Determining the Concentration of a Solution: Beer's Law

Some solutions have color because they absorb some, but not all of the colors of light that hit them. For example, copper solutions appear blue because they absorb most, or all, of the orange, red and yellow light that hits them. As a result most of the light that is reflected or passes through is blue (with some green and purple). In all cases the color that we see is the opposite (on a color wheel) of the color that is most absorbed.

This absorption occurs through when electrons change energy levels. Light with the right energy hits an ion of copper in solution. The energy is absorbed and an electron jumps to a higher level. When the electron drops back down, the light is re-emitted in a random direction (as opposed to the direction the photon was traveling). This results in a decrease in the amount of light of that color that emerges from the opposite side of the solution. Different ions can absorb different wavelengths of light and so have different colors.

In this experiment, you will learn about the relationship between absorbance and concentration for a solution—this relationship is known as *Beer's law*. You will be using a Colorimeter (a side view is shown in Figure 1) to measure the absorbance of solutions. A colorimeter (see diagram) passes light of a given color through a small container of solution, called a cuvette.

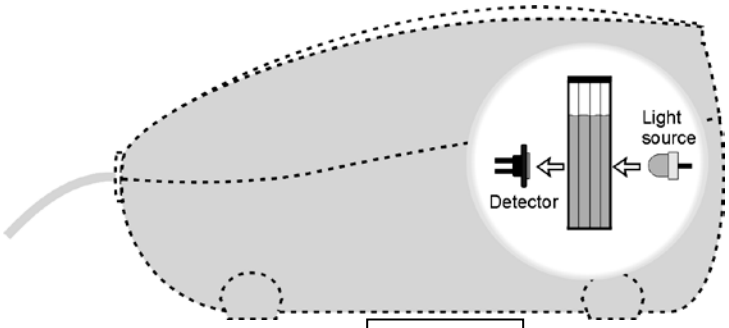

Figure 1

The solution we will be using is green and you will therefore be passing red light through it. In this experiment, red light from the LED light source will pass through the solution and strike a photocell. The colorimeter monitors the light received by the photocell as percent transmittance. You will design and carry out an experiment to create a standard curve, by graphing the relationship between concentration and absorbance of a series of nickel(II) sulfate solutions of known concentration, and use this standard curve to determine the concentration of an unknown nickel(II) sulfate solution.

OBJECTIVES

In this experiment, you will

- Design an experiment to determine the absorbance of a nickel (II) sulfate solution of unknown molar concentration
- Prepare and test the absorbance of five standard nickel (II) sulfate solutions.
- Calculate a standard curve from the test results of the standard solutions.
- Test the absorbance of a nickel (II) sulfate solution of unknown molar concentration.
- Calculate the molar concentration of an unknown $NiSO_4$ solution.

AP Chemistry Learning Objectives: 1.16, Science Practices 1.4, 2.2, 2.3, 5.1, 6.1, 6.2, 6.4

AVAILABLE MATERIALS

LabQuest	0.40 M nickel (II) sulfate, $NiSO_4$, solution (50 mL, maximum)
Optional: computer with LoggerPro	nickel (II) sulfate, $NiSO_4$, unknown solution
Vernier colorimeter	Beral pipettes
one cuvette	distilled water
five 20 × 150 mm test tubes	test tube rack
two 10 mL pipets or graduated cylinders	stirring rod
two 100 mL beakers	Parafilm
Kimwipes or lint-free tissues	Volumetric pipettes

Safety Precautions

Nickel(II) sulfate is a skin and eye irritant that is very hazardous if ingested. Avoid contact with eyes, skin and clothing. Wear chemical splash goggles, chemical resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Follow all laboratory safety guidelines.

PROCEDURE

Setting up the Colorimeter

1. Obtain and wear goggles. Connect a colorimeter to Channel One of a LabQuest interface.
2. Set up the data-collection mode.
   - Start a new file.
   - To select MODE, tap on the mode screen with the stylus.
   - Select EVENTS WITH ENTRY from the SELECT MODE menu. Enter an appropriate unit.
   - Select OK to return to the Main screen.
3. Set up the interface for the colorimeter.
   - Prepare a *blank* by filling an empty cuvette ¾ full with distilled water. Dry the outside of the cuvette with a Kimwipe. Place the blank in the cuvette slot of the colorimeter and close the lid.
   - Set the wavelength on the Colorimeter to 635 nm, press the CAL button, and proceed directly to Step 6. Do not press the CAL button again during the experiment!

