

2B. LIGHT, COLOR, AND CONCENTRATION

(Spectrometer Version)

Initial Question

If you've ever added a powdered drink mix to water, you realize that the more concentrated the drink, the deeper the color of the solution. Analytical chemists, particularly in the agricultural and medical fields, routinely use a quantitative approach called *spectroscopy* to determine the concentration of solute in a solution as it relates to the color of the solution.

How can you use electromagnetic waves to determine the concentration of a solution?

Materials and Equipment

Model 1

- Spectrometry Application
- Spectrometer
- Cuvettes
- Colored pencils
- Test tubes (5), large
- Test tube rack
- Kimwipes or tissues
- Pipet with pump or bulb large
- Distilled water and wash bottle
- Test tube rack
- 0.10 M Cobalt(II) nitrate ($\text{Co}(\text{NO}_3)_2$), 30 mL
- 0.10 M Nickel(II) nitrate ($\text{Ni}(\text{NO}_3)_2$), 30 mL
- 0.10 M Iron(III) nitrate ($\text{Fe}(\text{NO}_3)_3$), 30 mL
- 0.10 M Zinc nitrate ($\text{Zn}(\text{NO}_3)_2$), 30 mL

Model 2

- Spectrometry Application
- Spectrometer
- Cuvette
- Distilled water and wash bottle
- Test tube, large
- Test tube rack
- Pipet with pump or bulb, 10-mL
- Glass stirring rod
- Kimwipes or tissues
- 0.10 M Cobalt(II) nitrate ($\text{Co}(\text{NO}_3)_2$), 30 mL
- 0.10 M Nickel(II) nitrate ($\text{Ni}(\text{NO}_3)_2$), 30 mL
- 0.10 M Iron(III) nitrate ($\text{Fe}(\text{NO}_3)_3$), 30 mL
- 0.10 M Copper(II) sulfate (CuSO_4), 30 mL

Applying Your Knowledge

- Spectrometry Application
- Spectrometer
- Cuvette
- Pipet with pump or bulb, 10-mL
- Distilled water and wash bottle
- Kimwipes or tissues
- 0.10 M Copper(II) nitrate ($\text{Cu}(\text{NO}_3)_2$), 30 mL
- Copper(II) nitrate ($\text{Cu}(\text{NO}_3)_2$), unknown concentration, 6 mL

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wash your hands with soap and water after handling the solutions, glassware, and equipment.
- Nickel(II) nitrate, cobalt(II) nitrate, iron(III) nitrate, zinc nitrate and copper(II) sulfate are hazardous to the environment and should not be disposed of down the drain. Make sure you follow your teacher's instructions on how to properly dispose of these solutions.

Getting Your Brain in Gear

1. Which color of light has the higher energy—blue or red?

2. The atomic theory put forth by Bohr was based on the interaction of light with electrons at various energy levels. According to Bohr's theory, what could happen to an electron that was hit by a photon of light?

3. According to Bohr's theory, what must happen for an excited electron to move to a lower energy state?

4. According to Bohr's theory, how is the change in the electron's energy different if it absorbs the energy of red light versus absorbing the energy of blue light?

5. White light passed through a prism comes out as a rainbow. Describe white light in terms of a mixture of photons.

MODEL 1

Building Model 1 – Transmittance and Absorbance for Solutions

- Connect the spectrometer to the data collection system using a USB cable connection, or wirelessly connect to the system through Bluetooth pairing.
- Open the Spectrometry application.
- Place a sample of each of the 0.10 M solutions to be tested in a large test tube. You also need distilled water for a "blank."
- Select Analyze Solution from the options at the top of the screen.
- Select Calibrate Dark from the options at the bottom of the screen. The Spectrometer will turn off all internal lights and perform the calibration. A check mark will appear when the calibration is finished.
- Add distilled water to a cuvette. This should be the same distilled water that was used as a solvent for the solutions being analyzed. Place the cuvette into the spectrometer. Follow the cuvette handling guidelines listed below for the remainder of the investigation.
 - Always handle the cuvette by the ridged sides.
 - Wipe off any fingerprints using a lint free wipe (such as Kimwipes).
 - Place the cuvette into the spectrometer so that the ridged sides are facing the violet and green light icons and the clear sides face the white light and absorbance spectrum icons. The white light is what will pass through the samples.
- Select Calibrate Reference to calibrate the spectrometer with the distilled water (the water sample is called a "blank"). A check mark will appear when the calibration is complete.
- Why is it important to wipe the sides of the cuvette before placing it into the spectrometer?

