COLOR

OBJECTIVES:

1) Use the prism spectrometer to disperse white light into a continuous spectrum of color and tabulate the wavelengths of various colors which you can identify.
2) Observe the transmission properties of the three additive- primary color filters and the three subtractive-primary color filters.
3) Observe and interpret the color sensations resulting from mixing additive-primary colors and mixing subtractive-primary colors.
4) Be able to explain qualitatively the difference between additive and subtractive color mixing.

INTRODUCTION

White light is composed of light of all wavelengths in the visible range. Our color vision comes from the fact that we have three different kinds of color receptors (cones) in our retina. One kind of cones is sensitive to red; another is sensitive to green; and the third to blue. These three colors are called the primary colors. If our cones were sensitive to a different set of colors, those colors would have been our primary colors. All receptors are sensitive to a range of colors, e.g. "blue" to violet, indigo, and blue. What color we see is dependent on how much the cones are stimulated with respect to each other. For example, when green and red cones are simultaneously stimulated, we can see orange or yellow, depending on how much more intense the red is with respect to the green. By mixing three primary colors with different intensities, we can generate all possible colors.

In order for us to see anything at all, the light has to enter our eyes. The light can come directly from the light source, or it can be reflected from an object. The red light at a traffic signal is red because the light source is red. On the other hand, the red stop sign is red because it reflects red, and absorbs everything else.

There are two kinds of color mixing: additive and subtractive. In the case of additive coloring, we are adding with colors from more than one light emitter. For example, mixing a red light with a green light with equal intensity will result in yellow light. Additive color mixing is used to form color images on the screen of a color television. The screen has an array of dots, arranged in clusters of three. The three electron guns in the tube, representing the three additive colors, each stimulate a different dot in the cluster. By stimulating selected dots at the proper intensity, one can generate various colors on the face of the screen. The dots are so close together that they appear superimposed to our eyes. We see white when all three additive primaries are present.

Subtractive coloring deals with colors being selectively subtracted from a single light source. The source is most often white light, which contains all colors. If some colors are selectively absorbed (subtracted) the remaining light will be colored. This happens in one of two ways.

The first kind of subtractive coloring is to view light transmitted through a filter. This filtering is always a *subtractive* process. Filters are (somewhat confusingly) labeled as additive-primary color filters if the light transmitted is one of the additive- primary colors--red, green or blue. Filters are subtractive-primary color filters if the filter transmits light that is one of the subtractive primary colors - yellow, magenta or cyan.

The second subtractive method is viewing reflected light. Here light (usually white) strikes an object (pigment, paint, or dye) which selectively absorbs some color. The remaining colors are reflected (rather than transmitted as for filters). Most color we see every day is of this type of subtractive coloring. For example, yellow paint reflects both red and green, and absorbs blue. Magenta paint reflects both red and blue, and absorbs green. If you mix yellow paint with magenta paint, you will get red paint, because both blue and green are absorbed; red is the only color that is not absorbed by both types of paint. Black is seen when all light is absorbed.

In this experiment, we will use subtractive color mixing by filters rather than by pigments, since filters are more easily manipulated in the laboratory.

WHITE LIGHT **(contains all wavelengths)**	**BLUE** Short λ	**GREEN** Middle λ	**RED** Long λ
SUBTRACTIVE PRIMARY			
Yellow (absorbs blue)	**Blue**	Green	Red
Magenta (absorbs green)	Blue	**Green**	Red
Cyan (absorbs red)	Blue	Green	**Red**

The chart above demonstrates subtractive color mixing. White light is incident. Therefore, it contains red, green and blue light, the addition of primary colors. Each row shows a primary subtractive color. The table shows that each subtractive primary absorbs one additive primary color, as indicated by the shading. A mixture of magenta and yellow would absorb both green and blue, allowing only red to be seen.

The same chart can be used to predict the result of additive color mixing. Blue and green is the same as white light with red absorbed. Looking for the shading on red leads you to the cyan row, so blue and green = cyan.

The subtractive primary colors can be thought of as adding two additive primary colors or subtracting one additive primary from white light.

