How Do We See Colors? -- Lab #2

How is Light Absorbed?

Task #0 - Important Information

Just as in the Physics 141 lab course, graphical representations of your data will be very important in Physics 142. Your instructor will pass out a handout at the beginning of this lab to remind you how to create a graphical model of your experimental data. Because this handout is very important and you may want to refer to it throughout the semester, we strongly recommend that you tape it into your logbook. That way you will always have it available during lab this semester.

Task #1 - Getting Started

Your lab instructor will show you a light source as it looks when its light passes through different colored plastic sheets. Describe how the plastic sheets change the way the light appears to your eyes.

Task #2 - Setting up the Equipment

Today you will be studying how light is absorbed by colored plastic sheets and you will attempt to develop mathematical models that describe this absorption process. Before you begin your study, prepare the equipment and software by completing the following procedures.

a) Check that you have a light sensor attached to the interface box.

b) Start up the interface and computer at your station. Make a note of which computer you are using in your logbook. You should have also recorded other basic information such as the name of your lab partners. Once the computer has started up, open the folder "Physics 142 – Fall 2000" and start the file named "Lab #2 MBL– absorption".

c) At your lab station you should also find a light source attached to a power supply. This power supply sends out a constant voltage to the light, which will reduce the "noise" in your data that you may have noticed in the data you collected last week. To further reduce noise, make sure that the overhead lights are turned off. However, the window blinds should be open to let in a little light as you work. (Why do you think this light doesn't create "noise" in the data?)

Collect some data and test that the light sensor is working. For example, cover the detector with your hand, turn on a light, etc., and record the corresponding values.

1. Do these values make sense based on the light entering the detector? Why or why not?

Task #3 - How can you describe the absorption of light by a filter of a certain color?

Equipment: Light source, DC power supply, MBL set up, Light sensor, Envelope of colored (red, yellow, or blue) filters, Linear graph paper, Semi-log graph paper, *Excel* software, Meter stick, Masking tape.

Data Collection

Obtain an envelope of colored filters from your instructor (red, yellow, or blue). Open it up and take out the filters. Record a brief description of the filters you will be investigating in your logbook.

Turn on the light source. Hold one of the filters in front of the light sensor between the sensor and the light source. Adjust the position of the light sensor so that the intensity measurement has a value of about 95%. Make a note of this intensity reading for $n = 1$ (where n = the number of filters).

Measure and record the distance of the light sensor from the light's filament and keep this distance fixed during the following experiment.

2. Why do you think it's important to keep the distance between the sensor and light source constant?

Add a second filter and then take a new intensity reading. Continue to stack layers of these colored filters between the detector and the light source, adding one filter at a time. Record the light intensity reading for each number of filters. Add filters one by one in order to collect data from the initial scale reading (~95%) to less than $1/10^{th}$ of the initial value (that is, less than about 10%). Use a maximum of 20 filters. Record your data in a table.

3. Do you think you could ever obtain a value of 0% if you kept adding more and more filters? Explain why or why not.

Data Analysis

Begin the analysis by creating a graphical model of your data for n=1 to $n=n_{Maximum}$. Follow the Guidelines for Creating a Graphical Model and graph your *Intensity* vs. *Number of Filters* data on the linear graph paper. Tape your completed graph into your logbook.

4. In words, describe the relationship between light intensity and number of filters as shown by your graphical model.

To further understand your data, try graphing it on the semi-log graph paper as well. Your lab instructor can assist you in choosing an appropriate scale if you are unfamiliar with this kind of graph paper. Tape your completed graph into your logbook.

5. In words, describe the shape of the relationship between light intensity and number of filters as shown by this graph. Is this different than your answer to question #4? Describe any differences.

6. Using your graphical model of your data, estimate how many filters it takes to cut the light intensity by 1/2. Do this for three different values (say from 80% → 40%, 60% → 30%, and 50% → 25%). Can you draw any conclusions from these numbers?

It turns out that linear functions are not the only common form of data from real-world phenomena. Many sets of data are found to follow exponential trends.

