Beer’s Law Discovered

**Background**
Did you know that light can be used to study solutions? Scientists such as Pierre Bouguer and Johann Heinrich Lambert studied light as it passed through solutions in the 1700’s. In the 1800’s, August Beer contributed to the theories of Bouguer and Lambert to derive the Beer-Lambert Law, better known as Beer’s Law.

In a series of demonstrations, you will discover what these scientists did when they passed light through solutions. In order to understand their conclusions, we must understand some properties of light itself.

Light, or visible light, is made up of different wavelengths of electromagnetic radiation. In the visible light spectrum, red light carries the least energy and has the longest wavelength of all colors. Violet light carries the most energy of the visible light spectrum, and has the shortest wavelength. We see color based on the wavelengths of visible light absorbed and transmitted by objects. For example, the chlorophyll in plants absorbs many wavelengths of visible light, such as red and violet. Chlorophyll does not absorb green wavelengths of light, so plants transmit it. This is why many plants appear green in color.

Solutions transmit and absorb light, as well. The absorption and transmittance of light can be measured using equipment such as a colorimeter or a spectrophotometer. The light that is able to pass through the medium is known as transmittance, and is usually expressed as a percentage. The light that is not transmitted is absorbed by the medium. Absorbance is usually expressed as a value between 0 and 1. Absorbance and transmittance are indirectly proportional; that is, as the absorbance increases, the light transmitted through the medium decreases. In this demonstration, you will observe the light being absorbed or transmitted through solutions.

**Pre-Lab Questions**

Use the formula Absorbance = -log (%Transmittance/100) to solve the following problems.

1. A solution transmits 50% of the light that passes through it. Calculate the absorbance.

2. A solution has an absorbance of 0.39. Calculate the percent transmittance.

3. Would the light passing through the solution in pre lab question 1 or the solution from pre lab question 2 appear brighter as it passes through the solution? Explain.

**Objective**
The objective of this activity is to develop an understanding of Beer’s law and the relationship between light, concentration of solution, and path length.
Materials
- A red-colored drink mix packet (such as Kool-Aid)
- A blue-colored drink mix packet (such as Kool-Aid)
- 1.0g of sugar
- water
- Electronic scale or triple-beam balance
- Weighing boats
- Scoopula
- Glass stirring rod or spoon
- 3 250-mL beakers
- A 100-mL graduated cylinder
- A red laser pointer
- 1 piece of white cardstock

Safety
- Always wear safety goggles when handling chemicals in the lab.
- Wash your hands thoroughly before leaving the lab.
- Follow teacher instructions for clean-up of your materials and disposal of any chemicals.
- Do not consume lab solutions, even if they are otherwise edible products.
- Food in the lab should be considered a chemical not for consumption.
- Use caution when using a laser pointer. Do not shine the laser in your own eyes or in anyone else’s.

Procedure for Activity 1
1. Carefully open the blue drink mix packet. Obtain a 0.1 g sample of the drink mix. Place the 0.1 g sample in to one of the 250-mL beakers. Fill the beaker with water until there is a total volume of 200 mL of solution in the beaker.
2. Obtain a 0.3 g sample of drink mix. Place this in a second beaker. Fill the second beaker with water until there is a total volume of 200 mL of solution in the beaker.
3. Fold the white cardstock in half and place it standing up on the table behind the beaker.
4. Hold the laser pointer a few inches in front of the first beaker. Shine the laser through the solution. The light should go through the solution on to the cardstock behind the beaker.
5. Repeat step 4 using the second beaker. Do not discard any solutions. They will be used in later activities.
6. Compare the light shining through the two solutions. Make observations in the data table in the space provided for demonstration 1 and answer the questions pertaining to activity 1 in the analysis section.

