INVESTIGATION 2

How Can Color Be Used to Determine the Mass Percent of Copper in Brass?

CENTRAL CHALLENGE

What are the relationships between color, wavelength, absorbance, and concentration? You will need to understand these relationships in order to design an experiment that can quantitatively measure the absorption of light by a colored solution in order to determine the concentration of the absorbing species in that solution.

CONTEXT FOR THIS INVESTIGATION

Spectrophotometry is an extremely important tool used in forensic science to determine the detailed chemical composition of evidence obtained from a crime scene. It can be used to determine the concentration of either a single chemical species in solution or even the concentration of a species within a mixture of species in solution. For example, it can be used to determine the mass percent of copper in brass shell casings collected by the crime scene investigator (CSI), and then match the brass composition to a particular manufacturer.

PRELAB GUIDING QUESTIONS/SIMULATIONS

Step 1: You will be collecting data (in your group) to determine the relationship between wavelength (lambda, λ), concentration, and absorbance. You will use the interaction of light with solutions to determine the concentration of an absorbing species. However, it is important to identify what is doing the absorbing prior to determining the concentration of the absorbing species. Such information can be gathered by collecting absorbance data for a solution at various wavelengths.

Step 2: Your group will be given two different salt solutions of the exact same concentration. You are to measure the absorbance for each solution at every 20 nanometers from 400–700 nm to generate a spectrum and to determine the best wavelength at which to measure the absorbance of the two solutions. Make sure you use the appropriate spectrophotometer or colorimeter to collect such data. You will be sharing your absorption spectra with the rest of the class to identify what species in solution is actually absorbing light.

Step 3: Circle the salt solutions below to which your group is assigned:

salt 1 — copper (II) sulfate
salt 2 — copper (II) nitrate
salt 3 — zinc nitrate
salt 4 — zinc sulfate
salt 5 — iron (III) nitrate
salt 6 — iron (III) sulfate

Step 4: Look at the different plots or spectra for the six different salts. Can you identify the chemical species doing the absorbing (the metal ion, the polyatomic anion, or both)? How do you identify it?

Step 5: Engage in whole-class discussion to answer the following questions:

Extension Question 1. Why do we want to use a particular wavelength when determining the absorption of a particular chemical species? Is it important to measure absorbance for all wavelengths from 400–700 nm?

Extension Question 2. If you know the molar absorptivity of copper sulfate at 630 nm, explain how you could determine a wavelength where the molar absorptivity is half of that simply by examining the absorption spectrum.

Step 6: Make sure to write down your understanding of the relationship between concentration, absorbance, and wavelength to help inform your decisions throughout the remaining components of the lab.

PREPARATION

Materials

Spectrophotometer (or colorimeter)	Concentrated 15.8 *M* Nitric acid (HNO_3)
	10 mL of 0.400 *M* Copper(II) nitrate trihydrate ($Cu(NO_3)_2{\bullet}3H_2O$)
Various copper, zinc, and iron salt solutions (0.1 M)	1–2 g brass sample
3 thin-stem Beral pipettes	Digital balance, ±0.001 g
50 mL beaker with watch glass	Distilled water
5 mL and 10 mL graduated pipettes (or cylinders)	Pipette pump or pipette bulb
516 × 150 mm test tubes	1 cuvette
Test-tube rack	Tissues (preferably lint free)

Safety and Disposal

Concentrated nitric acid is corrosive and will attack and destroy metals, proteins, and most plastics. Avoid skin contact and neutralize any spills with baking soda, then rinse with copious amounts of water. The acid will discolor the skin for days after contact, so be sure to wear rubber gloves. The NO gas that forms quickly oxidizes in air to produce a toxic, reddish-brown gas of NO_2. For more information, read the Material Safety Data Sheet (MSDS) for nitric acid found at *http://www.ehso.com/msds.php*

Perform this reaction under a fume hood. Take normal laboratory precautions, including wearing splash-proof goggles and chemical-resistant gloves and apron at all times. The remaining brass solution should be neutralized by adding small amounts of solid baking soda until the bubbling has subsided and the pH is 5–9. Then the waste solution can be safely disposed of by following standard procedures as directed by your instructor.

