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The BEER-LAMBERT LAW

Learning Objectives

Students should be able to:

Content

- Identify each term in the Beer-Lambert law and explain its effect on absorbance.
- Explain the relationship between transmittance and absorbance.

Process

- Prepare and interpret graphs (information processing)
- Develop mathematical expressions to describe data (problem solving).

Prior Knowledge

- Calibration curves and linear equations

Further Reading

- D.C. Harris, *Quantitative Chemical Analysis*, 7th Edition, 2007 WH Freeman: USA, Section 18-2, p. 380.

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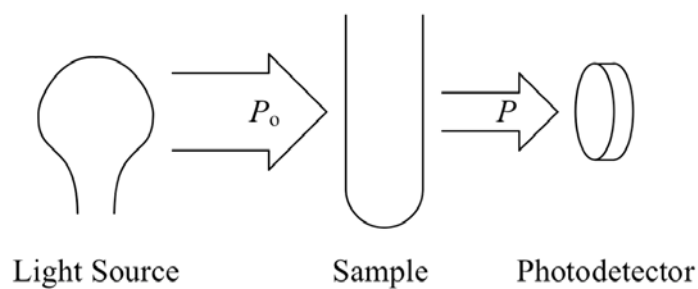
David Langhus

The BEER-LAMBERT LAW

Consider This . . .

Suppose that we have a solution that absorbs light.

Suppose further that we propose to analyze the solution using an instrument organized as shown below:



The light source might be an ordinary light bulb, a flashlight, or the sun. The photodetector could be a simple solar cell like one might buy at Radio Shack. The light shining on the sample has power P_o and the light that manages to get through the sample has power P . P_o and P may be expressed in Lamberts or lumens or ergs/sec/cm² or any other units, as long as they match.

The ratio P/P_o is known as transmittance, represented as T .

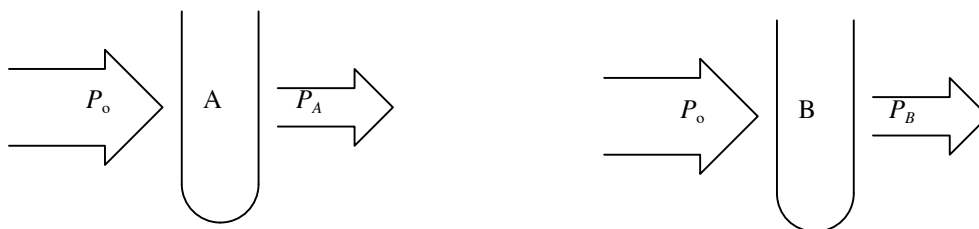
Percent transmittance, or % T , is simply 100 T .

Key Questions

1. Using the information above, write mathematical equations relating transmittance to P .
2. If some of the light is absorbed by the sample....
is P greater than, less than or equal to P_o ? Justify your answer to your group members.

is T greater than or less than 1? Justify your answer to your group members.

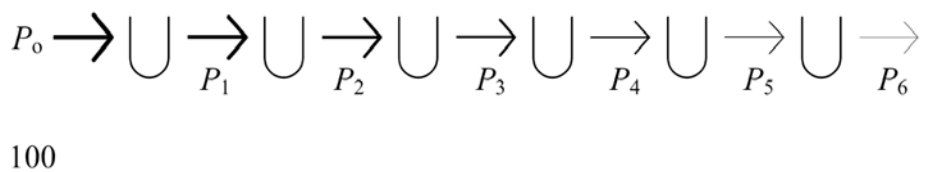
3. Absorbance indicates how much light is absorbed by a sample. If sample A (below) absorbs more light than sample B, which would be smaller, P_A or P_B ?



4. For samples A and B in question 3, which would have the higher transmittance? Which would have the higher absorbance? Explain your reasoning.
5. Discuss with your group members what happens to transmittance if absorbance increases or decreases. In complete sentences explain why transmittance and absorption are related in this way.