Properties of Exponential Functions:

A function *y(x)* is exponential if the rate of change of the y variable at any given point is proportional to the amount of y that exists at that same point,

$$\frac{\Delta y}{\Delta x} \propto y .$$

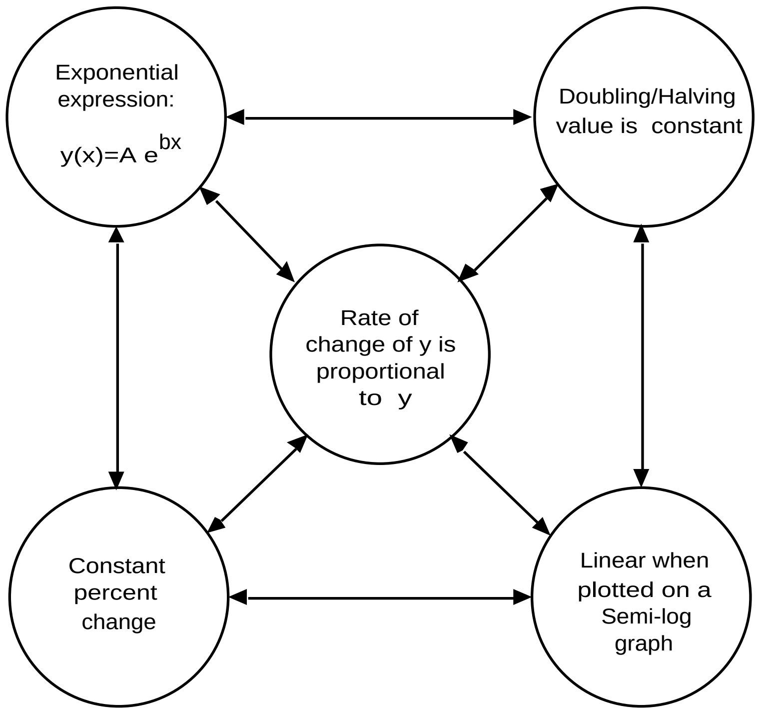
This implies that

(a) The change in x needed for y to change by a factor of 2 (either to double or to decrease by a half) is a constant.

(b) The percent change in y at each increment of x is constant.

(c) The data will be linear when plotted on a semi-log graph.

(d) The data can be represented mathematically with an expression of the following form: $y(x) = A\,e^{bx}$.



If any of these traits are true of a data set, then you know that the other statements are also true.

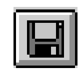
There are many exponential relationships in nature. Therefore, the ability to recognize this common pattern is very useful. The diagram above shows us how to recognize exponential data in several ways.

7. Based on the provided definition, do you think your data are exponential? Why or why not? Try to give at least two reasons.

Data Analysis Using *Excel*

We could continue to work with this data by hand, but it turns out that there is an easier way. There are computer spreadsheet programs such as *Excel* that have been designed to assist in the analysis of data. You will use the following steps to learn to use this program on the lab computers.

- Make sure that you are no longer collecting data with the *ScienceWorkshop* program.
- Start the *Excel* file named "Lab #2 Excel– absorption".
- Enter your data into the two columns: *# of filters* and *Intensity*. You can enter data by clicking on a cell once with the mouse and then typing the appropriate number.
- Once your data has been entered, you should save the file by clicking on the save button. Be sure to give the file a unique name and record this name in your logbook. You should save your work often to keep from losing any information if you have computer problems!!

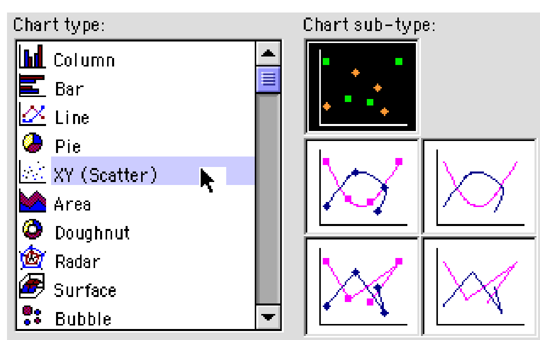


Now that your data is in *Excel*, you are ready to continue your analysis.

First of all, you should take into account that your data does not reach an intensity of 0%. This is a problem because we are looking for a relationship of the form $y(x) = A e^{bx}$ and not of the form $y(x) = A e^{bx} + b$. To correct for this, estimate the intensity reading if you used something like 20 to 30 of the filters (this should be a fairly small number). Now subtract this value from each of your intensity values and record the answer in the column called *Corrected Intensity*.

