Experiment 11

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

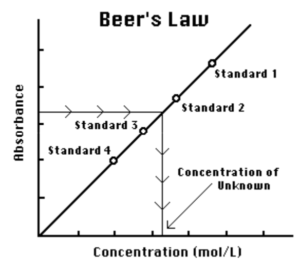

Figure 2

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.

OBJECTIVES

In this experiment, you will

- Prepare $NiSO_4$ standard solutions.
- 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

computer
Vernier computer interface
Logger*Pro*
Vernier Colorimeter
one cuvette
five 20 × 150 mm test tubes
tissues (preferably lint-free)
stirring rod
30 mL of 0.40 M $NiSO_4$
5 mL of $NiSO_4$ unknown solution
two 10 mL pipets (or graduated cylinders)
pipet pump or pipet bulb
distilled water
test tube rack
two 100 mL beakers

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. Connect the Colorimeter to the computer interface. Prepare the computer for data collection by opening the file “11 Beer’s Law” from the *Chemistry with Computers* folder of Logger*Pro*.

5. You are now ready to calibrate the Colorimeter. Prepare a *blank* by filling a cuvette 3/4 full with distilled water. 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. Calibrate the Colorimeter.

   a. Open the Colorimeter lid.
   b. Holding the cuvette by the upper edges, place it in the cuvette slot of the Colorimeter. Close the lid.

c. If your Colorimeter has a CAL button, Press the < or > button on the Colorimeter to select a wavelength of 635 nm (Red) for this experiment. Press the CAL button until the red LED begins to flash. Then release the CAL button. When the LED stops flashing, the calibration is complete. Proceed directly to Step 7. If your Colorimeter does not have a CAL button, continue with this step to calibrate your Colorimeter.

First Calibration Point

d. Choose Calibrate ▸ CH1: Colorimeter (%T) from the Experiment menu and then click Calibrate Now.

e. Turn the wavelength knob on the Colorimeter to the "0% T" position.

f. Type "0" in the edit box.

g. When the displayed voltage reading for Reading 1 stabilizes, click Keep.

Second Calibration Point

h. Turn the knob of the Colorimeter to the Red LED position (635 nm).

i. Type "100" in the edit box.

j. When the displayed voltage reading for Reading 2 stabilizes, click Keep, then click Done.

7. You are now ready to collect absorbance data for the five standard solutions. Click ▸ Collect. 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. After closing the lid, wait for the absorbance value displayed on the monitor to stabilize. Then click Keep type "0.080" in the edit box, and press the ENTER key. The data pair you just collected should now be plotted on the graph.

8. Discard the cuvette contents as directed by your teacher. Rinse the cuvette twice with the Test Tube 2 solution, 0.16 M $NiSO_4$, and fill the cuvette 3/4 full. Wipe the outside, place it in the Colorimeter, and close the lid. When the absorbance value stabilizes, click Keep, type "0.16" in the edit box, and press the ENTER key.

9. Repeat the Step 8 procedure to save and plot the absorbance and concentration values of the solutions in Test Tube 3 (0.24 M) and Test Tube 4 (0.32 M), as well as the stock 0.40 M $NiSO_4$. Wait until Step 12 to do the unknown. When you have finished with the 0.40 M $NiSO_4$ solution, click ■ Stop.

10. In your Data and Calculations table, record the absorbance and concentration data pairs that are displayed in the table.

11. Examine the graph of absorbance *vs.* concentration. To see if the curve represents a direct relationship between these two variables, click the Linear Fit button, . A best-fit linear regression line will be shown for your five data points. This line should pass near or through the data points *and* the origin of the graph. (Note: Another option is to choose Curve Fit from the Analyze menu, and then select Proportional. The Proportional fit has a y-intercept value equal to 0; therefore, this regression line will always pass through the origin of the graph).

12. Obtain about 5 mL of the unknown $NiSO_4$ in another clean, dry, test tube. Record the number of the unknown in the Data and Calculations table. 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. Read the absorbance value displayed in the meter. (**Important**: The reading in the meter is live, so it is **not** necessary to click ▸ Collect to read the

absorbance value.) When the displayed absorbance value stabilizes, record its value in Trial 6 of the Data and Calculations table.

13. Discard the solutions as directed by your teacher. Proceed directly to Steps 1 and 2 of Processing the Data.

PROCESSING THE DATA

1. Use the following method to determine the unknown concentration. With the linear regression curve still displayed on your graph, choose Interpolate from the Analyze menu. A vertical cursor now appears on the graph. The cursor's concentration and absorbance coordinates are displayed in the floating box. Move the cursor along the regression line until the absorbance value is approximately the same as the absorbance value you recorded in Step 12. The corresponding concentration value is the concentration of the unknown solution, in mol/L.

2. Print a graph of absorbance *vs.* concentration, with a regression line and interpolated unknown concentration displayed. To keep the interpolated concentration value displayed, move the cursor straight up the vertical cursor line until the tool bar is reached. Enter your name(s) and the number of copies of the graph you want.

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

Experiment
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Determining the Concentration of a Solution: Beer's Law

1. 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.
2. The 0.40 M $NiSO_4$ solution can be prepared by using 10.51 g of $NiSO_4•6H_2O$ 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 Computers*, for more information.
3. Solutions of $Ni(NO_3)_2$ also work well, and can be prepared by using 11.63 g of solid $Ni(NO_3)_2•6H_2O$ per 100 mL of solution.
4. 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:

   $$(55 \text{ mL} / 100 \text{ mL})(.40 \text{ M}) = 0.22 \text{ M}$$
5. 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 Computers*. This file has concentration scaled from 0 to 100% on the horizontal axis.
6. 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 to the brim.
7. 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). The calibration directions in Step 6 of the student procedure cover both Colorimeter models.

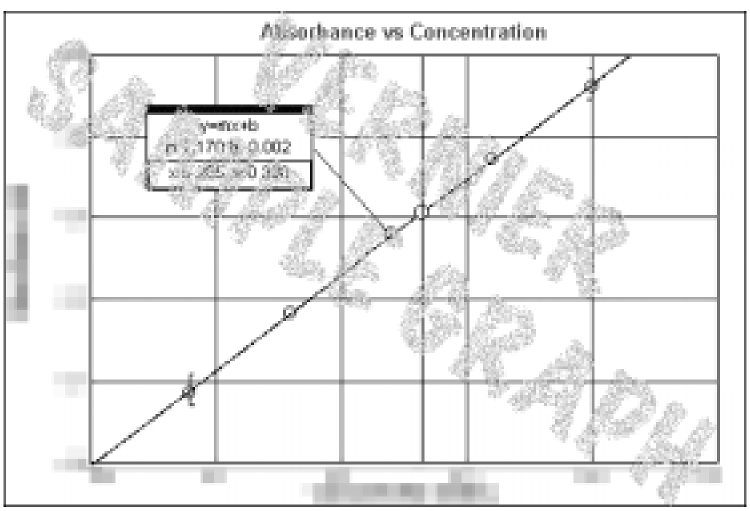
10. This experiment gives you a good opportunity to discuss the relationship between percent transmittance and absorbance. At the end of the experiment, students can click the Absorbance vertical-axis label of the graph, and choose Transmittance. The graph should now be transmittance *vs.* concentration.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