BEER’S LAW SIMULATION LAB

1. **TITLE**: Beer’s Law Simulation Lab

   http://phet.colorado.edu/en/simulation/beers-law-lab

2. **GRADE LEVEL**
   High School (10-12th Grades). First year college General Chemistry.

3. **PRIOR KNOWLEDGE**
   The students should be familiar with the wave nature of light. The students should have learned molarity and concentration prior to this lesson.

4. **OBJECTIVES (BLUEPRINT)**

The Beer’s Law Lab simulations designed to help students understand the concept of solution concentration and how it affects light absorption and transmittance (Chamberlain & Clark, 2015).

Purpose	**Main topic**	**Activity**	**Outcome**
SWBAT: Identify factors that influence the concentration of a solution SWABT: Calculate the changes in concentration when the influencing factors are changed.	Concentration	PhET simulation	Students will learn how the concentration is changed when (1) more solute is added (2) the volume of the solution is increased by adding H_2O (3) the volume of the solution is decreased by evaporation (4) Compare students’ predictions through calculations to simulation results.
Students will learn that the amount of light absorbed and transmitted depends on concentration, path length, and the solution type Students will learn that each solution has a different wavelength for maximum absorption.	Transmittance Absorbance Beer’s Law	PhET Simulation	SWBAT: predict how the intensity of light absorbed/transmitted will change with changes in solution type, solution concentration, container width, or light source, and explain why.

5. CONTENT/TERMS

Links to the glossary of terms provided. Click on each term to open a browser window to obtain additional information.

Solute Solvent Solution Concentration Molarity	Light complementary color Spectrophotometry Absorbance Transmittance Beer's law (The Beer-Lambert Law) Molar absorptivity Path Length Standard Curve

6. MATERIAL

- Laptop computers with latest version of Java installed
- Internet connection

7. **TIME** (120 min, Two class hours: Day 1 – Simulation 1; Day 2 –Simulation 2)

Activity	Time	
	Day1 -Concentration	**Day2-Beer's Law**
Students explore simulation screens	10 min	10 min
Introduction (by teacher)	10 min	10 min
Simulation Lab and completion of the lab handout	40 min	40 min

8. PROCEDURE

- The Students will work in pairs. Each group will receive a laptop computer. They will explore the controls of the simulation program for few minutes.

- Before beginning the simulation activity, teacher will review the following concepts:

1) Measurement of concentration of a solution.
2) Spectrophotometry.
3) Absorbance.
4) Transmittances.

- Then the teacher will introduce the simulation lab.

I. Concentration Tab

In this tab, students will learn about solution concentration, the factors that affect it, and what lead to saturated solutions (Chamberlain, 2012).

II. Beer's Law Tab

In this tab, students will learn that concentration, pathlength and solution type affect how much light is absorbed and transmitted. They will also learn that different solutions absorb different wavelengths of light, and that each solution has a different light wavelength for maximum absorption (Chamberlain, 2012).

- Students will follow the instructions of the student handout, and complete the activity.
- The teacher will walk around and assist students, as necessary.

STUDENT HANDOUT - BEER'S LAW SIMULATION LAB

Name________________________ Date___________

This activity was adapted from, the "Investigation of a Solution Color" by Clark and Chamberlain (2015). This program consist of two modules. We investigate each module with two separate simulation activities.

a. Module 1, Concentration = Simulation 1
b. Module 2, Beer's Law = Simulation 2

OVERALL LEARNING GOALS

- To understand how the spectrophotometer works.
- Determine relationship between colors absorbed to colors observed.
- Evaluate Beer's Law using absorbance and concentration data obtained from simulations.

SIMULATION 1: SOLUTE AMOUNT, VOLUME AND CONCNETRATION

The model

The model uses pure water as the solute. The volume of the solution is presumed to be the volume of the solvent and ignores the volume taken up by the solute.

$$\text{Concentration of the solution (Molarity, M, mol/L)} = \frac{\text{Moles of solute (mol)}}{\text{Volume (L)}}$$

Objectives

I. Determine the relationship between the solvent volume and amount of solute to the solute concertation.
II. Calculate the concentration of solution when solvent volume or the mount of solute is changed,
III. Describe a saturated solution and determine concertation of the saturated solution.
IV. Determine how the color of the solution is changed with the solute concentration.

