2A. LIGHT, COLOR, AND CONCENTRATION

(Colorimeter 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

- Data collection system
- Colorimeter
- Cuvette
- Sensor extension cable
- Pipet with pump or bulb, 10-mL
- White 3 × 5 index card or piece of paper
- Colored pencils
- Scissors
- Distilled water and wash bottle
- Kimwipes or tissues
- One of the following:
  0.10 M Cobalt(II) nitrate ($Co(NO_3)_2$), 30 mL
  0.10 M Nickel(II) nitrate ($Ni(NO_3)_2$), 30 mL
  0.10 M Iron(III) nitrate ($Fe(NO_3)_3$), 30 mL
  0.10 M Zinc nitrate ($Zn(NO_3)_2$), 30 mL

Model 2

- Data collection system
- Colorimeter
- Cuvette
- Sensor extension cable
- Distilled water and wash bottle
- Test tubes (5), large
- Test tube rack
- Pipet with pump or bulb, 10-mL
- Glass stirring rod
- Kimwipes or tissues
- One of the following:
  0.10 M Cobalt(II) nitrate ($Co(NO_3)_2$), 30 mL
  0.10 M Nickel(II) nitrate ($Ni(NO_3)_2$), 30 mL
  0.10 M Iron(III) nitrate ($Fe(NO_3)_3$), 30 mL
  0.10 M Copper(II) sulfate ($CuSO_4$), 30 mL

Applying Your Knowledge

- Data collection system
- Colorimeter
- Sensor extension cable
- Cuvette
- Pipet with pump or bulb, 10-mL
- Distilled water and wash bottle
- Kimwipes or tissues
- 0.10 M Copper(II) nitrate ($Cu(NO_3)_2$), 30 mL
- Copper(II) nitrate ($Cu(NO_3)_2$), 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

1. Start a new experiment on the data collection system.

2. Connect the colorimeter to the data collection system using the extension cable.

3. Place a 1 cm × 7 cm piece of white paper in the sample cell compartment of the colorimeter.

4. Press the green button and observe the light as it appears on the paper. You may need to shade the cell compartment from room light with your hand.

5. What colors of light appear on the paper (list at least three)?

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6. Record the color of light emitted by the colorimeter above their corresponding wavelengths in the Model 1 Data Table.

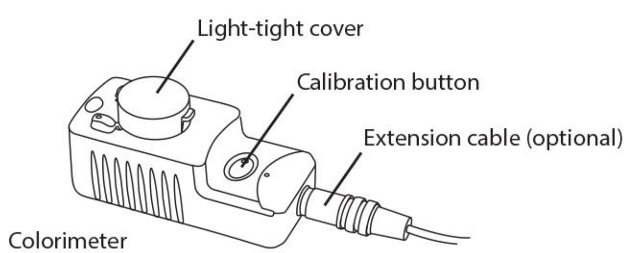
7. Obtain a sample of a 0.10 M solution to test in the colorimeter for Model 1. Your instructor will assign you either cobalt(II) nitrate, nickel(II) nitrate, iron(III) nitrate or zinc nitrate.

8. Record the color of your solution in the Model 1 Data Table.

9. Fill a cuvette at least ¾ full with distilled water.

10. Wipe off the sides of the cuvette and only handle it by the top.

11. Calibrate the colorimeter with the distilled water (the water sample is called a "blank").



12. Why is it important to wipe off the sides of the cuvette before placing it into the colorimeter?

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13. What is the approximate percent transmittance at each of the four wavelengths?

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14. What is the approximate absorbance at each of the four wavelengths?

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

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16. Place ~6 mL of your assigned 0.10 M test solution into the cuvette. Wipe the cuvette and handle it only from the top.

17. Place the cuvette in the colorimeter chamber and close the cover. Record your transmittance and absorbance data in the Model 1 Data Table for each of the four wavelengths.

18. Share your data with other groups to complete Table 1.

Model 1 – Transmittance and Absorbance for Solutions

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

0.1 M Solution	**660 nm**		**565 nm**		**468 nm**		**610 nm**	
	%*T*	***A***	**%*T***	***A***	**%*T***	***A***	**%*T***	***A***
$Co(NO_3)_2$ Color: ________								
$Ni(NO_3)_2$ Color: ________								
$Fe(NO_3)_3$ Color: ________								
$Zn(NO_3)_2$ Color: ________								

Analyzing Model 1

19. 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?

