Experiment 11
Beer's Law

OUTCOMES

After completing this experiment, the student should be able to:

- determine the wavelength (color) of maximum absorbance for a solution.
- examine the relationship between the absorbance and concentration of a solution.
- use absorbance data to determine the concentration of an unknown solution.

DISCUSSION

Colored compounds obtain their particular colors due to the wavelengths of light that they absorb and reflect (or transmit). Thus, a red solution transmits red light and absorbs other wavelengths. If one graphs how much light is absorbed by a compound at each wavelength, an absorption spectrum is obtained for the compound showing areas of high and low absorbance. For our red solution, the red wavelengths will have low absorbances (high transmittance) and the blue or green wavelengths will likely have higher absorbances (lower transmittance).

If we focus on one particular wavelength for a compound, we can use the absorbance of light to determine the concentration of a solution. In general, a higher concentration of a colored solution has more light-absorbing compounds and so it will absorb more light (or transmit less light) than a solution of lower concentration. Thus, when a graph of absorbance vs. concentration is plotted for solutions of known concentration, a direct relationship should result as shown in *Figure 1*. This direct relationship is known as Beer's Law and is shown by the equation

$$A = \varepsilon c l$$

where A is the measured absorbance, ε is the molar absorptivity (a constant for the particular solute you are analyzing that is related to how strongly the solute absorbs light of a particular wavelength), c is the molar concentration of the solute, and l is the path length or the distance that the light travels through the cuvette (usually 1 cm). For a single solute, absorbance and concentration are directly proportional if the path length is constant. When a linear trendline analysis is performed on a graph of absorbance vs. concentration, the slope is equal to the molar absorptivity, ε, if the path length is 1 cm.

In this lab, you will be using a colorimeter like that shown in *Figure 2*. In this device, light from an LED light source passes through a solution and strikes a photocell. The colorimeter will interpret the light received by the photocell and express it both as an *absorbance* and a *percent*

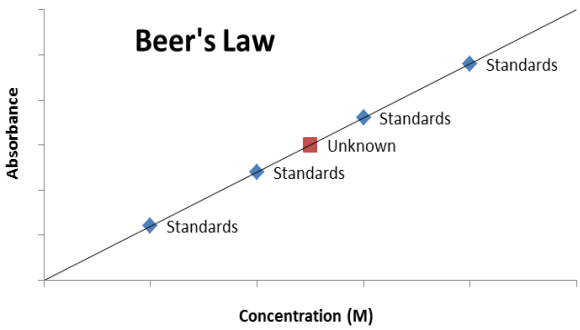

Figure 1

Figure 2

transmittance value. The solute you will be investigating is $CuSO_4$. You will prepare five copper(II) sulfate solutions of known concentration (standard solutions). The absorbance of each solution will be measured using the colorimeter, and a Beer's Law graph will be generated to determine the value of the molar absorptivity of $CuSO_4$. The concentration of an *unknown* $CuSO_4$ solution will then be determined by measuring its absorbance with the colorimeter and using the molar absorptivity from your trendline equation to determine its concentration.

MATERIALS

computer with *Logger Pro* and Interface
Vernier Colorimeter
pipets ranging from 1 -mL to 5 -mL
1 -cm square plastic colorimeter cuvette
stirring rod
five small, labeled test tubes
30 mL of 0.50 *M* $CuSO_4$
5 mL of an unknown $CuSO_4$ solution
pipet pump(s) or bulb(s)
KimWipes® or similar laboratory wipes
two 50 -mL beakers
test tube rack

PROCEDURE

⚠ ***Wear safety glasses or goggles at all times for this experiment.***
⚠ ***Avoid skin contact with the chemicals in this experiment.***
⚠ ***Never pipet by mouth.***

Note: If you are unsure of how to read pipets, please ask. The most common mistake in this lab involves measurements with the pipets. Any time a pipet is used with a new solution, rinse it with that solution before measuring.

1. Pour about 15 mL of 0.50 *M* $CuSO_4$ stock solution into a 50 -mL beaker. Pour about 15 mL of deionized water into a different 50 -mL beaker.

2. Connect the colorimeter to the LabPro interface. Next, open the *Logger Pro* application from the desktop or the Start menu. From within *Logger Pro*, open the "Probes & Sensors"

folder, then select the "Colorimeter" folder, and finally the "Absorbance-Conc" file. You are now ready to use the colorimeter.

3. Prepare a *blank* by filling a cuvette ¾ full with deionized water. Prepare a $CuSO_4$ *sample* cuvette by filling it ¾ full with the 0.50 *M* $CuSO_4$ solution.

