Question: what is the relationship between color, wavelength, absorbance, and concentration?

Teacher's Guide

In this experiment students are asked to discover the relationship between color, wavelength, absorbance, and concentration. First the class is divided into groups of 3 or 4 and the relationship between color and wavelength absorbed is studied. Next the students find the relationship between absorbance and concentration. Finally they are given an unknown copper(II) salt to identify. This task is not simple for students. The students need to identify what species produced by dissolution of the copper salt is absorbing. They then need to recognize that absorbance is directly related to moles or molarity and not to grams of copper salt. This in itself is an important aspect of this experiment and can serve to show why the mole concept and molarity are important and natural developments for chemists. Students determine that the same gram amounts of different copper salts do not give the same absorbance. From a known compound, $CuSO_4 \cdot 5H_2O$, the absorbance of the Cu(II) ion versus either grams or mol L^{-1} is established. Students soon realize the g L^{-1} is not a convenient or useful unit and come to the conclusion that mol L^{-1} is better. The students determine the moles of Cu(II) inone and hence the number of moles of their 1:1 Cu(II) salt. From the initial weight of the unknown salt and the moles, the molecular weight of the unknown is calculated. The students can identify their unknowns for a list of possibles.

It takes students quite a while to recognize that if they can find the number of moles of Cu(II) ion in their unknown they can identify it. It takes some doing also for them to figure out how to determine the number of moles.

For part I each group will collect the same data. The students should be able to identify a color with a wavelength. The object is to prepare students for part II, where the relation between what light is absorbed and what is transmitted will be explored.

For part II pooled data are needed. Each group should present absorbance vs. wavelength data and a plot of the absorbance spectrum. These data can be used to show that the absorption is due to the cation and not the anion for each compound.

Students should see from the plots of absorbance vs. wavelength that a blue solution ($CuSO_4$) absorbs red light and that a yellow solution ($FeCl_3$) absorbs blue light. The green solution ($NiSO_4$) exhibits two absorption maxima, one in the red and one in the blue region which give a solution that appears green to the eye. The pink solution ($CoSO_4$) absorbs in the midpoint of the 400-700 nm range and thus transmits blue and red light which give rise to the observed pink. An application of these observations may be made by giving the students spectra of colored solutions and asking them to identify the color of the solution.

In part III each group can find the relationship between absorbance and concentration from their own data. Many will use grams of compound or grams of compound per liter as a means of relating absorbance and concentration. There is no reason at this point to use molarity. However it may be interesting to point out that while within each group using one assigned compound a straight line can be obtained from a plot of absorbance versus grams per liter of compound, for another group using a different compound the slope will not be the same. Students should note that the same gram amounts of different compounds do not give the same absorbance.

Part IV requires considerable ingenuity on the part of the students. They need to recognize that moles are the key to the solution of their problem. They can be given a known copper compound ($CuSO_4 \cdot 5H_2O$, for example) from which they can prepare a standard curve. Once they see that the same relationship is obtained between absorbance and concentration in moles per liter, they recognize that they can analyze any copper salt for the copper ion. If the original weight of the salt and the moles of copper ion are known, the molecular weight of the salt can be calculated and hence identified. It may be necessary to point out that all the possible unknown salts contain only one copper atom per compound.

Colorimetry/Beer's Law Experiment

$CoSO_4 \cdot 7H_2O$	5 grams/500 mL
$CoCl_2 \cdot 6H_2O$	5 grams/500 mL
$Ni(NO_3)_2 \cdot 6H_2O$	25 grams/500 mL
$NiSO_4 \cdot 6H_2O$	25 grams/500 mL
$Fe(NO_3)_3 \cdot 9\ H_2O$	5 grams/500 mL
$FeCl_3 \cdot 6H_2O$	5 grams/500 mL
$CuSO_4 \cdot 5H_2O$	25 grams/500 mL

*Include 5 mL HNO_3 in all solutions.