Partner ________________________ Name ________________________

______________________________ Section ______________________

PROCEDURE

Place the incandescent lamp in front of the slit of the spectrometer. **Align the spectrometer as you did in the previous experiment**. Rotate the telescope to an angle for observing dispersed spectrum. The prism should be set for minimum angle of deviation (shift the spectrum as far to the zero angle as possible for the green portion of the spectrum, about 52°). **Note**: the data here is fairly subjective. *High accuracy is not expected*.

1. a) Observe the spectrum through the telescope and record the angles, δ, in degrees and minutes and in decimal degrees for the various colors you see.
   b) Convert angular ranges to wavelength ranges, using the method described below.

	ANGULAR RANGE				WAVELENGTH RANGE	
PRISM #____	**BEGIN**		**END**		**BEGIN**	**END**
COLOR	deg & min	dec. deg	deg & min	dec. deg	nm	nm
RED						
ORANGE						
YELLOW						
GREEN						
BLUE						
VIOLET						

Q: What is the minimum and maximum λ you see? How close is this to the usual range of human vision?

The following equation (1) relates angle to index of refraction.

$$n = \frac{\sin((a + b)/2)}{\sin(a/2)} \qquad (1)$$

You could use this and then convert the index of refraction to wavelength by using the graph of index of **refraction vs. wavelength** that you made in the previous experiment. A more convenient way is to use an algebraic representation of your curve of n vs. $1/\lambda^2$, known as Cauchy's formula:

$$n = A + \left(\frac{b}{l}\right)^2 .$$

Here $A = 1.6175$ and $b = 102.75$ nm for glass, when l is measured in nanometers (nm). This equation, for prisms with $\alpha = 60^\circ$, together with equation (1) gives

$$l = \frac{b}{\sqrt{2\sin((b + 60)/2) - A}}$$

2. Place each of the three additive-primary color filters (red, blue, and green) between the lamp and the collimator. Observe the resulting spectra through the telescope. Describe the colors transmitted. Record the angular ranges of the resulting spectra. Then convert angular ranges to wavelength ranges. You may see a continuous band of colors (the "main" band), then a gap, and a narrower range of colors.

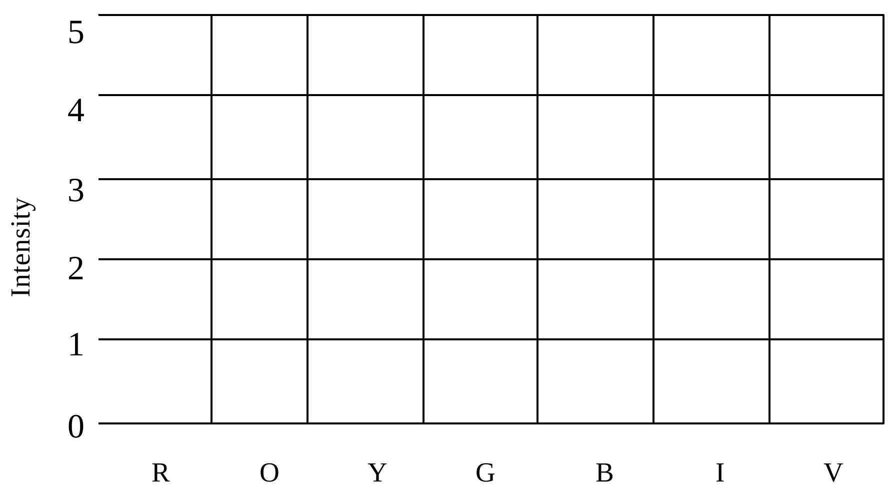
FILTER	COLORS SEEN (NOTE GAPS)	RANGE TRANSMITTED (MAIN BAND)			
		ANGLE (DECIMAL DEG)		**WAVELENGTH (NM)**	
		begin	**end**	**begin**	**end**
"RED"					
"GREEN"					
"BLUE"					

Q: What colors need to be absorbed by an ideal "RED" filter?

Q: How well do the filters match the color ranges you got in part 1?

