Determining the Concentration of a Solution: Beer's Law

LAB LQ 11
From *Vernier Chemistry with Labquest*

INTRODUCTION

The primary objective of this experiment is to determine the concentration of an unknown copper (II) sulfate solution. You will be using the V-spec to determine the absorbance. In the V-spec a red light from the LED light source will pass through the solution and strike a photocell. The copper (II) sulfate solution used in this experiment has a deep blue color. A higher concentration of the colored solution absorbs more light (and transmits less) than a solution of lower concentration. The V-spec monitors the light received by the photocell as either an *absorbance* or a *percent transmittance* value.

You are to prepare copper (II) sulfate solutions of known concentration (standard solutions). Each is transferred to a small, rectangular cuvette that is placed into the V-spec. The amount of light that penetrates the solution and strikes the photocell is measured to determine 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.
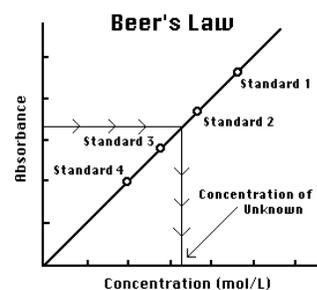

Figure 1

The concentration of an *unknown* copper (II) sulfate solution is then determined by measuring its absorbance with the V-spec. 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

- Use a V-spec 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 copper (II) sulfate solution.

MATERIALS

LabQuest
V-spec
Kimwipes
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

PROCEDURE

1. Obtain and wear goggles! **CAUTION:** *Be careful not to ingest any* $CuSO_4$ *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 $CuSO_4$ 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 $CuSO_4$). Pipet 2, 4, 6, and 8 mL of 0.40 M $CuSO_4$ 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 $CuSO_4$ 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 $CuSO_4$ (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 v-spec to LabQuest and choose New from the File menu.

5. Prepare a *blank* by filling an empty cuvette 3/4 full with distilled water. To correctly use a v-spec 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 V-spec.

6. Calibrate the v-spec.

    a. Tap sensors and choose calibrate. Then choose USB Spectrometer. Follow directions in window to complete calibration using blank prepared in step number 5.

7. Run a non-zero sample (prepared in step 3) on Full Spectrum to determine wavelength that is absorbed.

8. Set up the data-collection mode.

   a. On the Meter screen, tap Mode. Change the mode to Events with Entry.
   b. Enter the Name (Concentration) and Units (mol/L). Select OK.

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

   a. Start 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 v-spec.
   c. When the value displayed on the screen has 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 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 screen to stabilize and tap Keep. Enter **0.16** as the concentration in mol/L.
   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 $CuSO_4$. **Note:** Wait until Step 11 to do the unknown.
   f. Stop data collection.
   g. To examine the data pairs on the displayed graph, tap any data point. As you tap each data point, the absorbance and concentration values are displayed to the right of the graph. Record the absorbance and concentration data values in your data table.

10. Display a graph of absorbance *vs.* concentration with a linear regression curve.

    a. Choose Graph Options from the Graph menu.
    b. Select Autoscale from 0 and select OK.
    c. Choose Curve Fit from the Analyze menu.
    d. Select Linear for the Fit Equation. The linear-regression statistics for these two data columns are displayed for the equation in the form

$$y = mx + b$$

    where *x* is concentration, *y* is absorbance, *m* 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.

    e. Select OK. The 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.

11. Determine the absorbance value of the unknown $CuSO_4$ solution.
    a. Tap the Meter tab.

b. Obtain about 5 mL of the *unknown* CuSO₄ in another clean, dry, test tube. Record the number of the unknown in your data table.
c. Rinse the cuvette twice with the unknown solution and fill it about ¾ full. Wipe the outside of the cuvette, place it in the V-spec.
d. Monitor the absorbance value. When this value has stabilized, record it in your data table.

12. Discard the solutions as directed by your instructor.

PROCESSING THE DATA

1. To determine the concentration of the unknown CuSO₄ solution, interpolate along the regression line to convert the absorbance value of the unknown to concentration.

a. Tap the Graph tab.
b. Choose Interpolate from the Analyze menu.
c. Interpolate along the regression curve to determine the concentration of the unknown solution. Tap any point on the regression curve (or use the ► or ◄ key of LabQuest) to advance to the absorbance value that is closest to the absorbance reading you obtained in Step 11. The corresponding CuSO₄ concentration, in mol/L, will be displayed to the right of the graph.
d. Record the concentration 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