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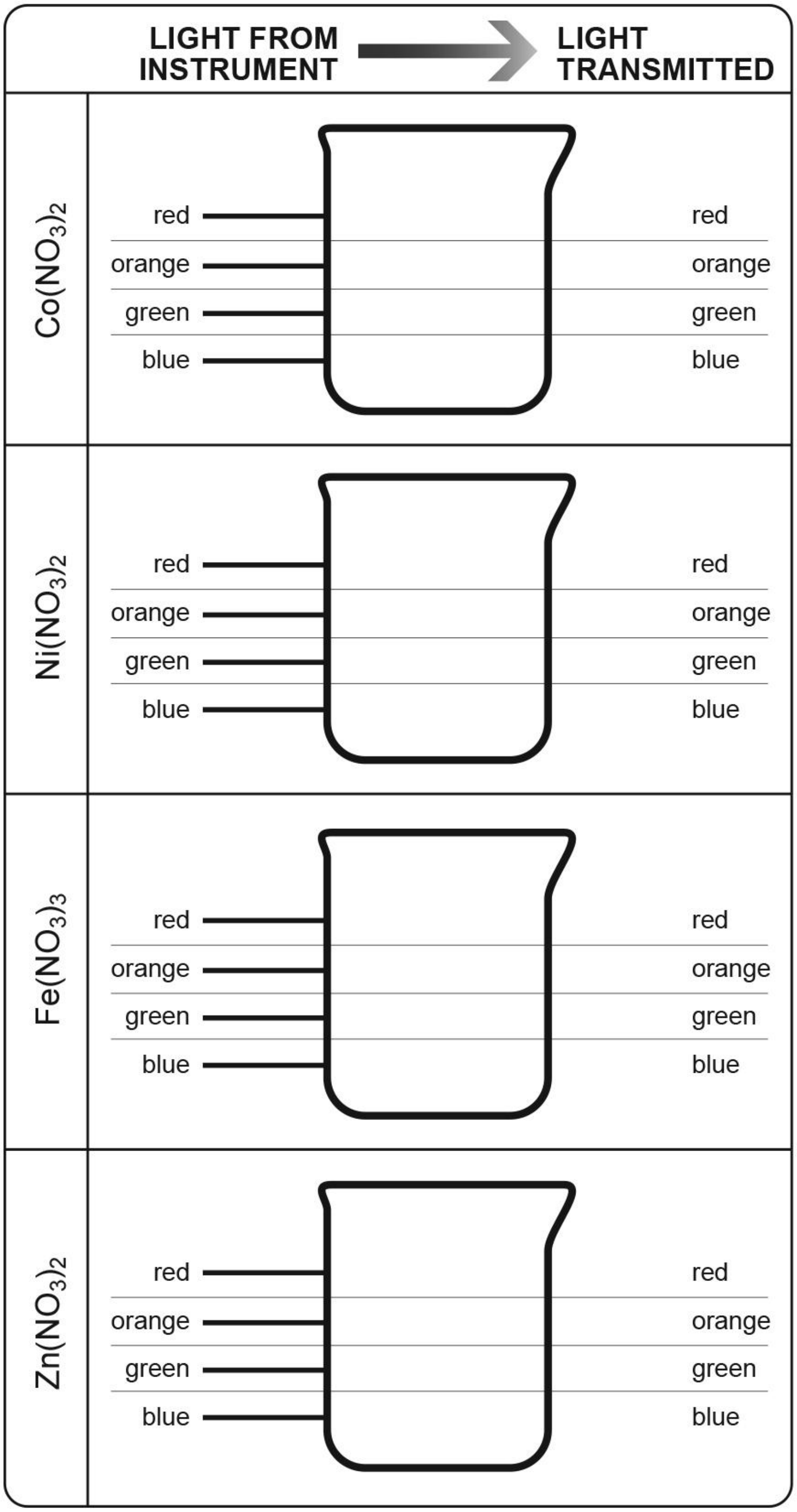
b) When a solution has a high transmittance for a certain color of light, does it also have a high absorbance for that color? Use specific evidence from Model 1 to justify your answer.

