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.

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.

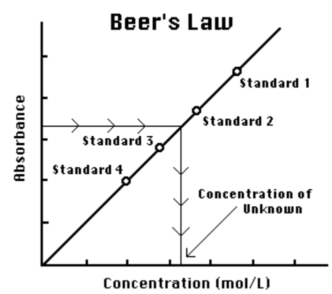


Figure 1

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 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 $NiSO_4$ standard solution.
- Use a Colorimeter to measure the absorbance value of each standard solution.
- Find the relationship between absorbance and concentration of a solution.
- Use the results of this experiment to determine the unknown concentration of another $NiSO_4$ solution.

MATERIALS

LabPro interface
Palm handheld
Data Pro program
Vernier Colorimeter
one cuvette
five 20 x 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 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 $NiSO_4$ 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.

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. Plug the Colorimeter into Channel 1 of the LabPro interface. Connect the handheld to the LabPro using the interface cable. Firmly press in the cable ends.

5. Prepare a *blank* by filling an empty cuvette ¾ 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 top of the cuvette slot on the Colorimeter.

6. Press the power button on the handheld to turn it on. To start Data Pro, tap the Data Pro icon on the Applications screen. Choose New from the Data Pro menu or tap [New] to reset the program.

7. Set up the handheld and interface for the Colorimeter.
   a. Place the blank in the cuvette slot of the Colorimeter and close the lid.
   b. On the Main screen, tap [Setup].

c. If the handheld displays ABSORBANCE in CH 1, press the < or > button 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. Proceed directly to Step 8. If the calculator does not display ABSORBANCE in CH 1, continue with this step to set up your sensor manually.

d. On the Setup screen, tap CH1:, then choose COLORIMETER from the list of sensors.

e. Tap Calibrate, then tap Calibrate Now.

First Calibration Point

f. Turn the wavelength knob of the Colorimeter to the 0% T position. In the Value field enter "0" as the percent transmittance. You can enter this information using the onscreen keyboard (tap "123"), or by using the Graffiti writing area. When the voltage reading stabilizes, tap Keep Pt 1.

Second Calibration Point

g. Turn the wavelength knob of the Colorimeter to the Red LED position (635 nm). Enter "100" as the percent transmittance. When the voltage reading stabilizes, tap Keep Pt 2.

h. Tap OK two times to return to the Setup screen.

8. Set up the data-collection mode.

   a. On the Setup screen, tap Mode:, then choose Events with Entry.
   b. Enter the Entry Label (Conc) and Unit (mol/L). You can enter this information using the onscreen keyboard (tap "abc"), or by using the Graffiti writing area.
   c. Tap OK twice to return to the Main screen.

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

   a. Tap Start to begin 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, place it in the Colorimeter, and close the lid.
   c. When the value displayed on the handheld screen has stabilized, tap Keep and enter "0.080" as the concentration (using the numerical keyboard displayed on the screen). Tap Enter. 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 handheld screen to stabilize and tap Keep. Enter "0.16" as the concentration in mol/L, and tap Enter.
   e. Repeat the procedure for Test Tube 3 (0.24 M) and Test Tube 4 (0.32M), as well as the stock 0.40 M $NiSO_4$. **Note:** Wait until Step 10 to do the unknown.
   f. Tap Stop when you have finished collecting data, then tap OK to view a graph of absorbance *vs.* concentration.
   g. To examine the data pairs on the displayed graph, tap ▶ or any data point. As you move the examine line, the absorbance and concentration values of each data point are displayed to the right of the graph. Record the absorbance and concentration data values in your data table (round to the nearest 0.001).
   h. Tap OK to return to the Main screen.

10. Determine the absorbance value of the unknown $NiSO_4$ solution. To do this:
    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, place it into the Colorimeter, and close the lid.
    c. Monitor the absorbance value displayed on the handheld screen. When this value has stabilized, record it in the Data Table.

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. Tap Analyze, then tap Curve Fit.
    b. From the Fit Equation menu, choose Linear. The linear-regression statistics for these two data columns are displayed for the equation in the form

    $$y = ax + b$$

    where x is concentration, y is absorbance, 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.
    c. Tap Interpolate on Fit to check it.
    d. Tap OK to display the regression curve on the graph of absorbance *vs.* concentration. 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. Now interpolate along the regression curve to determine the concentration of the unknown solution. Tap ◀, ▶, or any point on the regression curve to move the interpolation line. Move it to the absorbance value that is closest to the absorbance reading you obtained in Step 9. The $NiSO_4$ concentration, in mol/L, will be displayed to the lower right of the graph. Record this value 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

TEACHER INFORMATION

Determining the Concentration of a Solution: Beer's Law

1. The student pages with complete instructions for data-collection using LabQuest App, Logger *Pro* (computers), EasyData or DataMate (calculators), and DataPro (Palm handhelds) can be found on the CD that accompanies this book. See *Appendix A* for more information.

2. The light source for the nickel (II) sulfate solution is the red LED (635 nm). Since the $NiSO_4$ is green in color, the nearly monochromatic red light is readily absorbed by the solution.