Handling Cuvettes: Examine your cuvette to ensure that the clear sides are free from scratches. Cuvettes should be wiped clean and dry on the outside with a KimWipe before each measurement. Do NOT use a paper towel! Handle the cuvettes near the top of the ribbed sides. Solutions should be free of bubbles. Align the cuvette in the colorimeter so that the light passes through the smooth sides. **To avoid inconsistencies from different cuvettes, only *one cuvette* should be used for data collection for the entire experiment.** If you are refilling a cuvette with a different solution, a small amount of the new solution should be used to rinse the cuvette before filling. The only exception to this is determining the λ_{max} for a solution. In order to minimize waste from multiple fillings and rinses of the same solutions, you may use a blank and a sample cuvette. However, once the λ_{max} has been determined, a single cuvette should then be used to calibrate the colorimeter at that wavelength and to collect the remaining data for the experiment.

4. Place the blank cuvette in the colorimeter and calibrate the colorimeter at the desired wavelength. While most of the colorimeters used in the chemistry department are the rounded colorimeters which calibrate with the press of a button, you may occasionally encounter an older version which requires manual calibration. If this is the case, ask your instructor how to calibrate the colorimeter.

Calibration of Rounded Colorimeters: This colorimeter is identical to the one in Figure 2. Use the arrow buttons to select the desire wavelength. With the blank cuvette correctly positioned in the colorimeter and the lid closed, press the blue "Cal" button on top of the colorimeter. When the red light stops blinking, the colorimeter is calibrated and may be used.

5. Once the colorimeter has been calibrated, remove the blank cuvette are replace it with your sample cuvette. Close the lid, wait for the absorbance to stabilize, and record the absorbance of the solution.

6. Repeat steps 4 and 5 until the absorbance of the most concentrated $CuSO_4$ solution has been recorded at all of the wavelengths available on your colorimeter. Compare these absorbances and determine which wavelength gave the greatest absorbance. This wavelength is the λ_{max} for the solution.

7. Place the blank cuvette in the colorimeter and calibrate the colorimeter at λ_{max}. At this point, you will no longer be changing the wavelength of the colorimeter and will not need to calibrate it any more. You should now use **only** the blank cuvette for all remaining

measurements and rinse it with a small amount of the new solution any time that you empty and refill it.

8. Prepare 5.00 mL of the $CuSO_4$ solutions in Table 1 by diluting the 0.50 *M* $CuSO_4$ stock solution and place these solutions into five clean, dry, and labeled test tubes.

Table 1. Concentrations of $CuSO_4$ to prepare.

Test Tube	$CuSO_4$ concentration (*M*)
1	0.10
2	0.20
3	0.30
4	0.40
5	0.50

9. Measure and record the absorbances of each of the solutions from Table 1, as well as the absorbance of the deionized water blank, at λ_{max}.

10. Fill the cuvette about ¾ full with your unknown $CuSO_4$ sample. *Record your unknown number*. Measure and record the absorbance of the unknown as before. If the absorbance is greater than any of the measurements for the known $CuSO_4$ solutions, dilute the unknown solution and measure the absorbance again. Make sure to record the volumes used in your dilution.

⚠ ***Make sure to remove the cuvette from the colorimeter when done with the experiment.***

⚠ ***Dispose of all chemicals in the proper waste container.***

DATA ANALYSIS

1. Prepare a table on *Sheet 1* of an *Excel* spreadsheet that shows the amount of 0.50 *M* $CuSO_4$ and the amount of water used in test tubes 1 through 5. Save your spreadsheet using a filename convention of *Lastname1 Lastname2 Beers Law*.

2. Prepare a table on *Sheet 2* of your spreadsheet that shows the molarities and absorbances of each of your known $CuSO_4$ solutions. Make sure to include the value of λ_{max} with correct units.

3. Using *Excel*, prepare a graph that plots absorbance vs. concentration. Obtain the equation of the best-fit line, setting the y-intercept to zero. (Think: why should the y-intercept be set to zero?)

4. Using your trendline equation, determine the molar absorptivity, ε, of $CuSO_4$ with the correct units.

5. Use Beer's Law and the equation of your best-fit line to determine the concentration of your unknown solution. If you diluted your unknown, calculate the concentration of the undiluted solution and report the result.

6. Describe the preparation of 500.0 mL of 0.50 *M* $CuSO_4$ using solid $CuSO_4$ and water.

7. Using your trendline equation and Beer's Law, calculate the absorbance for 0.25 *M* $CuSO_4$ at λ_{max}.

POSTLAB ACTIVITY

You will be individually completing a postlab quiz on D2L. While taking the quiz, you will be given data to analyze. Therefore, you will need access to *Excel* while working on the quiz. Before leaving lab today, your instructor should check your work to make sure that you correctly understand the necessary concepts and calculations before beginning the quiz.