beaker to use in the fifth trial. Volumes and concentrations for the trials are summarized below:

Trial number	--- M stock NiSO ₄ (mL)	Distilled H ₂ O (mL)	Concentration (M)
1	2	8	
2	4	6	
3	6	4	
4	8	2	
5	~10	0	

4. Plug the Colorimeter into Channel 1 of the LabPro or CBL 2 interface. Use the link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends.
5. Prepare a *blank* by filling an empty cuvette $\frac{3}{4}$ full with distilled water. Seal the cuvette with a lid. To correctly use a Colorimeter 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 with its reference mark facing toward the white reference mark at the right of the cuvette slot on the Colorimeter.
6. Turn on the calculator and start the DATAMATE program. Press **CLEAR** to reset the program.
7. Set up the calculator and interface for the Colorimeter.
 - a. Place the blank in the cuvette slot of the Colorimeter and close the lid.
 - b. Select SETUP from the main screen.
 - c. If the calculator displays COLORIMETER in CH 1, set the wavelength on the Colorimeter to 635 nm (Red). Then calibrate by pressing the AUTO CAL button on the Colorimeter and proceed directly to Step 8. If the calculator does not display COLORIMETER in CH1, continue with this step to set up your sensor manually.
 - d. Press **ENTER** to select CH 1.
 - e. Select COLORIMETER from the SELECT SENSOR menu.
 - f. Select CALIBRATE from the SETUP menu.
 - g. Select CALIBRATE NOW from the CALIBRATION menu.

First Calibration Point

- h. Turn the wavelength knob of the Colorimeter to the 0% T position. When the voltage reading stabilizes, press . Enter "0" as the percent transmittance.

Second Calibration Point

- i. Turn the wavelength knob of the Colorimeter to the Red LED position (635 nm). When the voltage reading stabilizes, press . Enter "100" as the percent transmittance.
- j. Select OK to return to the setup screen.
8. Set up the data-collection mode.
- a. To select MODE, press once and press .
- b. Select EVENTS WITH ENTRY from the SELECT MODE menu.
- c. Select OK to return to the main screen.
9. You are now ready to collect absorbance-concentration data for the five standard solutions.
- a. Select START from the main screen.
- 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, place it in the Colorimeter, and close the lid.
- c. When the value displayed on the calculator screen has stabilized, press . Enter "molarity of diluted solution(actual value)" as the concentration in mol/L. 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. After closing the lid, wait for the value displayed on the calculator screen to stabilize and press . Enter "actual value of molarity" as the concentration in mol/L.
- e. Repeat the procedure for Test Tube 3 (diluted concentration) and Test Tube 4 (diluted concentration), as well as the molarity of the stock NiSO₄. **Note:** Wait until Step 10 to do the unknown.
- f. Press to stop data collection. The absorbance and concentration values have now been saved for the standard solutions.
- g. Examine the data points along the curve on the displayed graph. As you move the cursor right or left, the concentration (X) and absorbance (Y) values of each data point are displayed below the graph. Record the absorbance values in your data table (round to the nearest 0.001).
- h. Press to return to the main screen.
10. Determine the absorbance value of the unknown NiSO₄ solution. To do this:
- a. Obtain about 5 mL of the *unknown* NiSO₄ 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, place it into the Colorimeter, and close the lid.
- c. Monitor the absorbance value displayed on the calculator. When this value has stabilized, record it in your data table (round to the nearest 0.001).
- d. Dispose of the remaining solution as directed by your instructor.
11. Discard the solutions as directed by your instructor. Proceed directly to Steps 1–2 of Processing the Data.

PROCESSING THE DATA

1. To determine the concentration of the unknown NiSO_4 solution, plot a graph of absorbance vs. concentration with a linear regression curve displayed, then interpolate along the regression line to convert the absorbance value of the unknown to concentration. To do this:
 - a. Select ANALYZE from the main screen.
 - b. Select CURVE FIT from the ANALYZE OPTIONS menu.
 - c. Select LINEAR (CH 1 VS ENTRY) from the CURVE FIT menu. The linear-regression statistics for these two lists are displayed for the equation in the form

$$y = ax + b$$

where y is absorbance, x is concentration, a 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.

- d. To display the linear-regression curve on the graph of absorbance vs. concentration, press . This 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.
 - e. To interpolate along the curve, press . A cursor is displayed on the regression line, along with its X and Y coordinates below the graph. Use or to move the cursor to an absorbance value (Y value) that is closest to the absorbance reading you obtained in Step 10. The NiSO_4 concentration, in mol/L, will be equal to the corresponding X value. Record this value in your data table.
2. 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		
2		
3		
4		
5		
6	Unknown number _____	
Concentration of unknown		mol/L