Using Absorbance to Determine the Concentration of $CuSO_4$

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Abstract
This experiment was carried out to explore the relationship between the absorbance and concentration of colored solutions. After determining the λ_{max} was 635 nm for $CuSO_4$, the absorbance of six solutions of $CuSO_4$, ranging from 0.00 to 0.50 M, was found using a colorimeter. Graphical analysis revealed that the relationship between absorbance and concentration was directly proportional with a molar absorptivity of 2.81 $M^{-1}cm^{-1}$. The data obtained reinforced the connection between the color of a solution and the wavelengths of light which the solution absorbs and reflects. In addition, knowledge of the linear relationship between absorbance and concentration allowed for the determination that unknown solution #285 was 0.726 M $CuSO_4$.

Introduction
The world is full of a multitude of colors that are used for both practical and aesthetic purposes. The colors that are seen when looking at different objects are due to the ability of the compounds in those objects to absorb specific wavelengths of light. In other words, the colors that are seen are the ones that are *not* absorbed. The wavelengths of light that are absorbed are determined by the electrons in a compound.[1] As electrons move around, they can absorb energy and become excited. The energy, and thus the wavelength of light, the electrons absorb is determined by the type of atoms found in the compound and how those atoms are bound together. Different environments for electrons will also determine how much of a particular wavelength of light can be absorbed, a parameter which is reflected in the molar absorptivity of the compound.[2]

Because the color of a species is due to its ability to absorb light, the color should become darker or more intense as the concentration increases. The increase in concentration leads to more electrons in the sample which can then absorb more light at a particular wavelength. Thus, there should be a relationship between the concentration of the compound being studied and its absorbance. This relationship is best determined using a wavelength of light in a region of the visible spectrum where the maximum absorbance is observed. This wavelength is known as λ_{max} and is most sensitive to the changes in concentration.

The purpose of this experiment was to study the absorbance of $CuSO_4$. Because copper compounds tend to be blue in color,[3] it was hypothesized that the $CuSO_4$ would have a λ_{max} with a longer wavelength corresponding to a color more in the range of orange or red. Once the best wavelength for studying $CuSO_4$ was determined, it could then be used to examine the relationship between the absorbance and concentration of the compound and use that relationship to calculate desired information for unknown solutions.

Experimental Procedure
Six samples were prepared for analysis by diluting a 0.50 M $CuSO_4$ stock solution.[4] The amounts of the $CuSO_4$ stock solution and water used in each sample is indicated in Table 1. A Vernier colorimeter was attached to the LabPro interface and the LoggerPro software was adjusted to display absorbances. The

absorbance of the 0.50 M $CuSO_4$ was determined using a 1 cm cuvette at each of the four wavelengths on the colorimeter (Appendix 1), and 635 nm was chosen as the λ_{max}. The absorbance of each of the standard solutions was then determined at 635 nm. Unknown solution #285 was obtained and its absorbance was measured. Because the absorbance was higher than that of the 0.50 M standard, the unknown was diluted in a 1:1 ratio with DI water, and the absorbance was measured again.

Results

The absorbances of the $CuSO_4$ standard solutions were directly proportional to their concentrations (Table 1, Figure 1). The slope obtained for the graph is equivalent to the molar absorptivity since the cuvette had a pathlength of 1 cm. Thus, the molar absorptivity of $CuSO_4$ at 635 nm is 2.81 $M^{-1}cm^{-1}$. This molar absorptivity could be used to determine the concentration of unknown #285. The absorbance of the undiluted solution was much higher (1.683) than the 0.50 M standard solution. After diluting 2.00 mL of the unknown with 2.00 mL of DI water, the absorbance obtained was 1.021. This corresponded to a concentration of 0.363 M $CuSO_4$ for the diluted solution. The undiluted unknown #285 would therefore be twice that of the diluted, or 0.726 M $CuSO_4$.

Table 1. Preparation of standard $CuSO_4$ solutions and their absorbances at 635 nm.

Concentration of Standard $CuSO_4$ Solution (M)	Volume of 0.50 M $CuSO_4$ Stock Solution (mL)	Volume of DI Water (mL)	Absorbance at 635 nm
0.00	0.00	5.00	0.000
0.10	1.00	4.00	0.406
0.20	2.00	3.00	0.638
0.30	3.00	2.00	0.854
0.40	4.00	1.00	1.202
0.50	5.00	0.00	1.276

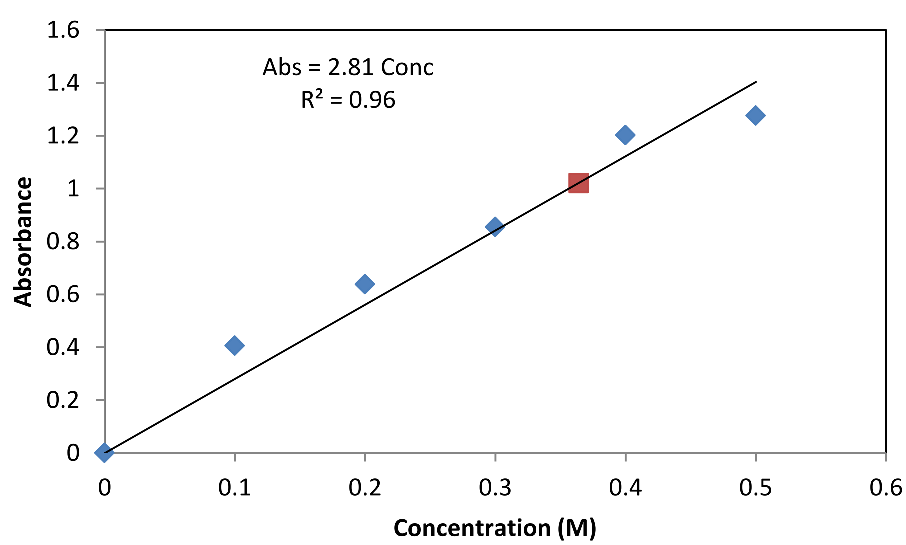

Figure 1. Determination of molar absorptivity of $CuSO_4$. The blue diamonds are from the standard solutions. The red square is the diluted sample of unknown #285.