Plan the experiment—Creating a standard curve

4. Obtain 50 mL of 0.40 M $NiSO_4$ solution and 100 mL distilled water in separate beakers.
5. As a lab group, discuss the following leading questions.
   - What concentrations will you prepare for your five standard $NiSO_4$ solutions?
   - How will you prepare your standard solutions?
   - What is the purpose of the blank?
   - What data do you need to record?
   - What is the independent variable? What is the dependent variable?
   - In what order will you test your standard solutions? Do you need to rinse the cuvette? If so, with what?
6. Design an appropriate data table in your notebook.

7. Have your instructor approve the plan before proceeding.

Conducting the experiment

8. Carry out the procedure to collect absorbance data for each of the standard solutions. Record the data in your laboratory notebook. Repeat any points that appear to not fit the line. Close the data collection before proceeding.

9. Obtain a small sample of the unknown. Measure its absorbance and record this in your lab notebook.

DATA ANALYSIS

1. Calculate the linear regression (best-fit line) equation of absorbance *vs.* concentration for the five standard $NiSO_4$ solutions. Print or sketch a graph showing the data and linear-regression equation for the standard solutions.

2. Share the slope of your linear regression curve with the class. Report the average slope based on the class data.

3. Determine the concentration of the unknown $NiSO_4$ solution. Explain how you arrived at your answer.

DISCUSSION

1. Explain what a spectrophotometer is and what it measures. How is a spectrophotometer different from the colorimeter used in this experiment?
2. What is the difference between absorbance and transmittance? Include an illustration with your answer. What is the mathematical relationship between absorbance and transmittance?
3. Return to the simulations of a spectrophotometer at http://phet.colorado.edu/en/simulation/beers-law-lab.
    a) Based on the simulation, what is the effect of path length on absorbance by a sample? Explain why this occurs.
    b) What is the effect of concentration of absorbance? Explain why this occurs.
4. When you use a spectrophotometer or colorimeter, should you set the wavelength of light to be the same color as that of the solution, or would a different color be more appropriate? Explain. (The PhET simulation could be useful here)
5. State Beer's Law in equation form. Explain what is represented by each symbol in the equation, with appropriate units.
6. What is the physical meaning of the molar absorbtivity constant? How is this determined from the data in this experiment?
7. Under what conditions are deviations from Beer's Law observed? Explain the origin of these deviations.
8. Compare the uses of UV-Vis, infrared and microwave spectroscopy. What kind of information can be obtained from these methods? (Reliable references?)
9. Discuss sources of error and ways to improve the accuracy and/or precision of your results.

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Preliminary Lab Assignment

Complete this assignment in your laboratory notebook.

1. Go to http://phet.colorado.edu/en/simulation/beers-law-lab and open up the Beer's Law Lab simulation.
    a) Select nickel(II) chloride as the solution. Set the concentration to 100. mM. (Note: 0.100 M = 100. mM)
    b) Set the wavelength to "variable" and choose absorbance mode for the spectrophotometer.
    c) Change the wavelength of the light beam. What wavelength gives the greatest absorbance for this solution? How does the color of this light compare to the color of the test solution?

    d) Set the wavelength to "fixed" and choose absorbance mode for the spectrophotometer. Set the path length to 1 cm.
    e) Collect absorbance data for the following solution concentrations.

Trial number	Concentration (mM)	Absorbance (A)
1	50	
2	100	
3	150	
4	200	
5	250	

    f) Using spreadsheet or graphing software, prepare a graph in which the absorbances given in the table are plotted against the concentration of nickel(II) chloride. This type of graph is called a "standard curve." Draw the best fit line and determine its slope. Print out the graph and place in in your lab notebook.
    g) The absorbance of a solution of unknown concentration is found to be 0.542. What is the concentration of this solution?

2. Determine the concentration of each of the following standard solutions.

Trial number	0.50 M $CuSO_4$ (mL)	Distilled H_2O (mL)	Concentration (M)
1	2	8	
2	4	6	
3	6	4	
4	8	2	
5	~10	0	