Light and Color 2: Absorption and Reflection of Light

Goal

- To develop a deeper understanding between the nature of light and color
- To explore the differences between additive and subtractive color
- To learn the relationship between the absorption spectrum of material and its color.

Background.

Absorption Spectrum of Molecules. One of the most obvious properties of any substance is its color. The understanding and use of color is, of course, central to viewing and producing art. The blue color of jeans and the prized Adire cloth of the West African Yoruba people comes from indigo, a specific organic compound. The color our eyes perceive depends on the relative intensities of the wavelengths of light absorbed by an object and those reflected by it. In an example from the plant kingdom, the chlorophyll of a spring leaf appears green to us because this molecule absorbs in the blue (435 nm) and red (660 nm) regions of the spectrum. The light reflected to our eyes centers around 550 nm, corresponding to green light. The relative intensities of these wavelengths in the light source (sunlight, balanced fluorescent bulbs, halogen lamps) shining on the leaves will alter the color perceived by the observer. The complementary nature of absorption of some wavelengths by a colored solution or filter and transmission of others will be explored in this part of the lab using a spectrophotometer, a *devise for giving quantitative measures of color.* A schematic diagram of a spectrophotometer is shown in Figure 1.

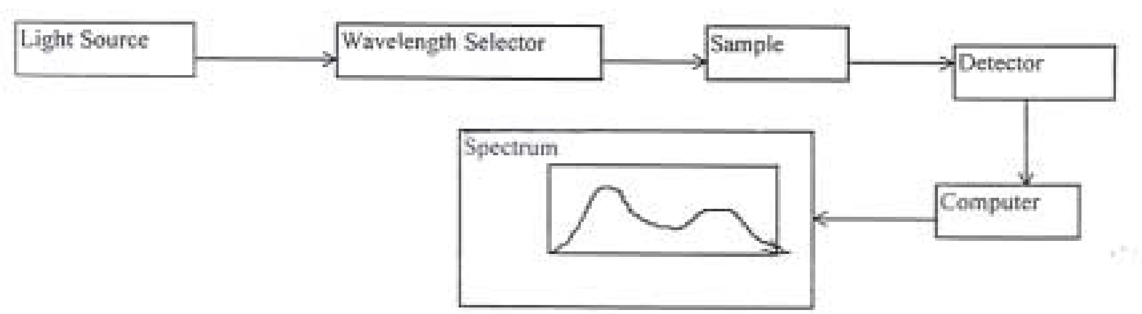

Figure 1. Components of a simple spectrophotometer. The spectrum shown was recorded as absorbance (defined below) as a function of wavelength.

The energy level diagram of a molecule differs from that of an atom in that it has many different energy levels. Consequently, instead of the sharp lines observed in the gas phase emission spectra of atoms (seen last week), the spectrum of light transmitted by a solution colored green by chlorophyll or another green dye, is much broader. Figures 2-5 illustrate the data obtained using a spectrophotometer such as the one you will be using in this experiment.

Figure 2 shows the relative intensity of the tungsten light source as function of visible wavelength. White light is precisely defined as light in which the intensity is constant throughout the visible spectrum. By this definition, does a tungsten light bulb generate white light?

