

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

The primary objective of this experiment is to determine the concentration of an unknown copper (II) sulfate solution. You will use a Colorimeter (a side view is shown in Figure 1) to measure the concentration of each solution. In this experiment, red light from the LED light source will pass through the solution and strike a photocell. 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 percent transmittance.

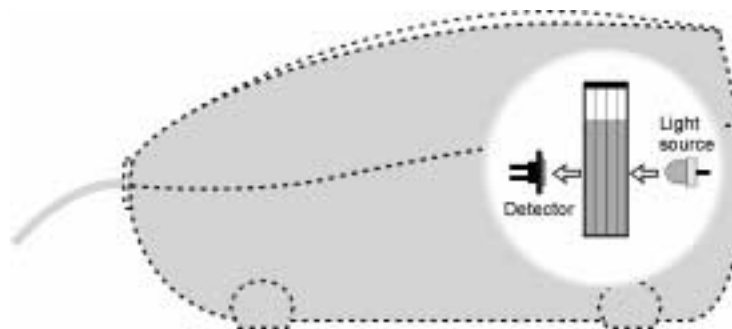


Figure 1

You will prepare five copper (II) sulfate solutions of known concentration (standard solutions). Each solution 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 you graph absorbance *vs.* concentration for the standard solutions, a direct relationship should result. The direct relationship between absorbance and concentration for a solution is known as *Beer's law*.

You will determine the concentration of an unknown  $\text{CuSO}_4$  solution 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. 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 and test the absorbance of five standard copper (II) sulfate solutions.
- Calculate a standard curve from the test results of the standard solutions.
- Test the absorbance of a copper (II) sulfate solution of unknown molar concentration.
- Calculate the molar concentration of the unknown  $\text{CuSO}_4$  solution.

## MATERIALS

Vernier computer interface	0.40 M copper (II) sulfate, $\text{CuSO}_4$ , solution
computer	copper (II) sulfate, $\text{CuSO}_4$ , unknown solution
Vernier Colorimeter	pipet pump or pipet bulb
one cuvette	distilled water
five $20 \times 150$ mm test tubes	test tube rack
two 10 mL pipets or graduated cylinders	stirring rod
two 100 mL beakers	tissues (preferably lint-free)


## PROCEDURE

- Obtain and wear goggles.
- Obtain small volumes of 0.40 M  $\text{CuSO}_4$  solution and distilled water in separate beakers.
- Label four clean, dry, test tubes 1–4. Use pipets to prepare five standard solutions according to the chart below. Thoroughly mix each solution with a stirring rod. Clean and dry the stirring rod between uses.

Trial number	0.40 M $\text{CuSO}_4$ (mL)	Distilled $\text{H}_2\text{O}$ (mL)	Concentration (M)
1	2	8	0.080
2	4	6	0.16
3	6	4	0.24
4	8	2	0.32
5	~10	0	0.40

- Connect a Colorimeter to Channel 1 of the Vernier computer interface. Connect the interface to the computer using the proper cable.
- Start the *Logger Pro* program on your computer. Open the file “17 Colorimeter” from the *Advanced Chemistry with Vernier* folder.
- Calibrate the Colorimeter.
  - Prepare a *blank* by filling an empty cuvette  $\frac{3}{4}$  full with distilled water. Place the blank in the cuvette slot of the Colorimeter and close the lid.
  - If your Colorimeter has a CAL button, set the wavelength on the Colorimeter to 635 nm, press the CAL button, and proceed directly to Step 7. If your Colorimeter does not have a CAL button, continue with this step to calibrate your Colorimeter.
  - Choose Calibrate ▶ CH1: Colorimeter from the Experiment menu, then click .
  - Turn the wavelength knob on the Colorimeter to the “0% T” position.
  - Type “0” in the edit box.
  - When the displayed voltage reading for Reading 1 stabilizes, click .
  - Turn the knob of the Colorimeter to the Red LED position (635 nm).
  - Type “100” in the edit box.
  - When the voltage reading for Reading 2 stabilizes, click , then click .

