Purpose

The color of light (or wavelengths of light) that are absorbed by a solution are related to the color visible to the eye. This lab explores the relationship of the color of the solution and the wavelengths absorbed. Additionally, this lab explores how the saturation of the color of a solution is related to the amount of light absorbed.

Learning Objectives

Describe the relationship between the wavelength of light absorbed and the color of a solution.

Predict the wavelength of light absorbed by a solution based on the color of the solution.

Describe the variables in Beer's law and make predictions as to how changes in these impact absorbance.

Predict relative absorbances of light of different concentrations of a solute using Beer's law.

Prepare a Beer's law plot and determine the equation for the line.

Use the Beer's law plot to determine the concentration of a solution of unknown concentration.

Interpret data to draw conclusions regarding the impact of different ions and cations on the absorbance of an ionic compound.

Laboratory Skills

None (PhET simulation)

Equipment

- Internet access (PhET simulation)

Chemicals

- none (PhET simulation)

Introduction

Introduction to Electromagnetic Radiation

The sun is the source of the electromagnetic radiation (EMR) that reaches the earth. EMR, which is commonly measured by wavelength, ranges from radio waves, which have wavelengths up to a mile long, to the very small wavelengths of gamma rays, which are smaller than the width of an atom. The entire range of EMR, the electromagnetic spectrum. is shown in Figure BL.1.

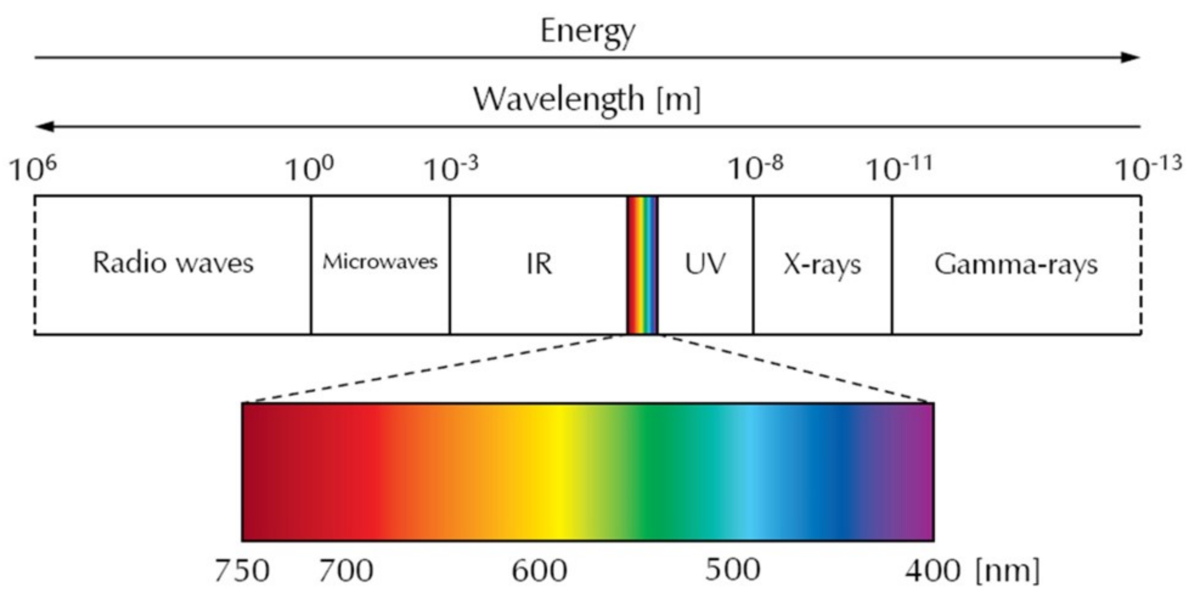

Figure BL.1: Electromagnetic spectrum

The portion of EMR detectable by the human eye is referred to as the visible spectrum and is a very small portion of the entire electromagnetic spectrum. The wavelengths of visible light range from 400 nm to 800 nm. Colorful objects absorb portions of the visible spectrum and reflect other wavelengths. The color observed by people corresponds to the reflected wavelengths. The complementary relationship between the most strongly absorbed wavelengths and the observed color of a substance can be predicted by referring to a color wheel, as in Figure BL.2.

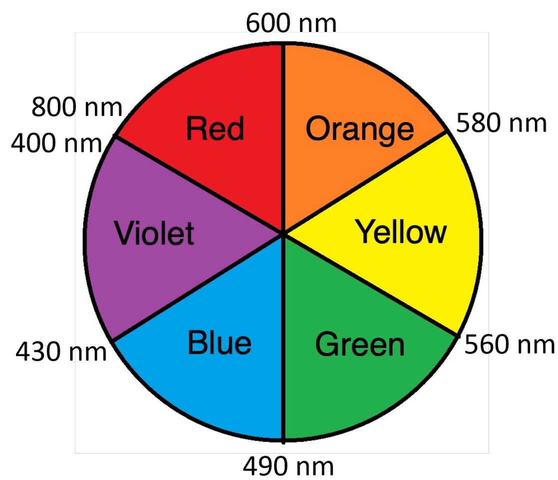

Figure BL.2: Color wheel showing the wavelengths associated with each range of colors.