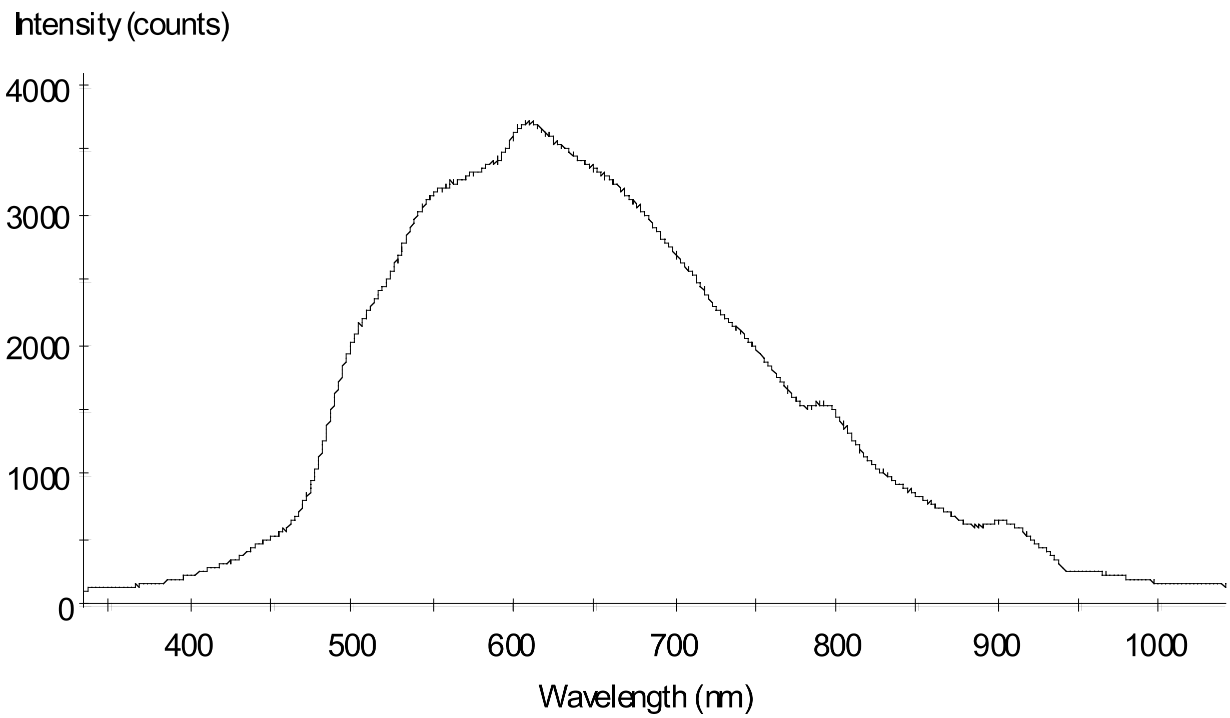

Figure 2. Intensity of Tungsten Light Source (arbitrary units) as a function of visible wavelength.

Figure 3 (next page) shows the intensity of this same light source as a function of wavelength in which a solution of a green dye was placed between the slit and the diffraction grating. The wavelengths at which this solution absorbs light are characteristics of the dye, just as the line spectra of a metal atom provide a signature for it. Note that little light with wavelengths between 600 and 650 nm passes through the solution. This minimum arises because of the absorption of light by the green dye of these particular wavelengths.

