

Spectroscopy and Conductivity of CuSO₄ Solutions

OBJECTIVE

To determine the concentration of an unknown aqueous CuSO₄ solution using two different solution properties (absorbance and conductivity) and to compare the accuracy of the two methods.

INTRODUCTION

In this lab activity, we will investigate some properties of solutions. A **spectrophotometer** is used to investigate how copper (II) sulfate solutions of different concentrations absorb light. A **conductivity meter** is used to see how the conductivity changes for solutions of different concentrations. You will determine the concentration of an unknown CuSO₄ solution using these two properties as well. To do this, you will use data collected by measuring the **absorbance** and **conductivity** of a series of **standards**, solutions of known concentration, to create a “calibration curve” (a graph). When absorbance is plotted as a function of concentration, the data follow an important equation called **Beer’s Law**, a linear mathematical relationship that can be used to identify the concentration of an unknown solution.

These types of analyses are common-place in industry and medical laboratory settings, allowing scientists to find concentrations of analytes, the chemicals under investigation, such as bilirubin in blood plasma, proteins, and waste-water contaminants.

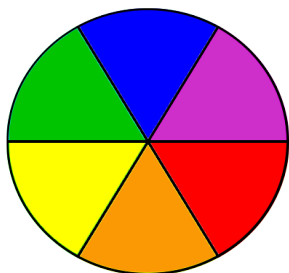
Spectrophotometry

A spectrophotometer is used to study the response of solutions to electromagnetic radiation. Visible spectrophotometry uses radiation from the visible spectrum (400–700nm). The light source is an incandescent bulb. A monochromator allows us to select a single wavelength (or narrow band of wavelengths) to analyze our samples. A detector measures the transmitted light. Analog spectrometers, such as the Spec-20, had two scales: one in percent transmittance and the other in absorbance. The absorbance scale is logarithmic with values from 0 to ∞ , while the percent transmittance scale is linear with values from zero to 100%. Traditionally, the percent transmittance was measured and then converted to absorbance using the equation $A = 2 - \log(\%T)$. To collect the data for this lab activity, we used a digital Vernier spectrometer which displays the absorbance value automatically – no need for a conversion calculation.

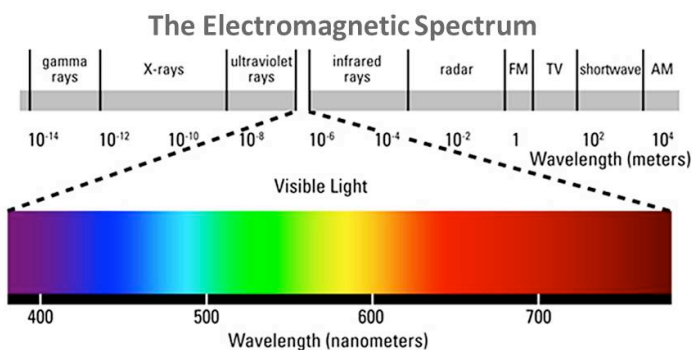
Beer’s Law is written as: $A = \epsilon \ell c$, where A is absorbance, ϵ is molar absorptivity of the chemical species being studied, ℓ is the path length, and c is concentration. Absorbance (A) is plotted on the y-axis and molar concentration of the absorbing substance (c) on the x-axis (abscissa), and results in a line with slope of $\epsilon \ell$. The pathlength (ℓ) in this experiment is 1.0 cm, and if absorbance and concentration are known, then the molar absorptivity (ϵ) is the slope of the line (at a given wavelength).

The linear relationship breaks down at high concentration due to non-ideal behavior of solutions. If a solution is too concentrated, too little light is transmitted, so the detector cannot measure the difference between the original light intensity, I_0 , and the transmitted light intensity, I_t . The color of a solution shows the light that is **transmitted**. The solution absorbs other colors, mainly the complementary color. Therefore, we choose to measure **absorbed** light at a wavelength that

represents the complimentary color (opposite on the color wheel) to that of the solution. For example, for a solution that appears to be violet in color, violet light is transmitted. Using the complementary color wheel, that tells us it absorbs the color opposite violet, which is yellow. So, if we were going to do this experiment with a violet solution, we would want to measure absorbance at a wavelength that represents yellow light (because that is where absorbance is at a maximum value). We can use the chart below corresponding to the Visible Light portion of the electromagnetic spectrum to choose the wavelength we want to measure absorbance at. In this case, we would choose a wavelength that is representative of yellow light, around 590 nm (nm = nanometer; 10^9 nm = 1 m).