Example of putting a calculation into *Excel*:

Next you can have *Excel* create a graph for you by using the following steps.



- Click once on the *Chart Wizard* button. 
- Step 1 – Select *XY Scatter* for the *Chart Type.*
- Step 2 – Click on the *Series* window.

  Enter a *Name* for your data (e.g., red filter).

  Click on the *X values* box and then highlight the number-of-filters data.

  Click on the *Y values* box and then highlight the corrected intensity data.
- Step 3 – Enter a *Title* for your graph and the name and units of each axis.
- Step 4 – Place chart as object in Sheet 1. Then click on *Finish.*

Your instructor can assist you with completing these tasks if you have problems.

8. Compare the graph created by *Excel* to the one you created by hand. Does the trend look the same?

You can turn your *Excel* graph into a semi-log graph as well. Simply select the Y axis scale by clicking once with the mouse on the Y-scale numbers. Go to the "Format" menu and select format "Selected Axis…". Look at the "Scale" options and select 

9. Compare this new graph created by *Excel* to the one you created by hand. Does the trend look the same?

Excel is also able to fit your data with an exponential mathematical model. You can try this kind of fit by using the following steps:

- Select the data by clicking once on one of the data points.
- Select “Add Trendline…” from the “Chart” menu.
- Select “Exponential” from the “Type” window.
- Select “Display equation on chart” from the “Options” window.
- Select “Display r-squared value on chart” from the “Options” window.
- Select “ok”.

Adjust your graph as necessary so you can see the data, trend line, and equation of the mathematical model. Prepare to print a copy of the graph. Select “Print…” from the “File” menu. Choose “*Microsoft Excel*” under the pull-down menu marked “*General*.” Verify that the option “Print Selected Chart” has been selected. Press the 

button.

You should now have printed one copy of the graph. If it worked, then print another copy for the remaining members of the group. If it did not work, then ask you instructor for assistance before trying to print again. Tape the printed graph in your logbook.

10. Rewrite the equation to include the appropriate variables (I, n) and units. Describe in words the quality of the fit for the trendline. Hint, a very good fit will give an R^2 value of almost 1.000. Does this evidence seem to support classifying your data as exponential?

Scientists often refer to the optical density of a sample. This quantity is defined as:

$$\text{Optical Density} = \log_{10}\frac{I_0}{I}$$

where I_0 is the initial light intensity before one (more) filter is added and I is the intensity after one (more) filter is added.

Using the ability of *Excel* to make calculations, calculate the optical density of your colored filter from your data. You should make a calculation for each time that you added a single filter.

Hint! Each time you added a single filter, you had a new value of I_0.

Hint! You will want to use an *Excel* formula of the form: =log(C7 / C8)

Record the individual values for the optical density as well as an average value in your logbook

11. From your data, what would you say is the best value of the optical density of this filter color and why do you think is best?

Task#4 - How does the absorption of light change if the color of the filters is changed?

You should now repeat your experiment and analysis with a new filter color. You do not need to graph this data by hand, but can put it into *Excel* right away after you have collected your data set. Create a semi-log graph of this new data set in *Excel* and have the software create a graphical and functional model of the data.

Print out a copy of this graph and equation and tape it into your logbook.

12. Compare the data and mathematical models for the two different colored filters. How are they alike and how are they different?

13. Estimate the Optical Density of this new filter color and report an average value. How does this value compare to the optical density of the previous filter color?

Concluding Questions

On one of the white boards in the room, record the following information for each filter color you investigated:

- color
- your mathematical model of the absorption of light by this filter color
- your best estimate of the optical density of this filter color

Make a note of the colors and information obtained by all other groups. Consider all of this information in answering the following questions.

14. Consider the equation, $I(n) = A\,e^{\mu n}$. What is the physical meaning of the variable *A*? What do you think the physical meaning of the variable μ is?

15. How did the value of *A* change for the different experiments? Is that change meaningful? Why or why not? How did the value of μ change for the different experiments? Is that change meaningful? Why or why not?

16. Which color of filter seems to be the most efficient absorber of white light? How do you know? Which color seems to be the least efficient? Explain.

17. In words, describe the significance of the optical density of a color filter. Explain your reasoning.

Don't forget your concluding questions…

If you were to repeat this experiment, what could you do differently to improve your results? (*Accuracy statement*)

What did all of this mean? (*Implications statement*)