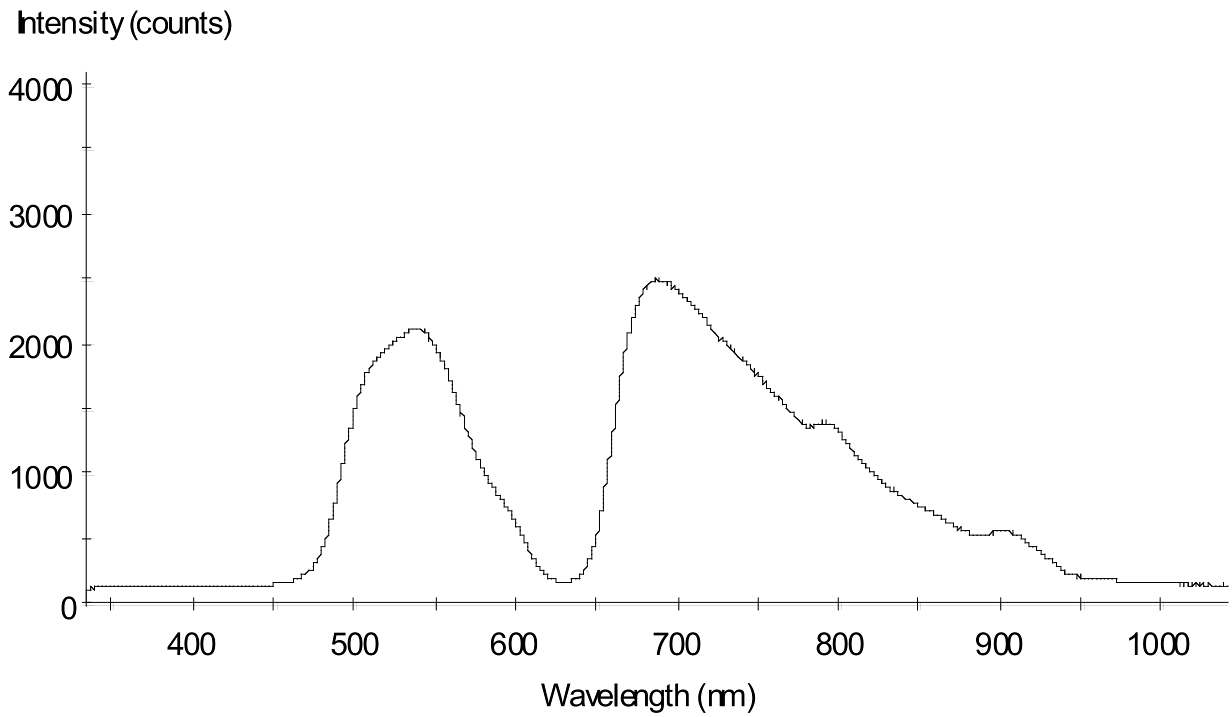

Figure 3. Intensity of Tungsten Light Source (arbitrary units) as a function of visible wavelength with green dye solution between light and detector.

Spectra are conventionally generated and presented in one of two different formats to eliminate the variation in intensity of the light source (i.e., the tungsten bulb of Figure 2) with wavelength: Transmittance (Figure 4) or absorbance (Figure 5) as a function of wavelength.

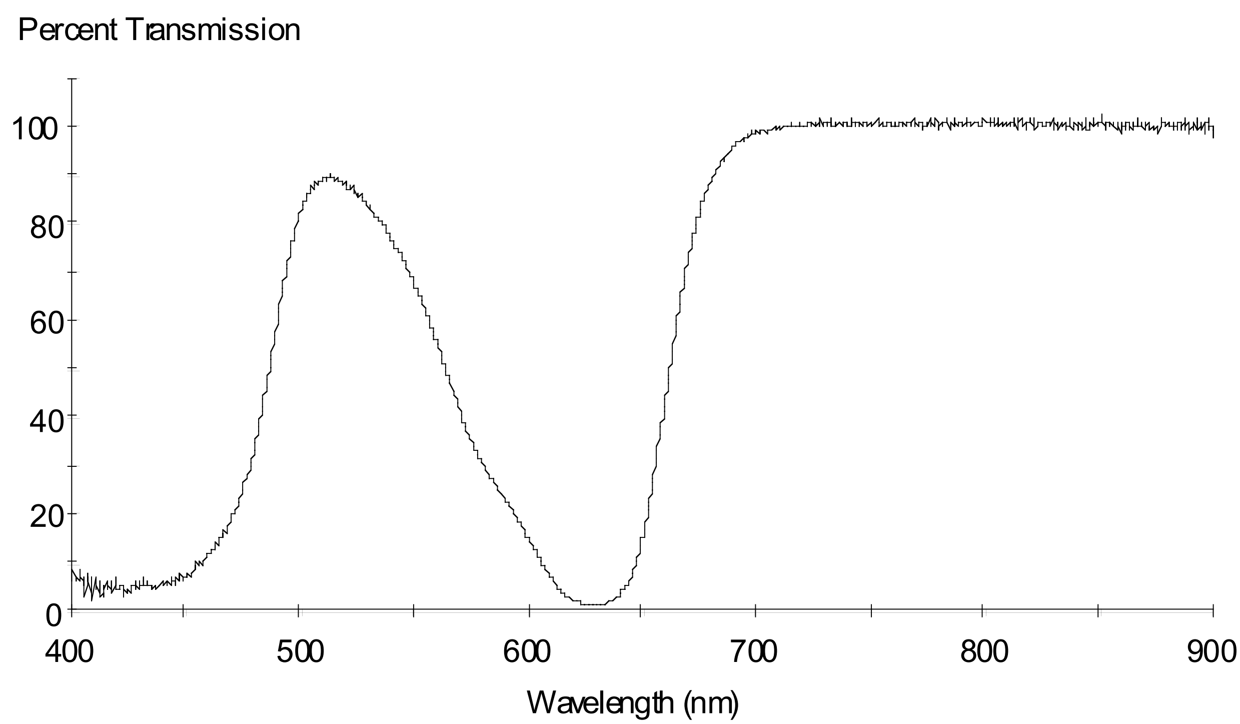

Figure 4. Transmittance (%) Spectrum of green dye solution from 400-900 nm.