The color an object reflects is directly across the color wheel from the wavelengths most strongly absorbed. Objects that absorb strongly in the red region of the visible spectrum appear green to human eyes.

Example BL.1

What color of light is most strongly absorbed by an object that is yellowish-orange in color?

The color absorbed is directly across the color wheel from the color observed. The color directly across from yellow-orange is blueish-purple.

Example BL.2

Estimate the wavelength of light most strongly absorbed by an object that is yellowish-orange in color.

The color directly across from yellow-orange is blueish-purple, which has a wavelength of approximately 430 nm.

All colorful solutions and objects absorb light due to the presence of chromophores (light-absorbing chemicals). Solutions containing greater concentrations of a chromophore absorb more light than more dilute chromophore solutions. This direct relationship between the amount of light absorbed and a chemical's concentration makes it possible to make measurements such as the amount of food dye in a sports drink or the amount of glucose in blood. These measurements require a spectrophotometer and an understanding of Beer's Law.

Concentration and Beer's Law

All colorful solutions and objects absorb light due to the presence of chromophores (light-absorbing chemicals). Solutions containing greater concentrations of a chromophore absorb more light than more dilute chromophore solutions. This direct relationship between the amount of light absorbed and a chemical's concentration allows us to make measurements such as the amount of food dye in sports drinks or the amount of cholesterol in blood. These measurements require a spectrophotometer and an understanding of Beer's Law.

Beer's Law equates the amount of light absorbed by a sample, A, to the product of three terms, one of which is the concentration, c, of the light absorbing substance. The other factors in Equation BL.1 are the molar absorptivity (ϵ), which is unique for each chromophore and b, the path length of the light through the sample. Equation BL.1 indicates a direct relationship between the absorbance and each of these factors. For example, the absorbance of light increases as the concentration increases because A is directly proportional to c. Visually, this means that a solution appears darker if there is more of a colored chemical present. Likewise, the fact that A is directly proportional to b means that if the pathlength (or the length the light travels through the solution) increases, the amount of light absorbed will also increase. A real world example of this is that you can see more easily through a narrow glass of colored water than you can through a glass twice as thick!

$$A = \epsilon bc \qquad \text{(Equation BL.1)}$$

A common laboratory instrument called a spectrophotometer is used to measure the concentration of light-absorbing chemicals in solution. Spectrophotometers contain a light source, a solution compartment and a detector. The detector measures the amount of light coming through a sample from the light sources. The light that comes through the sample is the transmittance, which is defined in Equation BL.2 as the fraction of the irradiance, I, that passes through the sample. I_0 is the amount of light that is detected when there is no sample to absorb it and I_t is the light that passes through the sample.

$$T = \frac{I_t}{I_0} \qquad \text{(Equation BL.2)}$$

Solutions are placed in a sample container called a cuvette, which is then placed in the sample chamber of the spectrophotometer. A light source shines light of a specific wavelength through the sample to a light detector. The detector measures transmittance and converts that to absorbance using Equation BL.3.

$$A = -log(\frac{1}{T}) \qquad \text{(Equation BL.3)}$$

For any particular light-absorbing substance, absorbance is measured over a range of wavelengths to determine the wavelength absorbed most strongly, known as λ_{max}. Absorbance at this wavelength can then be used to quantify the amount of that chromophore present in a solution.

The absorbance value is related to the concentration of the light-absorbing or colored species in the sample solution (which has a specific value: ϵ.

Beer's Law is a useful relationship to determine the concentration of a chemical in solution using a spectrophotometer to measure the absorbance. To be able to measure a concentration in an unknown solution, you must first measure the absorbance values of several known solutions and create a standard curve. The slope of the standard curve provides you with the molar absorptivity value (ϵ) and allows you to calculate the concentration of an unknown solution from its absorbance.

Procedure

Open the PhET lab simulation link on the Labflow course page.

Concentration

Drink Mix Solution

Click on the Concentration section and explore the simulation to familiarize yourself with the controls. Then, reset the experiment by clicking the orange button with the circular arrow before continuing.

1. Move the concentration probe over the solution to have the concentration displayed. Click on the shaker to add enough solid drink mix solute to have a concentration of at least 1 mol/L. This is the initial solution. Note the concentration and color of the initial solution on the report sheet.