The samples you will test are aqueous solutions. That is, water is the solvent. Both water and plastic can absorb visible light at some wavelengths. With this in mind, explain why the spectrometer is calibrated with a blank solution? (Hint: Using a "blank" in a spectrometer is similar to the "tare" button on a digital balance.)

- Place approximately 2 mL of each 0.10 M test solution into separate cuvettes.
- Place one of the cuvettes in the spectrometer chamber and start recording. After approximately 30 seconds, stop recording. Use the Scale to Fit tool to manually adjust the x and y axes to optimize the view of the data. Use the Add Coordinate tool, dragging the coordinates box to a



CALIBRATE DARK



CALIBRATE REFERENCE



START RECORDING



STOP RECORDING



EXPERIMENT OPTIONS



ANALYZE SOLUTION



ANALYZE CONCENTRATION



ANALYZE REACTION



SCALE TO FIT



ADD COORDINATE



SHOW LINEAR FIT



SHOW COMPARISON



SHOW SELECTION



SHOW DUAL Y-AXES

point on the curve, to find the maximum absorbance for the sample. Select the check mark when you have found the greatest absorbance. (If the check mark is not visible, tap the coordinates box to make it appear.)

- Record the wavelength of maximum absorbance in Model 1 Data Table 1. Rename the data run with the name of the solution tested.
- Select the y-axis label to toggle between Absorbance and Transmittance. Alternatively, the Show Dual Y-Axes feature will display both simultaneously. Record the color of the solution and color corresponding to the wavelength of Maximum Absorbance in Model 1 Data Table.
- Sketch the absorbance and transmittance curves for the solution. Either use solid and dashed lines to represent absorbance and transmittance or use two different colors.
- Use the same procedure to analyze each of the remaining solutions.