Procedure

1. From the main simulation page Click on "Concentration" icon.
2. Explore the controls of the Concentration screen for a few minutes.
3. Click and drag the concentration meter probe into solution. Place it near the bottom.
4. Meter reading should indicate "(0.000 mol /L).
5. Use the drain faucet on lower right or the "Evaporation" slider to remove solution. Stop at 0.3L mark.
6. There are 9 solutes to choose from. In this experiment we select Potassium Permanganate.
7. Click and drag the solid solute container back and forth to add solute to the beaker. Continue adding until the concentration reaches close to 0.400 mol/L. If you add too much solute, the solution becomes saturated and solute cannot be dissolved any more.

8. Record concentration of the volume in Data Table 1 for volume 0.3 L.
9. Keeping the solute amount the same, add water by moving the slider knob of the faucet in the upper left corner of the beaker. Stop at 0.5L.
10. Record the volume (0.5 L) and the concentration reading on the meter in Data Table 1.
11. Add water to reach 1 L. Record the concentration for 1L volume.
12. Keeping the solution level at 1L, keep adding solute until the solid begin to settle on the bottom of the beaker. "Saturated" sign should appear at this stage. Record the concentration of the solution.
13. Record your observations when more solute is added to the saturated solution.

Results

Data Table 1. Relationship between Volume and Concentration when the solute amount remains constant.		
	Volume (L)	**Concentration (mol/L)**
Initial	0.3 L	
Mid-point	0.5 L	
Final	1 L	
Saturated	1 L	

1) What happens to the color and concentration reading when the volume is increased without changing the solute amount?

____

____

____

2) What happens to the color and concentration reading when the volume is decreased without changing the solute mount?

____

____

____

3) What happens when more solute is added after solution become "Saturated"? Does the concentration value change?

____

____

____

4) Use $M_1.V_1 = M_2.V_2$ equation to calculate the concentration if water is added to the solution to reach the final volume 1.5L. (M_1 = initial concentration, V_1 = initial volume, M_2 = final concentration, V_2 = final volume).

Post –Simulation 1: Evidence and Reasoning

1. Can the solute affect the color of the solution? Can the anion of the solute affect the color of the solution? Provide supporting evidence for each of your responses.

2. How does the concentration of a solution affect its appearance? Does changing the concentration change the color, or the intensity of the color?

3. A beverage company is having trouble with production. The color of their drink mix is supposed to be light red. (Consistent with a 0.80 M solution), but that is not always the case. What is wrong? Provide a plausible reason for each observation.

   I. The color intensity is too low, it's too pale.

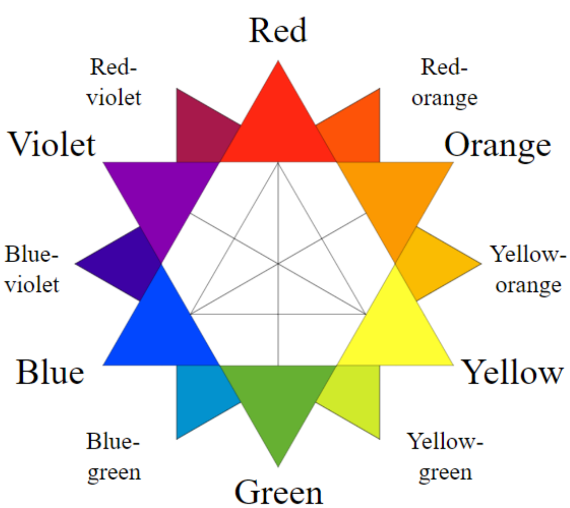
   II. The solution color is wrong! It looks blue.

   III. The solution started out with the correct color intensity, but over time, the appearance changed, becoming darker. The employees are sure nothing was added to the open vat.