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

20. 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.

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

22. Use colored pencils to color the beakers below containing the solutions from Model 1.

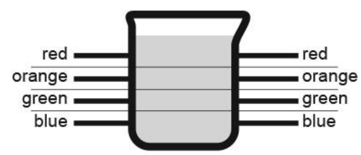


Key

- 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:



23. 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 wavelengths as they traveled through each solution. The diagrams should be consistent with the data collected in Model 1.

24. State the formula and color of the solution which absorbed the most

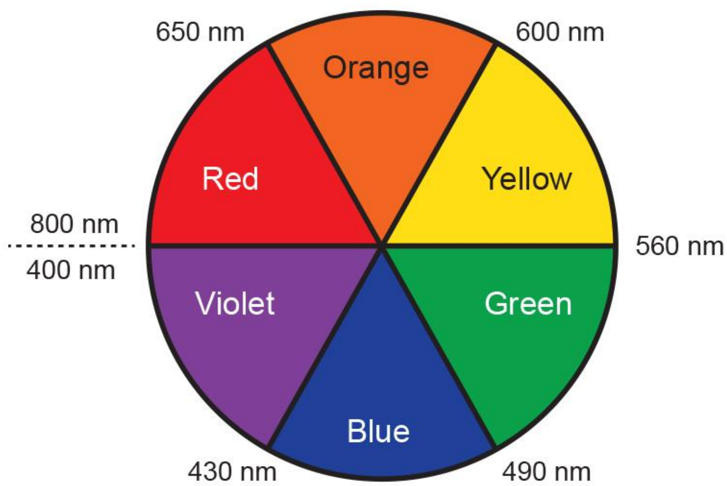
    a) green light

    b) blue light

    c) red light

25. 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.

26. 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.



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

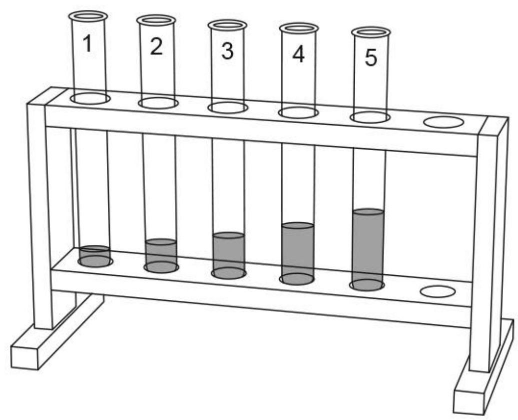
Connecting to Theory

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. Label five clean, dry test tubes “1” through “5” and place them into a test tube rack.



2. Pipet 2.0, 4.0, 6.0, 8.0 and 10.0 mL of your assigned colored 0.10 M solution into test tubes 1 through 5, respectively. (If you previously used a colorless solution, ask your instructor which colored solution you should use for Model 2.)

3. 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.

4. Why do the test tubes need to be dry? What error would be caused by wet test tubes?

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5. Calculate the concentration of the solutions in each test tube, and enter those values in the Model 2 Data Table.

6. Thoroughly mix each solution with a stirring rod.

   NOTE: Clean and dry the stirring rod before stirring a different solution.

7. Configure the data collection system to manually collect the absorbance and transmittance data of all four wavelengths and the solution concentration in a table. Define the concentration as a manually entered data set with units of molarity.

8. Begin with the solution with the lowest concentration. Rinse the cuvette twice with a small portion of the solution and then fill the cuvette two-thirds full.