2. Add water from the top faucet until the total volume in the container reaches the 1 L line. Note the concentration, color, and relative intensity of the solution.

3. Allow evaporation of the solution until the volume is about 0.3 L. Note the concentration, color, and relative intensity of the solution.

Exploring the Effect of Different Cations and Anions on Solution Color and Intensity

4. Reset the lab.

5. In the solute box at the top right, click the down arrow to change the solute to cobalt(II) chloride. Add cobalt(II) chloride as a solid to the water until the concentration is about 0.5 mol/L. Record the concentration, color, and intensity.

6. Remove the first solute by clicking on the Remove Solute button below the vessel and repeat with nickel(II) chloride, which has a different cation.

7. Add solid potassium dichromate to the water container until the concentration is about 0.25 mol/L. Note the concentration and the color and general intensity of its solution.

8. Remove the first solute and repeat with potassium permanganate, which has a different anion.

Beer's Law

Cuvette Width and Concentration

Click on the Beer's Law section in the bottom navigation and explore the simulation to familiarize yourself with the controls. Then, reset the experiment by clicking the orange button with the circular arrow before continuing.

1. With the initial drink mix solution in the cuvette, turn on the light to shine through the sample.

2. Change the detector to the absorbance setting, measure the cuvette width with the ruler, and record the concentration, cuvette width, and absorbance.

3. Increase the width of the cuvette to any setting, changing no other settings, and record the concentration, new cuvette width, and new absorbance.

4. Increase the concentration of the cuvette to any setting, changing no other settings, and record the new concentration, cuvette width, and new absorbance.

5. Reset the lab.

6. Adjust the concentration of the drink mix using the slider to any new concentration. Note the concentration in mM and absorbance for the solution and calculate the absorbance in M.

7. Repeat the measurement for three additional concentrations of the same solution, noting the concentration and absorbance for each sample.

Measuring Absorbance of Solutions at Two Wavelengths

8. Reset the lab and then place cobalt(II) nitrate ($Co(NO_3)_2$) in the cuvette. Record the color appearance of the solution.

9. Turn on the light at the preset wavelength. Record the beam color, wavelength of the light (in nm), and the absorbance of the solution at 100 mM.

10. Change the light to the variable setting and adjust the slider until the color of the beam matches the color of the solution. Record the beam color, wavelength of the light (in nm), and the absorbance of the solution at 100 mM.

11. Repeat steps 8 through 10 with potassium chromate (K_2CrO_4) and potassium permanganate ($KMnO_4$).

12. Plot your data of absorbance versus concentration (in M) using Excel. Add a trendline and report the equation of the line to determine the slope and *y*-intercept. Please review the video on using Excel if needed.

Concentration

Report Table BL.1: Drink Mix Solution

Drink mix solution	Concentration (M)	Color	Intensity change
Initial solution	______	______	N/A
Solution after adding water	______	______	______
Solution after evaporation	______	______	______

Effect of Different Cations and Anions on Solution Color and Intensity

Report Table BL.2: Solutions of $CoCl_2$ and $NiCl_2$

Solution	Concentration (M)	Color	General intensity
Cobalt(II) chloride	______	______	______
Nickel(II) chloride	______	______	______

Report Table BL.3: Solutions of KCr_2O_4 and $KMnO_4$

Solution	Concentration (M)	Color	General intensity
Potassium dichromate	______	______	______
Potassium permanganate	______	______	______

Beer's Law

Cuvette Width and Concentration

Report Table BL.4: Effect of Varying Cuvette Width and Concentration

Drink mix solution	Concentration (mM)	Cuvette width (cm)	Absorbance
Initial solution	______	______	______
Solution with adjusted cuvette	______	______	______
Solution with adjusted concentration	______	______	______

Beer's Law Plot

Report Table BL.5: Data for Beer's Law Plot

Drink mix solution	Concentration (in mM)	Concentration (in M)	Absorbance
Sample 1	______	______	______
Sample 2	______	______	______
Sample 3	______	______	______
Sample 4	______	______	______

Beer's law plot:
Slope ______ ***y*-intercept** ______

Using the molar absorptivity determined from your plot, calculate the expected concentration of a drink mix solution with an absorbance of 0.66. Show your work.

Using the molar absorptivity determined from your plot, calculate the expected absorbance of a drink mix solution with an concentration of 42 mM. Show your work.

Report Table BL.6: Absorbance at Two Wavelengths

	Cobalt(II) nitrate	**Potassium chromate**	**Potassium permanganate**
Solution color	______	______	______
Preset - Beam color	______	______	______
Preset - λ (nm)	______	______	______
Preset - Absorbance	______	______	______
Adjusted color - Beam color	______	______	______
Adjusted color - λ (nm)	______	______	______
Adjusted color - Absorbance	______	______	______