SIMULATION 2 : BEER'S LAW MODULE

Introduction

The interaction between visible light and the electrons of atoms or molecules determine the color of most objects. Visible light is the region of electromagnetic spectrum that human eyes are sensitive to.
The color of most objects depends upon the interaction between visible light and the electrons of atoms or molecules that make up the object. Visible light is a small portion of the electromagnetic spectrum that human is capable of "seeing". White light is composed of light in the wavelength range 400 - 700 nanometers (nm) combined together. When colored substances absorb energy in the visible region of the spectrum, the electrons transition from lowest-energy or ground electron levels to higher-energy configurations. These transitions are responsible for majority of the colors that we see in the natural world. When white light strikes a solution, light at certain wavelengths are absorbed. The colors we see correspond to the wavelengths of light transmitted from an object. When white light pass through a solution, light at certain wavelengths are absorbed. The color of the transmitted light is visible to the eye. When a light is prominently absorbed at a particular wavelength, a complementary relationship exists between the perceived color and the color absorbed (Figure 1 and Table 1).



Source: https://upload.wikimedia.org/wikipedia/commons/5/55/Color_star-en.svg

Figure 1. Representation of relationship between colors (Color Wheel).

Table 1: Pairs of complementary colors and the corresponding wavelength ranges.

Light absorbed: Wavelength (nm)	Light absorbed: Color	Complementary (subtraction) color seen
400–435	violet	green-yellow
435–480	blue	yellow
480–490	green-blue	orange
490–500	blue-green (cyan)	red
500–560	green	purple (magenta)
560–580	yellow-green	violet
580–595	yellow	blue
595–605	orange	green-blue
605–750	red	blue-green (cyan)

Source: https://chem.libretexts.org/

A spectrophotometer is an instrument that can filter out a single wavelength of light of a known intensity into a solution (Figure 2). When white light pass through a solution, lights at certain wavelengths are absorbed. Spectrophotometer can measure the intensity of light exiting the solution. If the solution contains substances that absorbs light, the intensity of light exiting the solution will be less than what entered the solution. The amount of light absorbed at that wavelength of light is dependent on the concentration of the absorbing substance in solution. In other words, higher the concentration of the substance that absorbs light, the less light will get through. This relationship is expressed by the Beer's law.

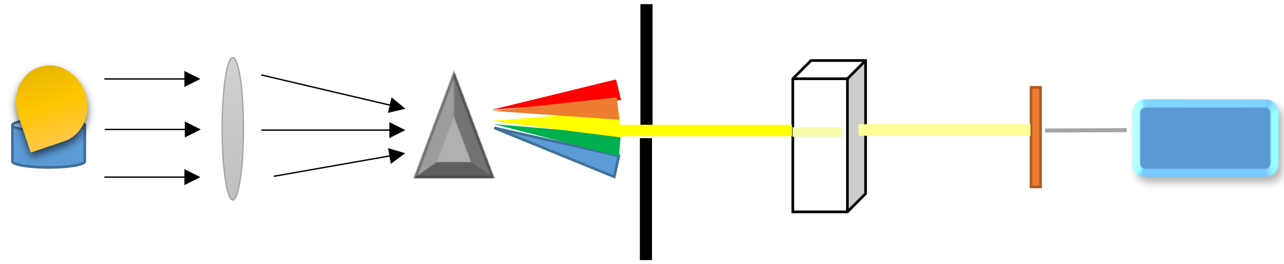


Figure 2. Basic components of a spectrophotometer
Source:
https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Kinetics/Reaction_Rates/Experimental_Determination_of_Kinetcs/Spectrophotometry

Model

The model uses experimental data on absorbance values and concentrations to calculate molar absorptivity for the simulation. Slightly different values may be obtained in an actual experiment.