Transmittance scale, % transmittance vs wavelength. In this case, the vertical scale, the y-direction, is expressed as the relative intensity of the light going through the colored solution, I, relative to its intensity passing through the solvent, I_0. Transmittance is given the symbol T.

$$T = \text{Transmittance} = I/I_0 \qquad (1)$$

$$\%\,T = 100\, I/I_0 \qquad (2)$$

Note the similarity of the transmittance spectrum of the green dye solution in Figure 4 with that in Figure 3; in this case the solvent for the dye was water. In this representation, one can readily see that the dye interacts with light with a wavelength of 630 nm (a minimum in Figure 4).

Absorbance scale, absorbance vs wavelength. The absorbance, given the symbol A, is mathematically related to the transmittance (and, for the spectrophotometers to be used here, automatically determined) as follows:

$$A = -\log(T) = 2 - \log(\%T) \qquad (3)$$

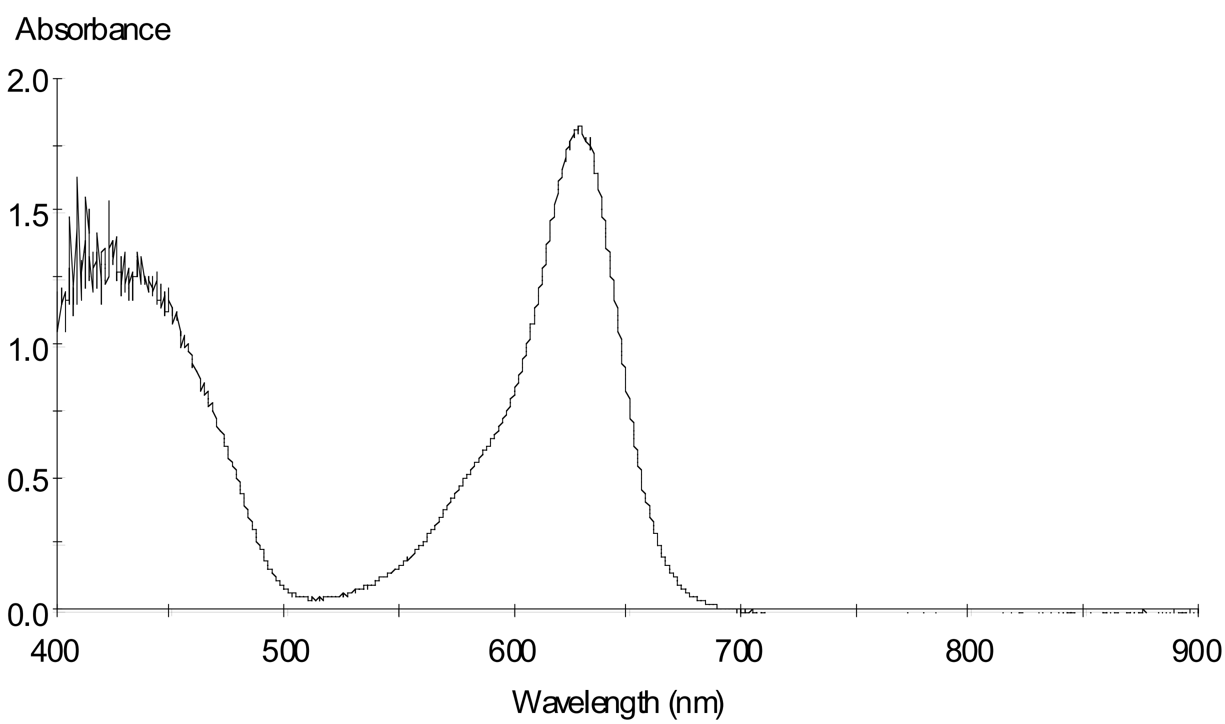

Figure 5. Absorbance Spectrum of green dye solution from 400-900 nm.