3. The 0.40 M $NiSO_4$ solution can be prepared by using 10.51 g of $NiSO_4 \cdot 6H_2O$ per 100 mL. **HAZARD ALERT:** Toxic; avoid dispersing this substance; dispense with care; Nickel dust is a *possible carcinogen*. Hazard Code: B—Hazardous.

   The hazard information reference is: Flinn Scientific, Inc., *Chemical & Biological Catalog Reference Manual,* (800) 452-1261, www.flinnsci.com. See *Appendix D* of this book, *Chemistry with Vernier*, for more information.

4. Solutions of $Ni(NO_3)_2$ also work well, and can be prepared by using 11.63 g of solid $Ni(NO_3)_2 \cdot 6H_2O$ per 100 mL of solution.

5. Unknowns can be prepared by doing dilutions starting with the 0.40 M $NiSO_4$ stock solution. For example, to prepare a 0.22 M unknown, use 55 mL of the standard plus 45 mL of water:

   $$(55 \text{ mL} / 100 \text{ mL})(.40 \text{ M}) = 0.22 \text{ M}$$

6. This experiment works well using solutions of green food coloring. A solution with an absorbance similar to 0.40 M $NiSO_4$ can be prepared by dissolving 8–9 drops of green Schilling Food Coloring in 1 liter of water. Check to see that the absorbance of this stock solution falls in the range of 0.40 to 0.80. Assign this solution a concentration of 100%. Students will follow the same procedure to dilute the stock solution to 80%, 60%, 40%, and 20%. If you use this method, have your students load the Exp 11b Colorimeter in the Experiment 11 folder in *Chemistry with Vernier*. This file has concentration scaled from 0 to 100% on the horizontal axis.

7. The cuvette must be from 55% to 100% full in order to get a valid absorbance reading. If students fill the cuvette 3/4 full, as described in the procedure, they should easily be in this range. To avoid spilling solution into the cuvette slot, remind students not to fill the cuvette 8. Since there is some variation in the amount of light absorbed by the cuvette if it is rotated 180°, you should use a water-proof marker to make a reference mark on the top edge of one of the clear sides of all cuvettes. Students are reminded in the procedure to align this mark with the white reference mark at the top of the cuvette slot on the Colorimeter.

8. The use of a single cuvette in the procedure is to eliminate errors introduced by slight variations in the absorbance of different plastic cuvettes. If one cuvette is used throughout the experiment by a student group, this variable is eliminated. The two rinses done prior to adding a new solution can be accomplished very quickly.

9. There are two models of Vernier Colorimeters. The first model (rectangular shape) has three wavelength settings, and the newest model (a rounded shape) has four wavelength settings. The 635 nm wavelength of either model is used in this experiment. The newer model is an auto-ID sensor and supports automatic calibration (pressing the CAL button on the

Colorimeter with a blank cuvette in the slot). If you have an older model Colorimeter, see www.vernier.com/til/1665.html for calibration information.

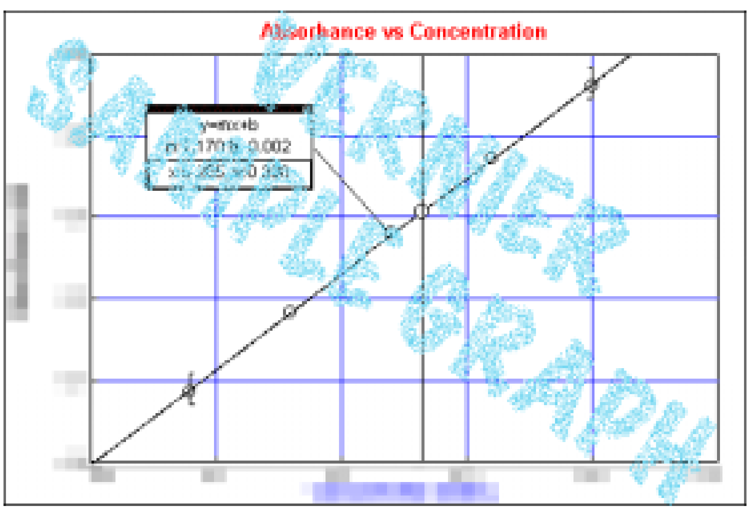
10. This experiment gives you a good opportunity to discuss the relationship between percent transmittance and absorbance. At the end of the experiment, students can click the Absorbance vertical-axis label of the graph, and choose Transmittance. The graph should now be transmittance *vs.* concentration. You can also discuss the mathematical relationship between absorbance and percent transmittance, as represented by either of these formulas:

$$A = \log(100 / \%T) \quad \text{or} \quad A = 2 - \log\%T$$

SAMPLE RESULTS

Trial	Concentration (mol / L)	Absorbance
1	xxxx	xxxx
2	xxxx	xxxx
3	xxxx	xxxx
4	xxxx	xxxx
5	xxxx	xxxx
6	xxxx	xxxx

Concentration of the unknown	xxxx mol/L



Absorbance vs. concentration for $NiSO_4$
with interpolation of the unknown displayed