Discussion

The purpose of this experiment was two-fold: to determine the λ_{max} and molar absorptivity of $CuSO_4$ and to use that information to establish the concentration of an unknown $CuSO_4$ solution. It was assumed that the $CuSO_4$ solution, being blue in color, would reflect lower wavelengths of light which correspond to the blue color and absorb better at higher wavelengths of light. This was supported by the results of the experiment. Of the four wavelengths available on the colorimeter (430 nm, 470 nm, 565 nm, and 635 nm), the greatest absorbance was observed at 635 nm (Appendix 1). Thus, the λ_{max} for the solution was determined to be 635 nm which corresponds to a red color.[5]

The absorbance of each of the standard $CuSO_4$ solutions was measured at 635 nm to determine the molar absorptivity of $CuSO_4$ at this wavelength. As shown in Figure 1, absorbance and concentration were directly proportional to each other. Based on Beer's Law ($A = \varepsilon cl$),[4] the slope of the line should be equal to the molar absorptivity multiplied by the cell pathlength. Since the cell pathlength for this experiment was 1 cm, the value of the molar absorptivity was equal to the slope of the line. Thus, it was determined that the molar absorptivity of the $CuSO_4$ at 635 nm was 2.81 $M^{-1}cm^{-1}$.

One factor that is obvious from Figure 1 is that the data was not as precise as desired based on the R-squared value of 0.96 obtained for the trendline analysis. It is assumed that the inconsistencies in the data were due to errors in the dilution of the stock solution when making the standard $CuSO_4$ solutions. Because no dilution was necessary for the 0.00 M and 0.50 M $CuSO_4$ solution, these two data points can be understood to be correct. If one imagines a line connecting these two data points, all of the other points would be above the line, meaning that their absorbances are greater than predicted for the concentrations. This would suggest that too much of the 0.50 M $CuSO_4$ stock solution was used in the preparation of the standards or too little DI water. Upon reflection, it was determined that the experimenter in charge of measuring the $CuSO_4$ solution read the pipettes incorrectly and that this was the source of the error. In the future, better communication between lab partners and double-checking measuring techniques would help to prevent these errors and improve the accuracy of the data.

The molar absorptivity determined from the standard $CuSO_4$ solutions can be used to calculate the absorbance of a known $CuSO_4$ solution or the concentration of an unknown $CuSO_4$ solution. For example, while a 0.25 M $CuSO_4$ solution was not used as a standard, its absorbance can be predicted to be 0.703 in a 1 cm cuvette:

$$A = \varepsilon cl$$
$$A = (2.81\ M^{-1}cm^{-1})(0.25\ M)(1.0\ cm)$$
$$A = 0.703$$

Likewise, for unknown #285, the concentration could be determined. Because the concentration of the unknown was greater than the 0.50 M $CuSO_4$ standard, the unknown was diluted with DI water in a 1:1 ratio. This resulted in a diluted solution with an absorbance of 1.021. Using Beer's Law, the concentration could then be calculated:

$$c = A/\varepsilon l$$
$$c = \frac{1.021}{(2.81 M^{-1}cm^{-1})(1.0\,cm)}$$

$$c = 0.363\ M$$

Because of the 1:1 dilution of the unknown with water, the concentration of the undiluted solution #285 would be twice that of the diluted solution, or 0.726 M $CuSO_4$. Although this does fit well with the standard solutions, it has already been noted that the trendline analysis was not very accurate. Therefore, it is likely that true value of the unknown concentration is slightly greater than 0.726 M.

Conclusion
Solutions of $CuSO_4$ absorb more light at higher wavelengths than at lower wavelengths, corresponding well with the blue color of the solution. The molar absorptivity of $CuSO_4$ at 635 nm is 2.81 $M^{-1}cm^{-1}$. Knowledge of this value allows for the determination that unknown #285 is at least 0.726 M $CuSO_4$.

References

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(3) Western Oregon University. Transition Metal Complexes and Color. http://www.wou.edu/las/physci/ch462/tmcolors.htm (accessed May 7, 2013).

(4) Anoka-Ramsey Community College. Determining the Concentration of a Solution: Beer's Law. http://webs.anokaramsey.edu/chemistry/Chem101/Labs/BeersLaw/BeersLaw-S13. pdf (accessed May 1, 2013).

(5) Visible Spectrum. http://www.giangrandi.ch/optics/spectrum/spectrum.shtml (accessed May 7, 2013).

Appendix 1. Determination of λ_{max} for 0.50 M $CuSO_4$.

Wavelength (nm)	Absorbance
430	0.000
470	0.001
565	0.796
635	1.276

Appendix 2
To prepare 700.0 mL of 0.30 M $CuSO_4$, you would need to use 33.5 g of $CuSO_4$ and add DI water until you obtain 700.0 mL of solution.

$$0.7000\,\text{L} \times \frac{0.30\,\text{mol}\,\text{CuSO}_4}{1\,\text{L}} \times \frac{159.62\,\text{g}\,\text{CuSO}_4}{1\,\text{mol}\,\text{CuSO}_4} = 33.5\,\text{g}\,\text{CuSO}_4$$