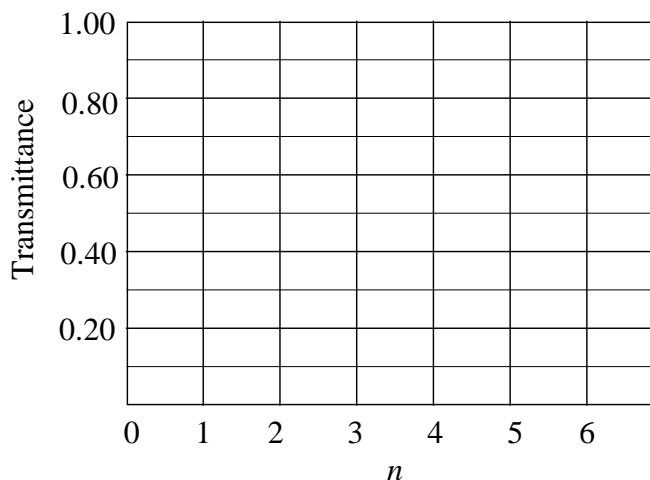
Consider This . . .

Suppose that we have multiple identical samples (in containers that do not absorb light) of a light-absorbing solution and we set them up in a line, shining P_0 down the line from one end:

**Key Questions**

- If 50% of the light is transmitted through each sample and the initial power, P_0 , is 100 arbitrary units, calculate values for P_1 through P_6 and fill in the blanks in the figure with these values. Compare your values with your group members.
- Using your equation for transmittance, each group member should calculate the total transmittance value for two different n values. Share your answers and graph the T values vs. n :

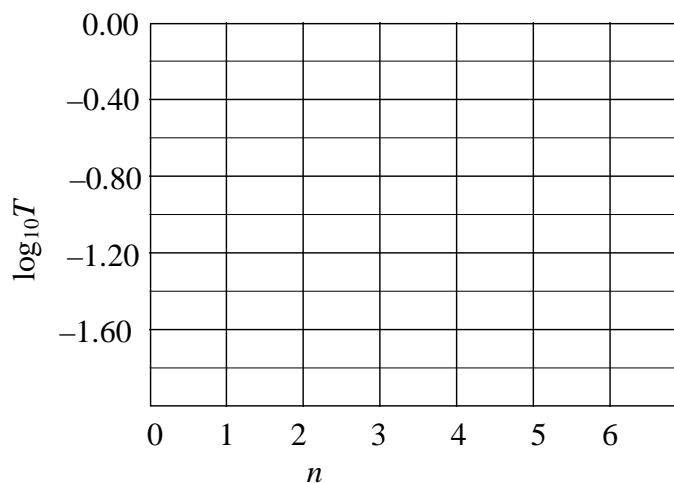
n	T
0	1.00
1	
2	
3	
4	
5	
6	



- Does the transmittance increase or decrease as n increases? Is the relationship between the transmittance and the number of samples the light has gone through linear?

9. Repeat the exercise above but this time plot $\log_{10}T$ vs. n .

n	$\text{Log}_{10}T$
1	
2	
3	
4	
5	
6	



Does $\log_{10}T$ appear to vary linearly with n ?

10. What sign does the slope of the $\log_{10}T$ vs. n plot have?

11. Compose a mathematical expression for $\log_{10}T$ as a function of n . Just use m to represent the slope of the line. You don't have to provide a value for m at this point.

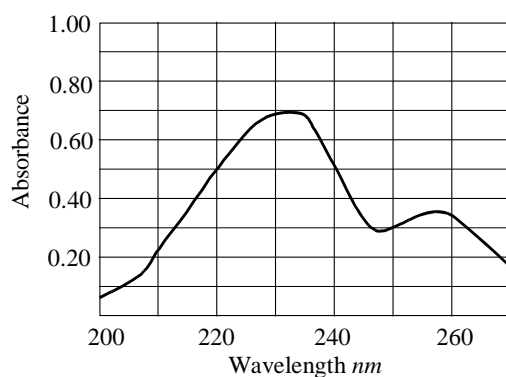
12. Suppose that each individual sample in the line of samples above is a slice of a mega-sample. In other words, one large container with 6 slices of solution put together. Describe the relationship between distance the light travels through the sample and $\log_{10}T$. Using b to represent the distance the light travels, modify your expression in 11 to take this into account.

13. Now think of the line of samples another way. Suppose each of the original 6 sample containers had a single absorbing molecule present. Discuss with your group the relationship between $\log_{10} T$ and the number of absorbing molecules.

14. How does the number of absorbing molecules relate to the concentration of the solution? Modify your relationship in question 12 to include the concentration (c) of the molecules in solution.

Consider This...