Procedure for Activity 2
1. Use only the solution in the second beaker from the first activity. Pour 50mL of this solution in the graduated cylinder.
2. Place the white cardstock behind the graduated cylinder. Hold the laser pointer a few inches in front of the graduated cylinder. Shine the laser through the solution so that the light goes through the solution on to the white cardstock behind it.
3. Repeat step 2 using the second beaker. Compare the light shining through the beaker and the graduated cylinder. Make observations in the data table in the space provided for demonstration 2 and answer the questions pertaining to activity
2 in the analysis section.
4. Pour the solution in the graduated cylinder back in to the second beaker.

**Procedure for Activity 3**
1. Open the red drink mix packet. Measure out a 0.3 g sample of the red drink mix. Place this sample in the third beaker. Fill this beaker with water until the total volume of the solution is 200mL.
2. Place the white cardstock behind the third beaker containing the red drink mix solution. Hold the laser pointer a few inches in front of the beaker and shine the laser through the solution on to the cardstock.
3. Place the cardstock behind the second beaker from demonstration 1. Hold the laser pointer a few inches in front of the beaker and shine the laser through the solution on to the cardstock.
4. Compare the light shining through the red solution and the blue solution. Write your observations in the data table in the space provided for demonstration 3 and answer the questions pertaining to activity 3 in the analysis section.

**Procedure for Activity 4**
1. Pour out the solutions from all of the beakers and rinse them thoroughly with water.
2. In one of the beakers, place a 0.1 g sample of sugar. Fill this beaker with water until the volume of solution reaches 200 mL.
3. In a second beaker, place a 0.3 g sample of sugar. Fill this beaker with water until the volume of solution reaches 200 mL.
4. Place the cardstock behind the first beaker. Holding the laser pointer a few inches from the beaker, shine the light through the solution on the cardstock.
5. Repeat step 4 with the second beaker.
6. Compare the light shining through the beakers. Record your observations in the data table in the space provided for demonstration 4. Answer the analysis questions pertaining to activity 4.
7. Clean up your area and return all materials according to your instructor’s directions.

**Data**

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<tr>
<th>Activity</th>
<th>Observations</th>
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Analysis

Activity 1
1. Can you tell which solution is more concentrated just by looking at them? How?

2. Which solution transmitted more light, the more concentrated solution or the less concentrated solution?

3. Which solution absorbed more light, the more concentrated solution or the less concentrated solution?

4. What is the relationship between concentration of solution and absorbance of light?

Activity 2
1. “Path length” is the distance through which the light travels through a medium. Which container had a longer path length?

2. What is the effect of shortening the path length on the absorbance of light?

3. Why might changing the path length affect the absorbance and transmittance of light?

Activity 3
1. Which solution transmitted more of the light?

2. Which solution absorbed more of the light?

3. Why would one solution absorb more light than the other when they both had the same concentration? Explain.

4. When measuring absorption, would you want the light shining through the solution to be the same color as the solution? Why or why not?

Activity 4
1. Was there an observable difference in the transmittance of light through the solutions?
2. Can light be used to measure the concentration of a colorless solution? Why or why not?

**Conclusion**
What is the relationship between the absorbance of light through a solution and the concentration of the solution? How does path length affect this relationship?

**Post Lab Questions**
The Beer-Lambert equation is written $A = abc$, where $A$ represents absorbance, $a$ represents the molar absorptivity constant of a compound, $b$ represents path length in centimeters, and $c$ represents the concentration of a solution (molarity).

1. The molar absorptivity constant of copper (II) sulfate is $2.81 \, \text{M}^{-1}\text{cm}^{-1}$. What is the absorbance of a 0.15M solution of copper (II) sulfate in a 1.0cm container?

2. Predict whether the absorbance of a 0.25M solution of copper (II) sulfate would be higher or lower than the absorbance calculated in post lab question 1 without doing any math. Explain your answer.

3. Copper (II) sulfate is a bluish color. If you could choose between a red wavelength or a blue wavelength of light to measure the absorbance of the solution, which would you choose and why?