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7. You are now ready to collect absorbance-concentration data for the five standard solutions.
  - a. Click .
  - b. Remove the cuvette from your Colorimeter and pour out the water. Using the solution in Test Tube 1, rinse the cuvette twice with ~1 mL amounts, and then fill it  $\frac{3}{4}$  full. Wipe the outside with a tissue, place it in the Colorimeter, and close the lid.
  - c. When the absorbance readings stabilize, click , type "0.080" in the edit box, and press the ENTER key. The data pair should now be plotted on the graph.
  - d. Discard the cuvette contents as directed. Using the solution in Test Tube 2, rinse and fill the cuvette  $\frac{3}{4}$  full. Wipe the outside, place it in the Colorimeter, and close the lid. When the absorbance readings stabilize, click , type "0.16" in the edit box, and press the ENTER key.
  - e. Repeat the procedure for Test Tubes 3 and 4. Trial 5 is the original 0.40 M  $\text{CuSO}_4$  solution. **Note:** Do not test the unknown solution until Step 9.
  - f. When you have finished testing the standard solutions, click .
  - g. Examine the graph of absorbance vs. concentration. Click the Linear Regression button, . A best-fit linear regression line will be shown for your five data points.
8. Record the absorbance values, for each of the five trials, in your data table.
9. Determine the absorbance value of the unknown  $\text{CuSO}_4$  solution.
  - a. Obtain about 5 mL of the *unknown*  $\text{CuSO}_4$  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  $\frac{3}{4}$  full. Wipe the outside of the cuvette, place it into the Colorimeter, and close the lid.
  - c. Read the absorbance value displayed in the meter. (**Important:** The reading in the meter is live, so it is not necessary to click  to read the absorbance value.) When the displayed absorbance value stabilizes, record its value as Trial 6 in your data table.
  - d. Dispose of any of the remaining solutions as directed.

### DATA TABLE

Trial	Concentration (mol/L)	Absorbance
1	0.080	
2	0.16	
3	0.24	
4	0.32	
5	0.40	
6	Unknown number ____	

### DATA ANALYSIS

1. Calculate the linear regression (best-fit line) equation of absorbance vs. concentration for the five standard  $\text{CuSO}_4$  solutions. Print a graph showing the data and linear-regression equation for the standard solutions.



## TEACHER INFORMATION

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1. This experiment conforms to the guidelines for the 17<sup>th</sup> laboratory experiment listed in the College Board AP Chemistry guide (the Acorn book).
2. The light source for the copper (II) sulfate solution is the red LED (635 nm). The nearly monochromatic red light is absorbed by the solution.
3. Prepare 100 mL of 0.40 M copper (II) sulfate solution by dissolving 9.99 g of  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  in sufficient distilled water to make 100 mL of solution.
4. A suitable unknown  $\text{CuSO}_4$  solution can be prepared by adding 50 mL of distilled water to 50 mL of the stock 0.40 M copper (II) sulfate solution.
5. You may substitute blue food coloring for the  $\text{CuSO}_4$ . Two recipes to try are: (a) 2 drops of food coloring per 100 mL of distilled water or, (b) 3 drops of food coloring per 150 mL of distilled water. Prepare each mixture and test them as the "0.4 M  $\text{CuSO}_4$  solution." Decide which solution produces the optimum absorbance for the experiment.
6. The cuvettes should be at least  $\frac{3}{4}$  full to get good absorbance measurements. However, the cuvettes need not be completely full and indeed should not in order to seal the cuvette with a plastic cap without spilling out some solution.
7. We recommend that each student lab team use a single cuvette to test their liquids in the Colorimeter. This will eliminate errors introduced by slight variations in the absorbance of different plastic cuvettes.

### HAZARD ALERTS

Copper (II) sulfate, pentahydrate: Skin and respiratory irritant; moderately toxic by ingestion and inhalation. Hazard code: C—Somewhat hazardous.

The hazard information reference is: Flinn Scientific, Inc., *Chemical and Biological Catalog Reference Manual*, P.O. Box 219, Batavia, IL 60510, (800) 452-1261, [www.flinnsci.com](http://www.flinnsci.com).

### ANSWERS TO THE DATA ANALYSIS QUESTIONS

Answers have been removed from the online versions of Vernier curriculum material in order to prevent inappropriate student use. Graphs and data tables have also been obscured. Full answers and sample data are available in the print versions of these labs.

## SAMPLE DATA AND GRAPH

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