Model 1 – Transmittance and Absorbance for Solutions

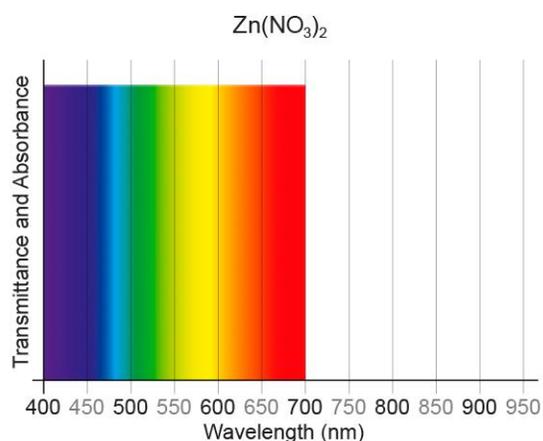
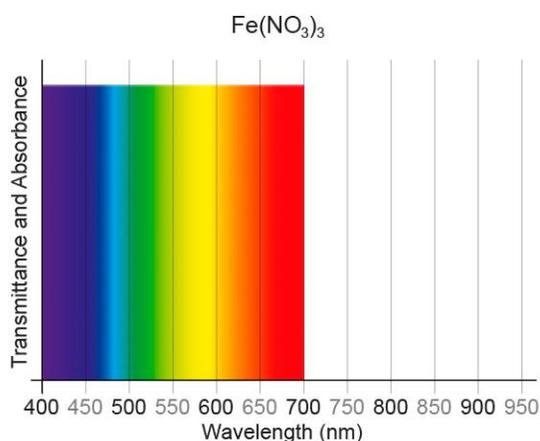
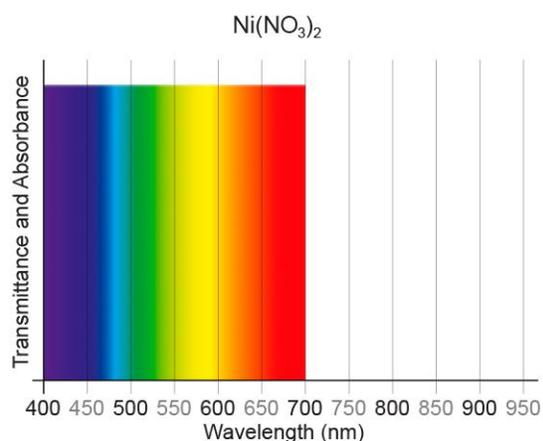
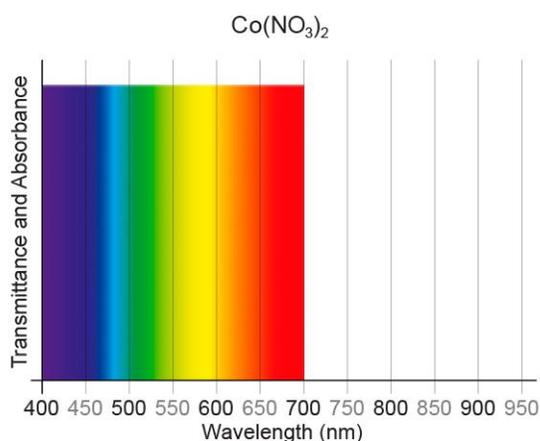


Table 1: Model 1 Data Table—Light absorbance for solutions of different colors

0.1 M Solution	Wavelength Selected (nm) for Maximum Absorbance	Approximate Color of the Solution	Approximate Color of Maximum Absorbance
$\text{Co}(\text{NO}_3)_2$			
$\text{Ni}(\text{NO}_3)_2$			
$\text{Fe}(\text{NO}_3)_3$			
$\text{Zn}(\text{NO}_3)_2$			

Analyzing Model 1

15. Consider the words “transmit” and “absorb” as they are used normally.

a) If a solution has a high transmittance for a certain color of light, what does that mean in terms of photons of light interacting with electrons in the solution?

b) When a solution has a high transmittance for a certain color of light, does it also have a high absorbance for that color?

c) Explain the relationship you stated above in terms of the interaction of photons of light with electrons in the solution.

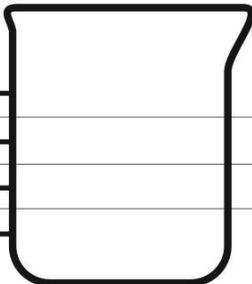
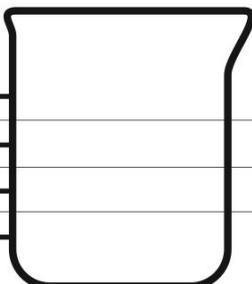
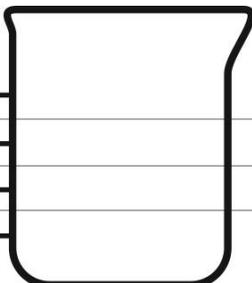
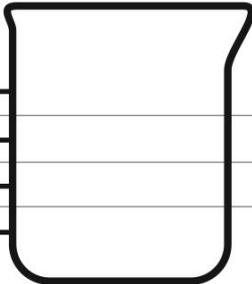
16. Consider the solutions in Model 1. When light is shone through a solution that matches the color of the solution, is it mostly transmitted or absorbed? Justify your answer with data from Model 1.

17. All of the solutions used in Model 1 were made by dissolving a salt in distilled water. For each solution, list the individual ions present after the salt has completely dissolved.