9. Wipe the cuvette clean and dry and place it into the colorimeter

10. Record the absorbance and transmittance in the Model 2 Data Table for each of the four wavelengths of light.

11. Rinse the cuvette and record data for each of the other four solutions of known concentration.

Model 2 – Varying Concentration

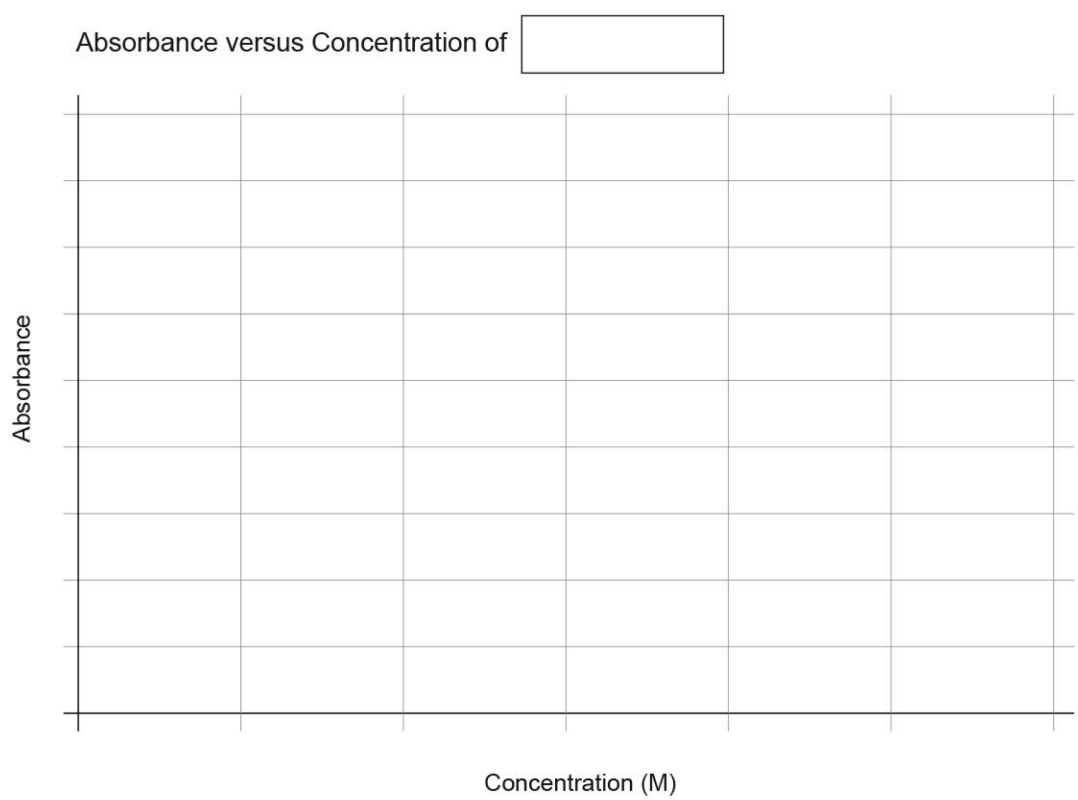
Solution: ______________________________

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

Test Tube #	Concentration (M)	Red (660 nm)		Green (565 nm)		Blue (468 nm)		Orange (610 nm)	
		%*T*	*A*	%*T*	*A*	%*T*	*A*	%*T*	*A*
1									
2									
3									
4									
5									

Analyzing Model 2 – Varying Concentration

12. Graph the four sets of absorbance versus concentration data for your solution. Use color pencil (or colored lines) to indicate the wavelength of light used to collect each set of data.



13. Which color of light provides absorbance data with the steepest slope? Which color of light gives data with the shallowest slope?

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14. Check with lab groups that tested different colored solutions. Record their answers to the question above regarding the color of light that provides the steepest slope in Table 3.

Table 3: Wavelength displaying the greatest change in absorbance as concentration changes

Parameter	Group Results for:			
	Cobalt(II) nitrate	Nickel(II) nitrate	Iron(III) nitrate	Copper(II) sulfate
Color of solution				
Color of light with steepest slope				
Color of light with shallowest slope				

15. In general, is the absorbance data with the steepest slope obtained from light that matches the color of the solution or from the complementary color?

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16. Imagine that your instructor gives you a sample of your solution of unknown concentration.

    a. Explain how your absorbance data might be used to find the concentration of that solution.

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    b. Would it be best to use the wavelength of light that gave the steepest slope or the shallowest slope in determining the concentration of your unknown? Explain your reasoning.

