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.

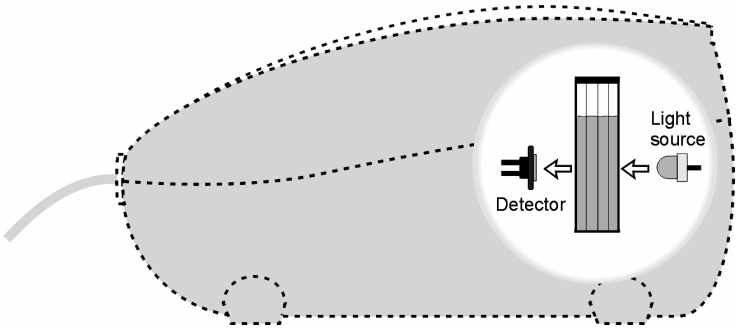


Figure 1

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 $CuSO_4$ 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 $CuSO_4$ solution.

MATERIALS

LabQuest
LabQuest
Vernier Colorimeter
two 10 mL pipets or graduated cylinders
five 20 × 150 mm test tubes
one cuvette
two 100 mL beakers
0.40 M copper (II) sulfate, $CuSO_4$, solution
copper (II) sulfate, $CuSO_4$, unknown solution
pipet pump or pipet bulb
distilled water
test tube rack
stirring rod
tissues (preferably lint-free)

PROCEDURE

1. Obtain and wear goggles.

2. Obtain small volumes of 0.40 M $CuSO_4$ solution and distilled water in separate beakers.

3. 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 $CuSO_4$ (mL)	Distilled H_2O (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

4. Connect the Colorimeter to LabQuest and choose New from the File menu. If you have an older sensor that does not auto-ID, manually set up the sensor.

5. Calibrate the Colorimeter.
   a. Prepare a *blank* by filling an empty cuvette 3/4 full with distilled water.
   b. Place the blank in the cuvette slot of the Colorimeter and close the lid.
   c. Press the < or > buttons 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.

6. On the Meter screen, tap Mode. Change the data-collection mode to Events with Entry. Enter the Entry Label (Conc) and Unit (mol/L) and select OK.
7. You are now ready to collect absorbance-concentration data for the five standard solutions.
   a. Start data collection.
   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 3/4 full. Wipe the outside with a tissue, place it in the Colorimeter, and close the lid.
   c. When the absorbance readings have stabilized, tap Keep and enter **0.080** as the concentration. Select OK. The absorbance and concentration values have now been saved for the first solution.
   d. Discard the cuvette contents as directed. Using the solution in Test Tube 2, rinse the cuvette twice with ~1 mL amounts, and then fill it 3/4 full. Wipe the outside, place it in the Colorimeter, and close the lid. When the absorbance readings have stabilized, tap Keep and enter **0.16** as the concentration in mol/L. Select OK.
   e. Repeat Part d of this step for Test Tube 3 (0.24 M), Test Tube 4 (0.32M), and the stock 0.40 M $CuSO_4$. **Note:** Do not test the unknown solution until Step 8.
   f. Stop data collection to view a graph of absorbance *vs.* concentration.
   g. To examine the data pairs on the displayed graph, select any data point. As you tap each point, the absorbance and concentration values of each data point are displayed to the right of the graph. Record the absorbance values in your data table.
8. Determine the absorbance value of the unknown $CuSO_4$ solution.
   a. Obtain about 5 mL of the *unknown* $CuSO_4$ 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 3/4 full. Wipe the outside of the cuvette, place it into the Colorimeter, and close the lid.
   c. Tap Meter and monitor the absorbance value displayed on the screen. When this value has stabilized, record it in the 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 $CuSO_4$ solutions. Print or sketch a graph showing the data and linear-regression equation for the standard solutions.

2. Determine the concentration of the unknown $CuSO_4$ solution. Explain how you made this determination.

3. Describe an alternate method for determining the molar concentration of your unknown sample of copper (II) sulfate solution, using the standard data.

TEACHER INFORMATION

Determining the Concentration of a Solution: Beer's Law

1. This experiment conforms to the guidelines for the 17th laboratory experiment listed in the College Board AP Chemistry guide (the Acorn book).

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

3. 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.

4. Prepare 100 mL of 0.40 M copper (II) sulfate solution by dissolving 9.99 g of $CuSO_4 \cdot 5H_2O$ in sufficient distilled water to make 100 mL of solution.

5. A suitable unknown $CuSO_4$ solution can be prepared by adding 50 mL of distilled water to 50 mL of the stock 0.40 M copper (II) sulfate solution.

6. You may substitute blue food coloring for the $CuSO_4$. 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 $CuSO_4$ solution." Decide which solution produces the optimum absorbance for the experiment.

7. The cuvettes should be at least 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.

8. 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.

9. If you are using a calculator and EasyData, there are several different combinations of equipment that will work for collecting data with a Colorimeter. The most common method, which works for both the TI-83 Plus and TI-84 Plus families of calculators, is to use a Colorimeter connected to a LabPro or CBL 2.

   The other method, which uses the USB port on TI-84 Plus calculators, is to connect a Colorimeter to an EasyLink. Be sure to use fresh batteries in your calculator since the Colorimeter draws all of its power from the calculator. For more information on EasyLink refer to *Appendix H*.

HAZARD ALERTS

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

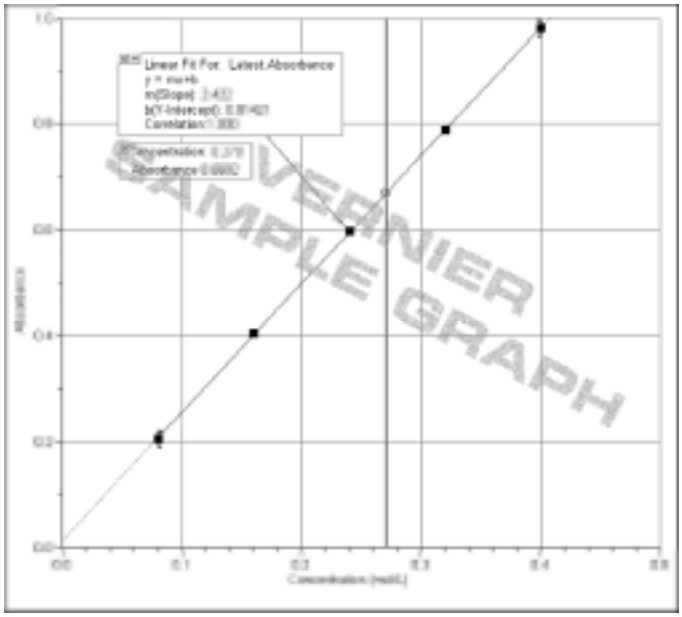
The hazard information reference is: Flinn Scientific, Inc., *Chemical and Biological Catalog Reference Manual,* P.O. Box 219, Batavia, IL 60510, (800) 452-1261, www.flinnsci.com.

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



Plot of absorbance vs. concentration of $CuSO_4$ with an unknown interpolated along the linear fit