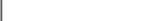
Cobalt(II) nitrate =
 Nickel(II) nitrate =
 Iron(III) nitrate =
 Zinc nitrate =

18. Identify the ions that cause the solutions to have color.

19. While the spectrometer allows you to analyze absorbance and transmittance for the entire range of wavelengths in the visible spectrum, for the models below consider only the maximum wavelength for red, orange, green, and blue. Use colored pencils to color the beakers below containing the solutions from Model 1.

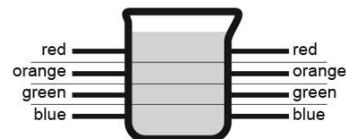
	LIGHT FROM INSTRUMENT	→	LIGHT TRANSMITTED
$\text{Co}(\text{NO}_3)_2$	red orange green blue		red orange green blue
$\text{Ni}(\text{NO}_3)_2$	red orange green blue		red orange green blue
$\text{Fe}(\text{NO}_3)_3$	red orange green blue		red orange green blue
$\text{Zn}(\text{NO}_3)_2$	red orange green blue		red orange green blue

Key

	all transmitted
	a lot transmitted
	some transmitted
	none transmitted

Example

If all lights (red, orange, green, and blue) came from the instrument fully and were transmitted fully through the solution, it would be illustrated like this:



20. In the diagrams above use solid or dotted lines of the appropriate color to represent both the incoming light and the outgoing light for each of the four indicated colors as they traveled through each solution. The diagrams should be consistent with the data collected in Model 1.

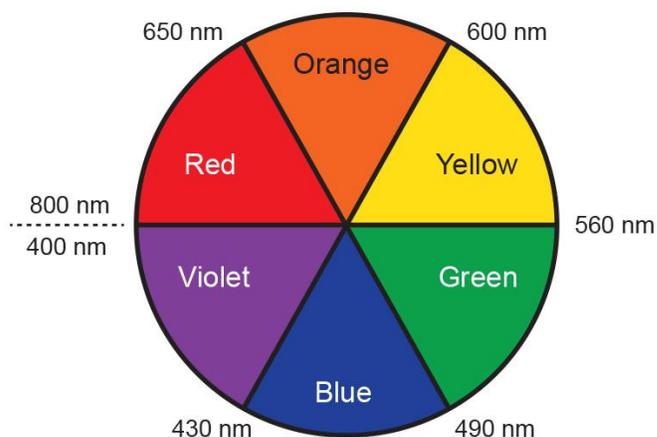
21. State the formula and color of the solution which absorbed the most;

a) green light

b) blue light

c) red light

22. Consider the color wheel below. Red and green are considered complementary colors, as are violet and yellow. When light is shone through a solution that is a complementary color to that of the solution, is it mostly transmitted or absorbed? Justify your answer with data from Model 1.



23. Can wavelengths of visible light be used to analyze the concentration of colorless solutions? Justify your answer with evidence from Model 1.

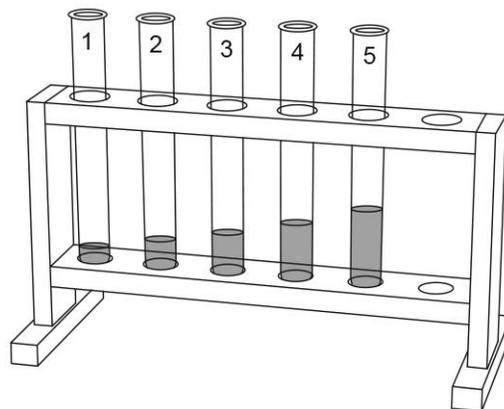
Connecting to Theory

When we look at something white, our eyes are picking up light of every wavelength that is reflecting off of that object. Colored objects absorb one or more wavelengths of light, however, so our eyes only receive part of the visible spectrum. Thus our brain registers the object as having a color. A red object, for example, might absorb blue, yellow and green wavelengths. Our brain receives the reflected violet, red and orange wavelengths and “averages” them together, making us think we have seen red.

