

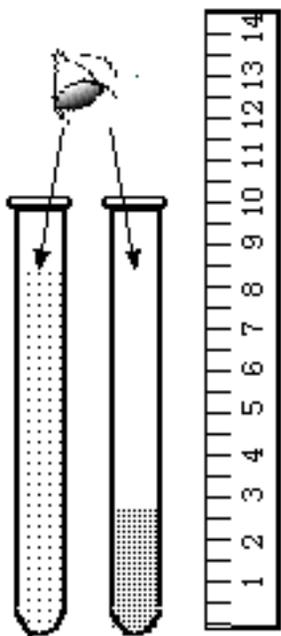
Determining the Concentration of a Solution Using Visual Analysis and a Colorimeter

Background: In order for a compound to have a color, it must absorb some portions of visible light. Visible light is one form of electromagnetic radiation with wavelengths ranging from approximately 350 nm to 800 nm. White light contains all wavelengths in this visible region. A compound will absorb visible radiation when it possesses the energy needed to move an electron from its lowest 'ground' state to some higher excited state. When a sample absorbs visible light, the color we perceive is the sum of the remaining colors that are reflected or transmitted by an object and strike our eyes. An opaque object reflects light, whereas a clear one transmits light. If an object absorbs all wavelengths of visible light, then no wavelengths reach our eyes, and the color appears to be black.

The Cu^{2+} ions in the unknown aqueous solution form the complex ion, $\text{Cu}(\text{H}_2\text{O})_6^{2+}$, which is blue. This means that when "white" light (all wavelengths) passes through the solution, red light is being absorbed and the dominant emerging color is blue.

Beer's Law can be applied to relate the absorbance of the unknown solution to its concentration. This law states that the amount of light absorbed at a particular wavelength, A , is related to the molar concentration of the $\text{Cu}^{2+}(\text{aq})$, c , by the equation $A = abc$, where " a " is an absorptivity constant at a particular wavelength, and b is the thickness or depth of the sample.

You are to prepare a copper (II) sulfate solution of known concentration (standard solution). Use the visual comparison test to determine the concentration of the unknown solution. The amount of light absorbed by a solution is directly related to its concentration and the depth of the solution through which the light passes. By comparing the depth of two solutions with the same color intensity, the molarity of an unknown solution can be determined based upon the known concentration of the other solution.



The intensity of the color of a solution in a test tube depends upon *both* the concentration of the solution and the depth of solution in the tube. A higher concentration of the colored solution has a darker, more intense color than a solution of lower concentration. The greater the depth of a solution in the tube, the more particles there are to absorb the light between the light source and the eye. This makes the color appear to be more intense.

To determine the concentration (molarity) of an unknown solution, place it in a test tube on top of a piece of white paper, next to a test tube filled with a solution of known concentration (molarity). While visually comparing the color intensity of each tube, use a pipet to remove liquid from the more concentrated solution until the intensities appear to be the same. At this point, the following relationship applies:

$$(\text{Molarity}_1) (\text{Depth}_1) = (\text{Molarity}_2) (\text{Depth}_2)$$

Problem: Can you determine the molarity for a copper (II) sulfate solution of unknown concentration using a visual comparison or a Colorimeter?

Procedure:

1. Determine the mass of copper (II) sulfate pentahydrate that is needed to prepare a 25.0 mL sample of a 0.40 M solution. Put this mass into a clean beaker and dissolve in ~15 mL of distilled water. Pour the solution into a 25.0 mL volumetric flask (or a graduated cylinder). Rinse the beaker 2 or 3 times with a few mL of distilled water, and add these washings to the flask. Then add enough distilled water to have a final volume of exactly 25.0 mL.