Unknowns

Cupric chloride dihydrate
Cupric sulfate pentahydrate
Copper(II) acetate monohydrate
Copper(II) bromide
Copper(II) nitrate hemipentahydrate

Student Experiments

I. What is the Relationship Between Color and Wavelenght?
Turn on a Spectronic 20. Set the wavelength to 700 nm. Open the cell compartment and insert a rolled 3" x 5" index card to trip the shutter. Note the color observed at the right-bottom of the card. The intensity of the light can be increased by rotating the 100% control knob clockwise. Repeat this experiment every 25 nm until you reach 400 nm. Prepare a table of wavelength and color observed.

II. What is the Relationship Between Color and Wavelenght Absorbed?
Each group will be assigned a solution prepared from the following salts:

$CoSO_4 \cdot 7H_2O$
$CoCl_2 \cdot 6H_2O$
$Ni(NO_3)_2 \cdot 6H_2O$
$NiSO_4 \cdot 6H_2O$
$Fe(NO_3)_3 \cdot 9\ H_2O$
$FeCl_3 \cdot 6H_2O$
$CuSO_4 \cdot 5H_2O$

Read INSTRUCTIONS FOR THE SPECTRONIC 20. In addition, your instructor or lab assistant will demonstrate how to use this instrument. Record a spectrum of the assigned solution. Start at 700 nm and end at 400 nm. Take a reading every 25 nm. Record the absorbance of each wavelength.

Do not forget to zero and to reset 100% T after every wavelength change

After you have scanned the full range(700-400nm) find the wavelength (± 5nm), λ max, associated with the greatest absorbance.

Why is a solution of $CuSO_4 \cdot 5H_2O$ blue?

Explain why a solution containing Ni^{2+} ions is green in terms of absorbed light.

Why is an $FeCl_3 \cdot 6\ H_2O$ solution yellow?

In terms of transmitted light explain why a solution containing Co^{2+} ions is pink.

III. What is the Relationship Between Absorbance and Concentration ?

Each group will work with its assigned solution.

Prepare of diluted TEST SOLUTION. Pipet 10mL down of the assigned solution into a 100-mL volumetric flask. Dilute to volume and make sure that the contents are mixed well. This solution has a concentration of 10mL of TEST SOLUTION per 100 mL of solution. Similarly, prepare solutions with 25, 50 and 75mL of the TEST SOLUTION per 100mL of solution.

Set the wavelength of the Spectronic 20 spectrophotometer to an appropriate wavelength. Determine the absorbance for the 10, 25, 50, 75 ML dilutions and the TEST SOLUTION itself.

Prepare a plot of absorbance (vertical axis) vs. concentration (horizontal axis). Find an analytical relation between absorbance and concentration.

Do you expect that solutions containing the same number of grams of $Ni(NO_3)_2 \cdot 6H_2O$ and $NiSO_4 \cdot 6H_2O$ will have the same absorbance? Do they?

Report

Include the following in your report:

- A table of wavelength and color
- The spectra (graph) of all the four TEST SOLUTIONS. The λmax for each.
- An analysis of the spectra of the TEST SOLUTIONS based on the color(s) absorbed and the color observed.
- A table of absorbance and concentration (mL of TEST SOLUTION per 100mL of solution). Include the data for the test solution itself.
- A plot of absorbance (vertical axis) vs. concentration (mL of TEST SOLUTION per 100 mL of solution). Include the data for the test solution itself. Prepare plots for all four colored solutions.

IV. How Can An Unknown Copper Salt Be Identified?

Each student will be assigned an unknown copper salt to be identified. The possible salts are:

CuF_2

$CuCl_2$

$CuCl_2 \cdot 2H2O$

$CuBr_2$

CuI_2

$Cu(C_2H_3O_2)_2 \cdot H_2O$

$Cu(NO_3)_2 \cdot 6H_2O$

$Cu(NO_3)_2 \cdot 2.5H_2O$

CuO

CuS

$CuSO_4$

$CuSO_4$

$CuSO_4 \cdot 5H_2O$

$Cu(CN)_2$

$Cu(BO_2)_2$

Design and carry out an analysis that will allow you to identify the unknown compound.