MODEL 2

Building Model 2 – Varying Concentration

1. Connect the spectrometer to the data collection system using a USB cable connection, or wirelessly connect to the system through Bluetooth pairing.
2. Label five clean, dry test tubes “1” through “5” and place them into a test tube rack.



Your instructor will assign you one of the colored solutions. Pipet 2.0, 4.0, 6.0, 8.0 and 10.0 mL of your 0.10 M solution into test tubes 1 through 5, respectively.

4. Wash the pipet and use it to deliver 8.0, 6.0, 4.0, and 2.0 mL of distilled water into test tubes 1 through 4 so that each test tube has 10.0 mL of solution.
 5. Why do the test tubes need to be dry? What error would be caused by wet test tubes?
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6. Calculate the concentration of the solutions in each test tube, and enter those values in the Model 2 Data Table.
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7. Thoroughly mix each solution with a stirring rod.
NOTE: Clean and dry the stirring rod before stirring a different solution.
 8. Open the Spectrometry application and calibrate the spectrometer (dark and reference) with a "blank" cuvette.
 9. Rinse a cuvette twice with a small portion of the solution from Test Tube 1 and then fill the cuvette at least two-thirds full.
 10. Wipe the cuvette clean and dry and place it into the spectrometer.
 11. Select Analyze Solution from the menu at the top of the screen and start recording data. After approximately 30 seconds, stop recording data.
 12. Use the Add Coordinate tool, dragging the coordinates box to a point on the curve, to find the maximum absorbance for the sample. Select the check mark when you have found the greatest absorbance. (If the check mark is not visible, tap the coordinates box to make it appear.)
 13. Select Concentration from the options at the top of the screen; this will take you to a different page within the application. In the table provided on the page, edit the given concentration with the value you calculated for the least concentrated dilution. Start recording data. Once the absorbance value—which is shown in the table—has stabilized, select the check mark next to the value to record it. Copy the information into the Model 2 Data Table.

14. Repeat the steps above for the solutions in test tubes 2–5: rinsing a cuvette, filling with a dilution, editing the concentration value in the table, and selecting the check mark when the absorbance value has stabilized.
14. Toggle the y-axis to Transmittance. Scale to Fit if necessary. Record the Transmittance value in the Model 2 Data Table.
15. Once absorbance data has been recorded for all five dilutions, stop data collection. Be sure to copy all absorbance and transmittance values into Model 2 Data Table.
16. Record the absorbance and transmittance data from other labs groups.