INVESTIGATION

Procedure

1. Determine the mass of a 1–2 gram sample of brass to ± 0.001 g. Place the sample in a small beaker.
2. Assuming your brass sample is 100 percent copper by mass, calculate the minimum volume of concentrated 15.8 *M* $HNO_3(aq)$ that needs to be added to react completely with the brass. Under the fume hood, have your teacher add approximately 2 mL more than this volume of 15.8 *M* $HNO_3(aq)$ so that the acid is in excess, and then your teacher will cover the beaker with a watch glass.
3. After the metal dissolves completely, add 50 mL of distilled water to the beaker **(again, your teacher will perform this part of the investigation)**. Then you will remove the beaker from the fume hood and transfer the solution to a 100 mL volumetric flask. Rinse the beaker 3–4 times with 5 mL of distilled water and add the washings to the flask. Dilute to a final volume of 100.0 mL. The excess nitric acid will dissolve the zinc and copper metals in the brass.
4. Obtain 10.0 mL of 0.400 *M* $Cu(NO_3)_2(aq)$ stock solution in a 10 mL graduated cylinder. Determine what volume is required to make 10.00 mL of 0.200 *M* $Cu(NO_3)_2(aq)$. Use a volumetric pipette to transfer this volume of the stock solution into a clean test tube. Then add a sufficient amount of distilled water to reach 10.00 mL. Thoroughly mix the solution. Repeat the dilution process to make 10.0 mL each of three more additional dilute solutions that are 0.100 *M*, 0.0500 *M*, and 0.0250 *M*, respectively. Have your instructor verify your dilution calculations!
5. Based upon the results of the prelab experimentation, set the wavelength of the SPEC 20 to that which is strongly absorbed by the blue-colored Cu^{2+} solutions. Ideally, the maximum absorbance value should be ≤ 1. Since absorbance is a logarithmic function of the percent transmittance, the instrument is in a nonlinear region to measure the light passing through when the absorbance value is at a range of 1–2. When selecting a wavelength for measurement, keep in mind that a wavelength at maximum absorbance provides maximum sensitivity but the smallest concentration range, while a wavelength with a smaller absorbance would provide less sensitivity but a larger concentration

range to be measured in the experiment. Have your teacher approve of your selected wavelength before you continue with the next step.

6. Calibrate the SPEC 20 to read 0% transmittance with no cuvette in the instrument, and 100% transmittance with a blank inside (cuvette filled with distilled water).

7. Empty the water from the "blank" cuvette. Using the most dilute $Cu(NO_3)_2$ standard solution, rinse the cuvette twice with ~1 mL amounts and then fill it three-quarters full. Wipe the outside with a tissue, place it in the SPEC 20, and close the lid. Read and record the absorbance value. Discard the cuvette contents back into the original test tube.

8. Continue testing the other solutions, starting with the most dilute $Cu(NO_3)_2$ to the most concentrated (0.400 *M*). Finally, determine the absorbance value of the unknown $Cu(NO_3)_2$ solution from your brass sample. Using the absorbance and concentration values for the five standard solutions, prepare a graph of the absorbance (y) versus the concentration (x) values. Draw a best-fit straight line for your data and calculate the slope and y-intercept for Beer's plot. Then determine the concentration of your unknown brass solution. This is a good opportunity to use a spreadsheet program to plot the data and perform a linear regression.

9. Use a visual comparison test to also determine the concentration of the unknown solution. The amount of light absorbed by the 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.

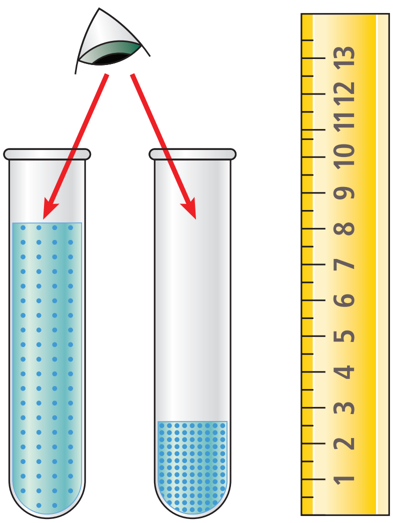

Figure 1. Visual comparison method

The intensity of the color of a solution in a test tube depends upon both the concentration of the solution and thd 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 a tube, the more particles there are to absorb the light beween the light source and they 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 pipette to remove liquid from the more concentrated solution until the intensities appear to be the same. At this point, the following relationship applies:

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

10. Fill a 16 × 150 mm test tube with the unknown brass solution. Use your standard 0.400 *M* $Cu(NO_3)_2$ to fill a second 16 × 150 mm test tube to a depth where the color intensity appears to match that of the unknown. Calculate the molarity of the unknown based upon this visual comparison method and compare to the molarity determined by the SPEC 20.
11. Dispose of all solutions as directed by your teacher. Rinse the cuvettes with distilled water. Return all equipment to your teacher for final approval.