The formula for the Beer's Law is represented by;

$$A = \varepsilon c l$$

Where,

A	=	absorbance (absorbance is unitless)
ε	=	the constant molar absorptivity or molar extinction coefficient (L $mol^{-1}cm^{-1}$)
c	=	concentration of the solution (mol/L)
l	=	length of the light path in cm

Objectives

1. Explain the difference between the **transmittance** and **absorbance** of light.
2. Describe the relationship between observed color and light absorbance.
3. Determine the **wavelength of maximum absorbance** ($ƛ_{max}$).
4. Describe what happens to the **absorbance** of light by a solution when the concentration of the solution is increased or decrease.
5. Describe what happens to the **transmittance** of light by a solution when the concentration of the solution is increased or decreased.
6. Determine the relationship between the **concentration and the absorbance** at maximum wavelength of absorbance ($ƛ_{max}$).
7. Determine the relationship between the **concentration and the transmittance** at $ƛ_{max}$.
8. Use the Absorbance vs. Concentration plot to determine the **molar absorptivity** and the concentration on an unknown colored solution.
9. Predict how the intensity of light absorbed/transmitted will change with changes in solution type, solution concentration, container width, or light source, and explain why.

Procedure

Explore the controls in the Beer's Law screen for a few minutes
Note: A spectrophotometer measures the amount of light absorbed by a sample in comparison to the amount emitted by the light source. In this tab, you can investigate how a UV-Vis spectrometer functions. When a solution becomes more concentrated, it looks darker (the color intensity increases). A spectrophotometer allows you to measure and quantify this phenomenon.

1. Absorbance vs Transmittance
   1.1. Explore the differences between absorbance and transmittance (online sources) and answer question 1.

2. Relationship between observed color and light absorbance.
   2.1. On the Beer's Law screen, select "**Drink Mix**" as the solution. Set wavelength to "preset". Turn on light source. Record the color of the solution, color of the light beam and the wavelength in "Data Table 2".
   2.2. Repeat above for remaining solutions and complete the data table 2.
   2.3. Compare data you've entered into Data Table 2, with Figure 1 (Color Wheel) and Table 1 of the introduction, write your answer to question # 2 (Post Simulation: Evidence Reasoning section).

Data Table 2. **Relationship of observed color to color absorbed (Complement colors).**			
Solution	Color of the solution	Color of the light beam at maximum absorbance	Wavelength at maximum absorbance
Dink Mix			
$Co(NO_3)_2$			
$CoCl_2$			
$K_2Cr_2O_7$			
K_2CrO_4			
$NiCl_2$			
$CuSO_4$			
$KMnO_4$			
$Co(NO_3)_2$			

3. Determine the **wavelength of maximum absorbance** (λ_{max}).
   3.1. Select "$KMNO_4$: Potassium Permanganate" for the solution.
   3.2. Set wavelength to "Variable". Move the slider to set wavelength to 400 nm. Drag and position the probe in path of the light beam. Record absorbance and transmittance readings displayed on the meter. Complete row 1 of the Data Table 3 with absorbance and transmittance values you obtained.
   3.3. Repeat above step for indicated 50nm increments of the wavelength settings and complete the Data Table 3.

Data Table 3. **Absorbance vs. Transmittance Data for $KMNO_4$ solution (____ µM)**		
Wavelength (nm)	Absorbance	Transmittance
400		
450		
500		
550		
600		
650		
700		
750		

4. Absorbance Vs Solution Concentration.
   4.1. Move the rule below the Cuvette and make sure that the width of the cuvette (Path Length) is 1 cm.
   4.2. Set the $KMNO_4$ concentration to 50 µM.
   4.3. Turn on the light source and move the probe into light path.
   4.4. Select Wavelength "Preset". Wavelength (λ_{max}) is indicated as 544 nm. We are measuring Absorbance for solutions of varying concentrations at λ_{max}.
   4.5. Record absorbance value at $KMNO_4$ concentration 50 µM and enter the value on Data Table 4.
   4.6. Change the concentration to 100 µM and record absorbance value on **Data Table 4**.
   4.7. Complete the table for remaining wavelengths.

Data Table 4.
$KMNO_4$ concentration (µM) Vs. "Absorbance" of light.

$KMNO_4$ concentration (µM)	Absorbance
50	
100	
200	
300	
400	
500	
600	
700	
750	

5. % Transmittance Vs Solution Concentration.
   5.1. Select the meter to collect Transmittance data.
   5.2. Repeat steps of procedure 4 above and complete **Data Table 5** for % Transmittance of light.