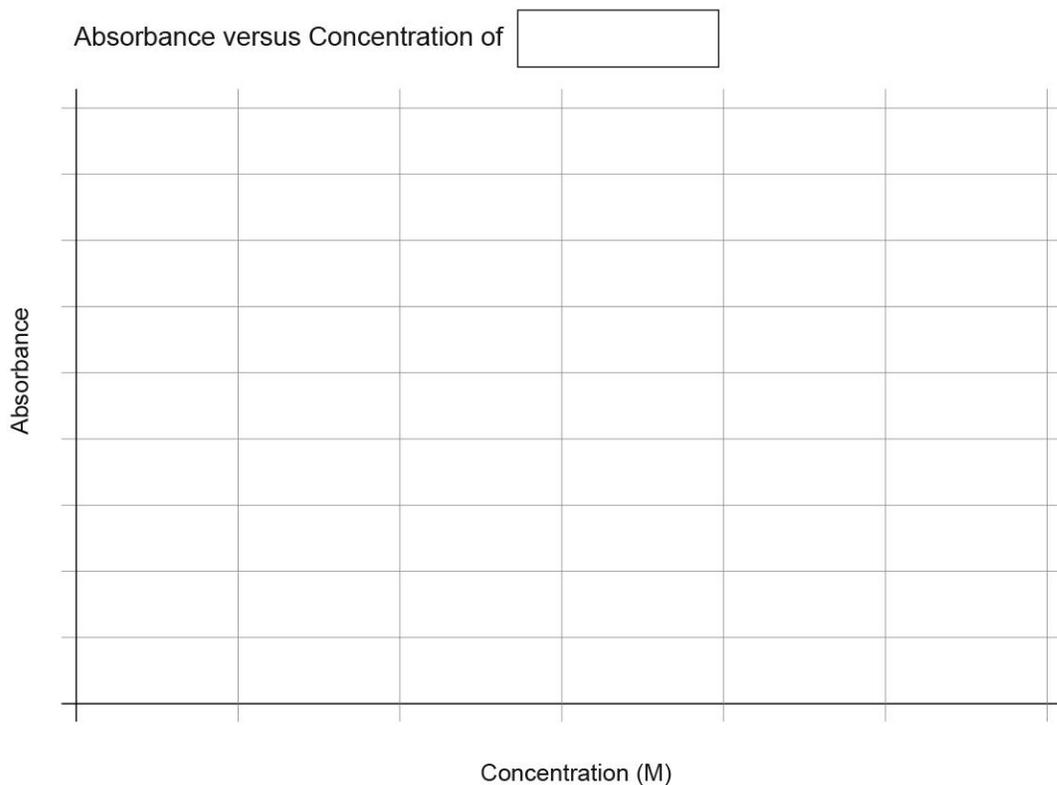
Model 2 – Varying Concentration

Table 2: Model 2 Data Table—Detecting the concentration of a solution using light

		CuSO ₄		Co(NO ₃) ₂		Fe(NO ₃) ₃		Ni(NO ₃) ₂	
Test Tube #	Conc. (M)	Abs.	Trans.	Abs.	Trans.	Abs.	Trans.	Abs.	Trans.
1									
2									
3									
4									
5									

Analyzing Model 2 – Varying Concentration

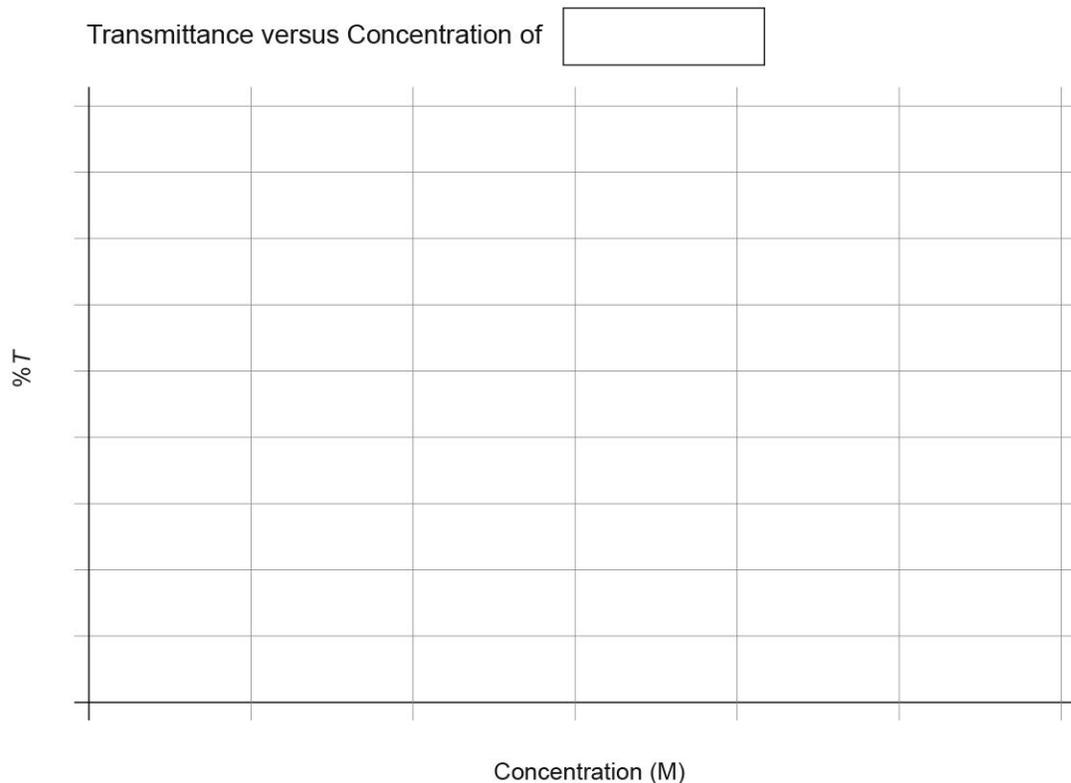
16. The spectrometer "Concentration" page provides a graph of absorbance versus concentration for a solution based on the wavelength selected on the "Analyze Solution" page. Graph absorbance versus concentration data for your solution.