Note that a solution that absorbs no more light than water will have 100% transmittance, % T = 100, and an absorbance of 0, A = 0. Conversely a solution that absorbs 90% of the incident or allows only 10% of the light to pass has 10% T and an absorbance of 1.00. (You may want to check the values yourself.)

Figure 5 contains the absorbance spectrum of the green dye solution. Comparison of Figures 4 and 5 shows the reciprocal relationship between transmittance and absorbance. The minimum transmittance for this solution around 630 nm (Figure 4) corresponds to a maximum in the absorbance (Figure 5) at the same wavelength. In analyzing the data obtained in this experiment, you will hopefully develop an understanding the utility of the absorbance scale for presenting spectral data. In addition, students will complete experiments to develop further their understanding of additive and subtractive color.

Experimental

A. Obtaining spectra using an Ocean Optics Spectrometer. The instructor and lab assistant will assist students in collecting spectra with this instrument. General procedures, taken directly from the Ocean Optics manual, are attached for reference purposes. The spectra to be collected are as follows:
   1. Output of tungsten light source (similar to Figure 2.)
   2. The spectra of at least two different color filters as intensity, transmittance, and absorbance versus wavelength (similar to Figure 3,4, and 5, respectively.) The purpose of these exercises is to relate the color observed to the spectra in the three modes.
   3. Copies of these spectra should be printed.

B. Obtaining spectra using the Hewlett-Packard Diode Array Spectrophotometer. The instructor and lab assistant will assist students in collecting spectra with this instrument. A short set of directions is attached for reference purposes. Prepare four solutions of at least one of the Durkee food dyes as follows:

> Squeeze one drop of Durkee's food dye into a 250 ml beaker. Carefully add 200 ml (graduated cylinder) of distilled water to it and mix thoroughly. Make three additional solutions using 2, 3, and 4 drops of food dye, respectively, with the same volume of water.

Collect the visible absorption spectrum of all 4 solutions. Record (an/or mark) the wavelength and numerical value of the maximum absorbance in the visible region of the spectrum. The purpose of this exercise is to see how the absorbance changes with the concentration of the solution. Make sure you record your observations of the solutions themselves. Copies of the spectra obtained should be printed.

C. Additive and subtractive mixing. Slide projectors fitted with various filters will be available for this experiment.

1. Using a spectroscope, evaluate the color of light obtained using the various combinations of the red (R), green (G), and blue (B) filters: R + G, G + B, R + B, and R + G + B.

2. What is the result of adding yellow light and blue light? In painting, when yellow and blue paints are mixed, they give green. The light observed is that reflected from the paint, a subtractive effect. Compare this mixing of paint with mixing of the same colors of light.

3. Try other combinations of filters to make sure you understand the difference between additive and subtractive colors.

4. Provide a single question to be presented to the class (i.e., what would a lemon look like in blue light?) for a discussion of additive and subtractive color.

D. Two other optional experiments will be available for student exploration of chemistry and color.

Analysis of data and discussion of results.

1. <u>Ocean Optics Data.</u> Use the spectral data obtained to compare the interaction of light with filters of two different colors. Your discussion should include a comparison of transmittance and absorbance representations of visible absorption spectra.

2. <u>Absorbance Data obtained with HP Diode Array spectrophotometer</u>. Compile your data in a table such as the following one:

Number of drops of dye/200 ml of water	Appearance of Solution	Absorbance, λ_{max}
1		
2		
3		
4		

a. Examine your data to determine the relationship between absorbance and concentration.
b. Suggest a relationship between your results and the appearance of a multi-layered painting.
c. From your spectral data, do you conclude that the dyes are "pure" colors or mixtures? Why?

3. <u>Additive and subtractive color</u>. Discuss your question and its answer.