Data Table 5.
$KMNO_4$ concentration (µM) Vs. "% Transmittance" of light.

$KMNO_4$ concentration (µM)	Transmittance (%)
50	
100	
200	
300	
400	
500	
600	
700	
750	

<u>Data Analysis</u>

I. A plot of absorbance against the wavelength is called an absorbance spectrum. To show relationship between wavelength and absorbance; generate a scatter plot on an excel sheet with Absorbance on Y-axis and the Wavelength on X-axis.
    i. Enter data into an Excel spreadsheet in columns in the same order as they appear in the Data Table 3.
    ii. Select data from column 1 and 2 including the headings.
    iii. Click on the Scatter plot icon to generate the plot.
    iv. Determine the wavelength at maximum absorbance from the resulting graph.

II. To show relationship between wavelength and Transmittance, follow steps above (i to iii) using data from Columns 1 and 3 of the Data Table 3.

III. Absorbance Vs. Concentration -Beer's Law Plot

    i. Copy data table 4 into an Excel spreadsheet. Generate a plot with Absorbance on Y-axis against the concentration on X-axis.
    ii. Add a trend line to create a best-fit straight line to your linear data set along with the equation that correspond to the best-fit.

IV. % Transmittance Vs. Concentration

    i. Copy data table 5 into an Excel spreadsheet. Generate a plot with % Transmittance on Y-axis against the concentration on X-axis.
    ii. Compare this chart to the Absorbance Vs. Concentration chart obtained above.

Post –Simulation: Evidence and Reasoning

1) Explain the difference between the transmittance and absorbance of light.

____
____
____

2) How does the color absorbed related to observed color of the solution (Compare data from Data Table 2 to Figure 1 of the “Introduction” section to justify your answer?

____
____
____
____
____
____

3) Investigate the green light passing through the $KMnO_4$ solution and graph your results. When **$KMnO_4$** was used as the solution, light source directs **green** light through the solution.

   a. Where the green light is more intense?

   ____

   b. Where the green light is least intense?

   ____

   c. Where does the intensity of light changing?

   ____

4) Refer to Data Table 4 in which you entered Absorbance values for varying concentrations of $KMNO_4$ solution. What happens to the absorbance when the concentration is doubled?

____

5) What is the ƛmax KMnO4 solution? ________________________

6) Use the graph of Absorbance vs Concentration to obtain the slope of the line.
Note: As you have noted above, the absorbance of a sample depends on the concentration (c), light path in centimeters (l) the solute and ƛmax. The Beer's Law describes this relationship in the following equation.
$A = \varepsilon\, l\, c$
Where ε is the molar absorptivity coefficient which is unique to the solute.

a. What is the pathlength (l) used in this simulation? ________________

b. What is the slope of the graph of Absorbance vs. Concentration? __________________

c. Using the slope and the equation above, determine the molar absorptivity (ε) of KMnO4 solution.

Slope (m) = ____________ μM^{-1}

$A = \varepsilon\, l\, c$

$Y = m^*x$

$m = \varepsilon\, l$

$\varepsilon = m/l$ = ____?_________ $\mu M^{-1}/1$ cm or ($\mu M^{-1} cm^{-1}$)

However, the molar absorptivity ε is usually written with the units $M^{-1}.cm^{-1}$

$1\ M = 10^6\ \mu M$

$\varepsilon = 10^6\ \mu M.\ M^{-1}$.__?__$\mu M^{-1} cm^{-1}$.

Molar absorptivity of $KMnO_4$ solution = _________________$M^{-1}cm^{-1}$

REFERENCE:

Chamberlain, J., & Clark, T. (2015, June 23). Beer's Law Lab. Retrieved November 11, 2017, from http://phet.colorado.edu/en/simulation/beers-law-lab

Rohrig, B. (2015, October). Artificial Dyes. Retrieved November 11, 2017, from https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/2015-2016/october-2015/articial-dyes.html