A spectrophotometer is an instrument that can measure the absorbance of a sample at different wavelengths of light. A graph of the absorbance of a sample as a function of wavelength obtained from such an instrument is called a spectrum. The spectrum shown below is for a particular concentration of solution of a compound using a 1.000 cm wide sample vial.

**Key Questions**

15. For this analysis what terms in your relationship of question 14 are held constant?
16. What is the absorbance of this compound at 233 nm and 257 nm under these conditions?
17. What term in your relationship from question 14 must be wavelength-dependent in order for this relationship to apply?
18. Read the description of the analysis carefully. With your group discuss other variations that would change the absorption values and therefore the value of the constant.

Consider This . . .

The absorbance, A , of a solution is related to the distance through which light travels in a sample and the concentration of the sample by means of the Beer-Lambert Law or simply Beer's Law:

$$A = abc$$

a = absorptivity, a constant that depends on wavelength and the absorbing species.

b = path length, distance through the sample.

c = concentration of absorbing species in the sample

Key Questions

19. Draw a sketch of what you think a plot of A vs. c should look like if a and b are held constant. Will it be linear?

20. What value should the slope and y-intercept of the plot have? Explain your reasoning.

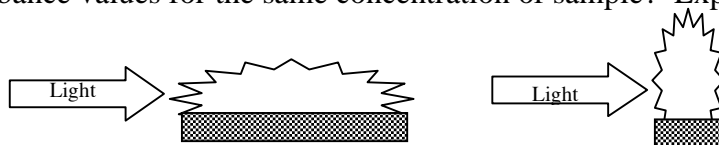
Discuss with your group the relationship between Beer's Law and your expressions in 11 – 14. When you think you know how they relate, answer the following:

21. In question 12, you identified the relationship between $\log_{10}T$ and b , the distance through which light travels in the sample. Is the relationship between A and b predicted by Beer's Law consistent with your determination? If so, how are they similar? If not, how do they differ?

22. Is the relationship predicted by Beer's Law between A and c consistent with that which you obtained between $\log_{10}T$ and c ? If so, how are they similar? If not, how do they differ?
23. Discuss with your group how the absorbance should be defined in terms of transmittance. After everyone has agreed, write a mathematical statement that shows the relationship between absorbance, A , and transmittance, T .
24. Based on your understanding of Beer's Law and in consultation with your group, summarize in complete sentences the relationships between concentration, pathlength, absorptivity and absorbance. What other variables must be kept constant in order for Beer's Law to apply?
25. What are two things you learned about Beer's Law during this activity?
26. In what ways did this activity enhance your ability to write mathematical expressions to describe relationships?

Applications

27. What is the value of absorbance that corresponds to 35.0 %T?
28. Molar absorptivity is the absorptivity when concentration is in units of molarity and the pathlength is in centimeters. If a 1.53×10^{-5} M solution has an absorbance of 0.426 in a 1.00 cm cell when measured at a wavelength of 254 nm, what is the molar absorptivity of the compound?
29. A solution suspected of containing copper is analyzed. To determine the standard curve, the absorbance of five standards ranging from 0.125 mg/ml Cu to 1.25 mg/ml Cu was measured and graphed against the concentration. The slope of the linear best fit line was determined to be 0.6136 and the y-intercept was 0.0142. If three samples of the unknown solution have absorbance values of 0.438, 0.434, and 0.439 what is the concentration of the unknown?
30. A spectrophotometer will often produce values of both Absorbance and % Transmittance. Which would be the easiest for you to use to determine the concentration of a compound in solution? Explain.
31. Suppose that in measuring a sample of iron using an absorption spectrophotometer, you find that the absorbance is too high for the instrument to measure accurately. Based on Beer's Law, what are two options you might employ to lower the absorbance value?
32. In an Atomic Absorption (AA) instrument a flame is the sample holder. In the configurations below would the short, wide flame or the tall narrow flame give the highest absorbance values for the same concentration of sample? Explain why.



33. Beer's Law has some limitations. It works well for monochromatic radiation, dilute solutions, and when the absorbing compounds are not participating in a concentration - dependent equilibrium. Plot the following data using Excel and determine the highest concentration in which Beer's Law applies.

Conc (mg/L)	Absorbance
1.00	0.0334
5.00	0.1635
10.00	0.3284
15.00	0.4965
20.00	0.6026
30.00	0.7781
50.00	0.8652