Data Collection and Computation

1. Prepare a data table to record all of your measured data and calculated values.
2. Show the calculations used to prepare the $Cu(NO_3)_2(aq)$ with known molarities by diluting the 0.400 *M* $Cu(NO_3)_2(aq)$ standard solution.
3. Determine the molarity of the $Cu(NO_3)_2(aq)$ found in 100.0 mL of the brass solution using both the SPEC 20 (or colorimeter) analysis AND the visual comparison method. Support your answers with the appropriate calculations.
4. Determine the mass of Cu dissolved in the brass solution based upon the molarities calculated in Step 3, and use these values to calculate the mass percent of Cu in the brass sample using both experimental techniques.
5. Compare the mass percent of Cu values that were determined by the two different experimental methods for finding the molarity of the brass solution. Which method do you think will provide a more accurate value? Justify your answer.

Argumentation and Documentation

Use a shared Google Docs Excel spreadsheet to analyze the precision of the class data. Enter your group's values for the calculated mass percent of copper in brass based upon the spectrophotometer (colorimeter) in one column and the visual comparison method in another column. Calculate the averages and standard deviations for both methods. Which method provided a more precise value? Justify your answer.

POSTLAB ASSESSMENT

This lab involves several key skills and concepts that are part of the AP Chemistry curriculum, making it ideally suited for a formal lab report as a postlab assessment. Special emphasis should be placed on the two methods of analysis used to determine the molarity of the brass solution, and your comparison of the precision and probable accuracy of the class average values for the mass percent of copper in brass. However, your teacher may assign a different postlab assessment such as the following lab practical.

The following lab practical can be used to assess your ability to interpret a Beer's law plot and apply it to a new situation.

Problem: Based upon the Beer's law plot shown in Figure 2 for the absorbance of $CuSO_4(aq)$ versus its concentration, what mass of copper could be produced by a complete reaction of excess zinc metal with 50.0 mL of a $CuSO_4(aq)$ that has a measured absorbance of 0.685?

x Concentration (mol/L)	y Absorbance
0.08	0.186
0.16	0.372
0.24	0.587
0.32	0.753
0.40	0.955

Linear Fit for Latest/Absorbance
y = mx + b
m (Slope): 2.399
b (Y-Intercept): –0.005494
Correlation: 0.9995
RMSE: 0.01151

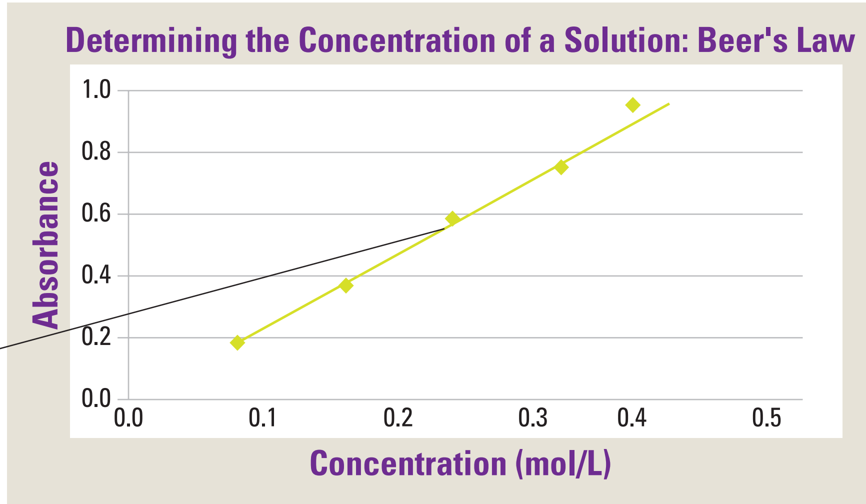

Figure 2. $CuSO_4$ Beer's law sample data and graph

SUPPLEMENTAL RESOURCES

Links

"Color Vision Interactive Simulation." University of Colorado at Boulder, PhET Interactive Simulations. Accessed July 31, 2012.
http://phet.colorado.edu/en/simulation/color-vision

"Light Waves and Color — Lesson 2." The Physics Classroom. Accessed July 31, 2012.
http://www.physicsclassroom.com/class/light/u12l2c.cfm

"The Franklin Institute Resources for Learning — Light and Color." The Franklin Institute. Accessed July 31, 2012.
https://www.fi.edu/color-science

Reference

Brown, Theodore L. "Chemistry of Coordination Compounds." In *Chemistry: The Central Science*, Theodore L. Brown, H. Eugene LeMay Jr., Bruce E. Bursten, and Catherine J. Murphy, 1031–1033. Upper Saddle River, NJ: Pearson Education, 2009.