2. Another solution of copper (II) sulfate with an unknown molarity is used to fill a test tube.
3. Prepare four dilutions of the 0.40 M CuSO₄ using the following procedure:
 - a. Measure 8.0 mL of the 0.40 M CuSO₄ solution in a graduated cylinder and add 2.0 mL of distilled water. Mix in a beaker then fill a 13 x 100 mm test tube with the 0.32 M diluted CuSO₄ solution.
 - b. Repeat this process using the appropriate volumes of 0.40 M CuSO₄ and distilled water to make solutions with concentrations of 0.24 M, 0.16 M and 0.08 M
4. Launch Graphical Analysis. Connect the Colorimeter to your Chromebook, computer, or mobile device.
5. Calibrate the Colorimeter.
 - a. Place the blank in the cuvette slot of the Colorimeter and close the lid.
 - b. 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. Set up the data-collection mode.
 - a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
 - b. Enter **Concentration** as the Event Name and **mol/L** as the Units. Click or tap Done.
7. You are now ready to collect absorbance-concentration data for the five standard solutions.
 - a. Click or tap Collect to 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 and place it in the device. Close the lid on the Colorimeter.
 - c. When the value has stabilized, click or tap Keep and enter **0.080** as the concentration in mol/L. Click or tap Keep Point. 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. Place the cuvette in the device, wait for the value displayed on the screen to stabilize, and click or tap Keep. Enter **0.16** as the concentration in mol/L. Click or tap Keep Point.
 - e. Repeat the procedure for Test Tube 3 (0.24 M) and Test Tube 4 (0.32 M), as well as the stock 0.40 M CuSO₄. **Note:** Wait until Step 10 to test the unknown.
 - f. Click or tap Stop to stop data collection.
 - g. To examine the data pairs on the displayed graph, click or tap the graph. Record the absorbance and concentration data values in your data table.
8. Display a graph of absorbance vs. concentration with a linear regression curve.
 - a. Click or tap Graph Tools, , and choose Edit Graph Options.
 - b. Enter **0** as the value for both the Left value for the x-axis and the Bottom value for the y-axis. Dismiss the Graph Options box.
 - c. Click or tap Graph Tools, , and choose Apply Curve Fit.
 - d. Select Linear as the curve fit and Dismiss the Curve Fit box. 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.

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.

9. 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 and place it into the device.
 - c. Monitor the absorbance value. When this value has stabilized, record it in your data table.
10. Discard the solutions as directed by your instructor. Before closing Graphical Analysis, continue to the Processing the Data section.

PROCESSING THE DATA

1. To determine the concentration of the unknown CuSO_4 solution, interpolate along the regression line to convert the absorbance value of the unknown to concentration.
 - a. Click or tap Graph Tools, , and turn on Interpolate.
 - b. Click or tap any point on the curve to find the absorbance value that is closest to the absorbance reading you obtained during the Procedure. Record the corresponding CuSO_4 concentration, in mol/L, in your data table.
2. (optional) Print a graph of absorbance vs. concentration, with a regression line and interpolated unknown concentration displayed.
3. Fill a 13 x 100mm test tube with the unknown solution. Use your standard 1.00 M CuSO_4 to fill a second 13 x 100mm test tube to a depth where the color intensity appears to match that of the unknown. Measure the depth in mm of both solutions and calculate the molarity of the unknown based upon this visual comparison method. Compare to the molarity determined by the Colorimeter.
4. All solutions may be washed down the drain and flushed with water. Rinse the cuvettes with distilled water. Return all equipment to your teacher for final approval.

Calculations and Conclusions:

1. Show the calculation used to determine the mass of copper (II) sulfate pentahydrate needed to prepare 25.0 mL of 0.400 M solution.
2. Show the calculations used to determine the molarities of the solutions in Test Tubes 1-4, which were prepared by diluting the 0.400 M CuSO_4 solution.
3. Based upon the absorbance of the unknown solution, what is its estimated molarity using the graph. Label the data point for your unknown CuSO_4 solution on the graph printed out from the Graphical Analysis program.
4. Based on the statistical analysis (slope and y-intercept values) of the best fitting straight line, calculate the molarity of the $\text{CuSO}_4(\text{aq})$ found in the unknown solution.
5. Show the calculations used to determine the molarity of the unknown solution by the visual comparison test.
6. Obtain the accepted value for the concentration of the unknown solution from your teacher, then calculate the percent error for this experiment, using the Colorimeter and Visual Comparison. Which method is more accurate?
7. What would be the predicted absorbance for a 0.50 M copper (II) sulfate solution.

This experimental procedure and sample data collected can be viewed at https://youtu.be/O1P_89KLLLY