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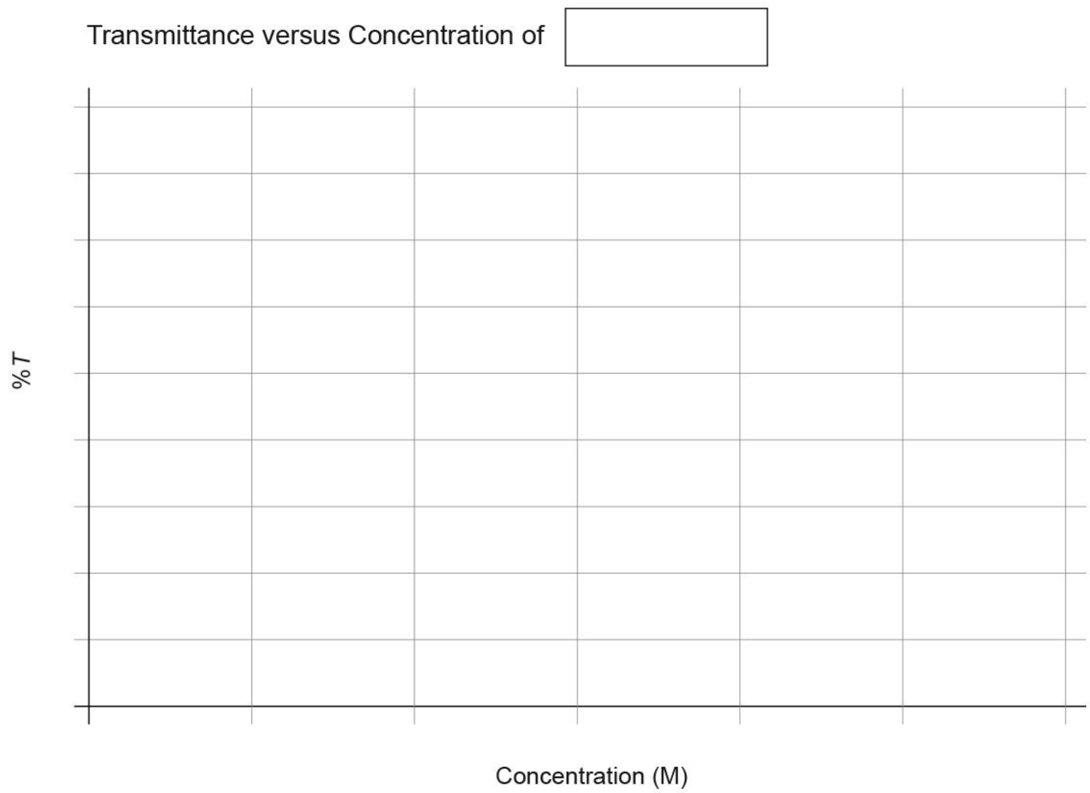
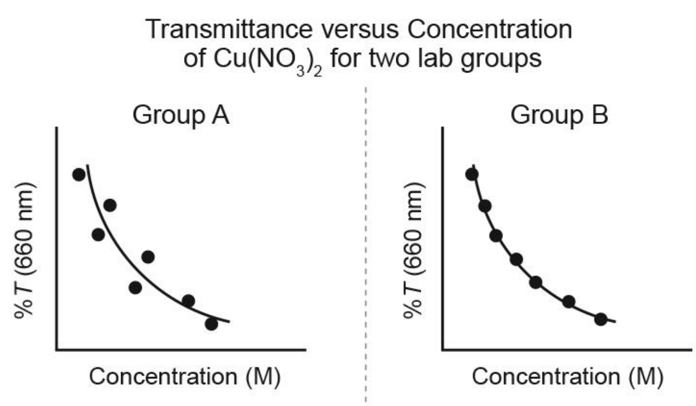
17. Graph the percent transmittance data that corresponds to the absorbance data with the steepest slope. Which set of data, %*T* or *A*, would be the easiest to model with a mathematical equation? Justify your answer.



18. Consider the data below collected by two different lab groups for copper(II) nitrate solution at 468 nm on the same colorimeter. (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.

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

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?