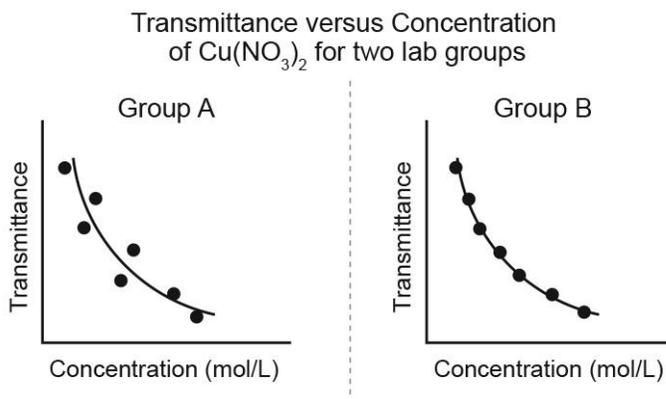
17. In general, does the color of the maximum absorbance light match the color of the solution or is it from the complementary color?

18. Imagine that your instructor gives you a sample of your solution of unknown concentration. Explain how your absorbance data might be used to find the concentration of that solution.

19. Graph the percent transmittance data that corresponds to the absorbance data with the steepest slope. Which set of data, T or A , would be the easiest to model with a mathematical equation? Justify your answer.



20. Consider the data below collected by two different lab groups for copper(II) nitrate solution at 468 nm on the same spectrometer. (Assume the spectrometer was working properly in both cases.)



- a) Discuss how the quality of the data compares between the two groups.

b) Propose at least two reasons why the data might differ between the two groups.

Connecting to Theory

Spectroscopy is the study of the interaction of electromagnetic radiation and matter. In spectroscopy and spectrophotometry, two terms are inescapable: transmittance and absorbance. Transmittance T is defined as the ratio of the intensity of light after it passes through a medium being studied (I) to the intensity of light before it encounters the medium (I_0).

$$T = \frac{I}{I_0}$$

Chemists more commonly refer to the percent transmittance % T , which is simply $\frac{I}{I_0} \times 100$.

Because the percent transmittance is exponentially related to concentration of solute, the use of absorbance, which gives a linear relationship, is often preferred.

$$A = -\log T = -\log \frac{I}{I_0} ; \text{ note that } A = -2 \log (\%T)$$

If one knows the percent transmittance, one can calculate absorbance and vice versa. Most modern spectrophotometers have both a % T and an absorbance scale. With a digital instrument, it is simply a matter of changing modes to display either value.

Beer's Law, is one of the most fundamental and widely applied spectroscopic laws. It relates the absorbance of light to the concentration c of the solute, the optical path length b and the molar absorptivity a of a solution.

An operation statement of Beer's Law can be represented as

$$A = abc$$

The molar absorptivity is a constant that depends on the nature of the absorbing solution system and the wavelength of the light passing through it. A plot that shows the dependence of A on wavelength is called a spectrum.

Applying Your Knowledge– Determining the Concentration of an Unknown

Your instructor will provide you with a bottle of 0.10 M copper(II) nitrate and a sample of an unknown concentration of copper(II) nitrate. Propose and carry out a plan to determine the concentration of the copper ion in the unknown. What is the concentration of the unknown?