Complementary Color
Wheel



Visible Region of Electromagnetic Spectrum
(wavelength in nanometers)

Before continuing with this activity, you will need to watch the video corresponding with this lab! The video (approximately 8 minutes) contains images and explanations for how the data was collected in this experiment: <https://screencast-o-matic.com/watch/cYjlbGxDu>

CALCULATIONS AND DATA COLLECTION

PART 1 - Preparation of a 0.500 M CuSO_4 Stock Solution

1. Calculate the mass of solid required to prepare 100.0 mL of a 0.500 M aqueous solution of copper (II) sulfate pentahydrate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) to the nearest hundredth of a gram. Show your work below! (*Hint: you will need to calculate the molar mass of copper (II) sulfate pentahydrate – add the mass of the 5 water molecules to the molar mass of the copper (II) sulfate.*)

Mass of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ _____

This is the stock solution (0.500 M) used to prepare the diluted solutions below (solutions at lower concentration). Note that this stock solution was also used as one of the standards to measure absorbance and concentration. It will be included in both of your calibration curves!

Part 2 – Preparation of Diluted Standard Solutions of CuSO₄

2. The table below lists the concentrations of the four standard solutions you will use to create the calibration curve. You will need to use the dilution equation ($C_iV_i = C_TV_T$) to calculate the volume of 0.500M stock solution required to make 40.0 mL of each standard solution (A-D). Calculate the amount of deionized water to combine with the stock solution as well. Show all calculations below and fill in the table below with the Volumes.

Concentration of CuSO₄ Standard Solutions	Volume of 0.500 M CuSO₄ Solution (mL)	Volume of Deionized Water (mL)
0.300 M		
0.250 M		
0.100 M		
0.050 M		

Absorbance and Conductivity Data (units for Conductivity are mS = microSiemens)

Solutions	Absorbance (NO UNITS)	Conductivity (mS)
0.500 M CuSO₄	1.143	29.78
0.300 M CuSO₄	0.720	19.20
0.250 M CuSO₄	0.623	16.57
0.100 M CuSO₄	0.235	8.19
0.050 M CuSO₄	0.131	4.79
UNKNOWN CuSO₄	0.940	25.79
Deionized Water		0.00207
Tap Water		0.703

DATA ANALYSIS

You are going to plot two calibration curves (graphs) using the standard solutions (solutions of known concentration) and use these graphs to identify the concentration of the unknown. Note that the data collected for conductivity of deionized water and tap water will NOT be included in your graphs; you will use that data to answer a question below!

- Plot Conductivity (y-axis) vs. Concentration (x-axis) with the data for the stock and diluted solutions using Microsoft Excel.
 - **Do not use the conductivity measurement of your unknown sample in your graph!** It is impossible anyway because you do not know the concentration (x-value) of your unknown. It's unknown!! You should have 5 data points from the standard solutions.
 - The data should include a (0,0) point because a correctly calibrated instrument should have a conductivity reading of zero when there is no CuSO_4 present.
 - Perform a linear regression (add a trendline) and show the equation for the line and the R^2 value on the graph.
 - **Print or save the graph to submit along with this lab activity.**
- Plot Absorbance (y-axis) vs Concentration (x-axis) with the data for the stock and diluted solutions using Microsoft Excel.
 - **Do not use the absorbance measurement of your unknown sample in your graph!** Again, you should have 5 data points from the standard solutions.
 - The data should include a (0,0) point because a correctly calibrated instrument should have an absorbance reading of zero when there is no CuSO_4 present.
 - Perform a linear regression (add a trendline) and show the equation for the line and the R^2 value on the graph.
 - **Print or save the graph to submit along with this lab activity**

3. Calculate the concentration of the unknown (using the equations of the lines for each method) obtained with the conductivity data and with the absorbance data. Show your work and enter the data into the table below.

Solutions	Absorbance (NO UNITS)	Conductivity (mS)
UNKNOWN CuSO ₄	0.940	25.79
Equation of the Line (from Excel)		
R ² value (from Excel)		
Concentration of Unknown CuSO ₄ solution		
Percent Error		

4. If the **accepted value** for the concentration of the unknown CuSO₄ solution is 0.400M, **calculate the percent error for each method**. Show your work below and enter the values into the table above.

5. Summarize the relationship between absorbance and concentration in one coherent sentence. Do the same for the relationship between conductivity and concentration.

6. Which method (absorbance or conductivity) shows a stronger correlation between the two variables. How do you know?

7. Which method would you expect to produce a more reliable result? Explain why. *Hint: Think about what is actually being measured in each of the methods... in Spectrophotometry, we are measuring absorbance for a single wavelength of light. In Conductivity, we are measuring the total amount of ions in solution.*

8. Compare the percent error for each method. Which instrument gives the most accurate results, absorbance or conductivity? Is this what you expected? Explain.

9. A wavelength of 650 nm was selected to measure the absorbance of CuSO_4 . Explain why this wavelength was used. Identify the color and wavelength of the light being transmitted and the light being absorbed in this experiment.

10. In 1-2 sentences, report and compare the conductivity measurements for tap water and deionized water. Why did the tap water have a different conductivity than distilled water?