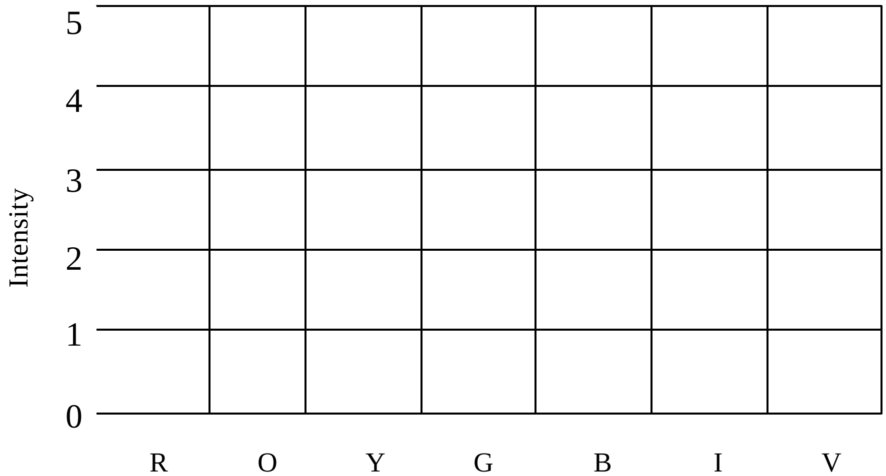
3. Place each of the three subtractive-primary color filters (cyan, magenta, and yellow) between the lamp and the collimator. Observe the resulting spectra through the telescope. Plot qualitatively the intensities of the transmitted colors in the graphs below. Label horizontal axis with the colors you see. Assign the intensities qualitatively (e.g., 5 = no change with or without the filter, 0 = color gone completely with filter). Fill in the plot like a histogram.

"CYAN"



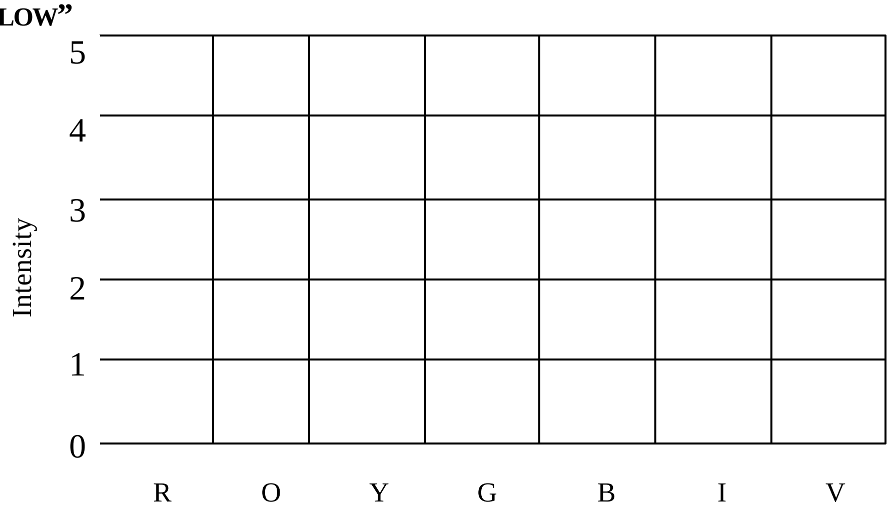
Q: What colors did you expect to be able to see for "CYAN"?

“MAGENTA”



Q: How does this observation differ from what you expected to see for magenta?

“YELLOW”



Q: How could you use a set of subtractive-primary color filters to make a “GREEN” filter? Does it work?

4. **Additive color mixing**: In this part of the experiment you will use the "projector box" to observe additive color mixing. The projector box is the large black box located at the side or in the back of the room. It contains three different independent light sources. The knobs on the sides let you adjust the intensity of each of the lights independently. For example, by adjusting the knobs so that the blue light is off and the red and green lights are of equal intensity, we can see what color we produce where they overlap. You can make accurate predictions for these colors using the table on page 2.

MIXTURE	PREDICTED COLOR	PERCEIVED COLOR
RED+GREEN		
RED+BLUE		
GREEN+BLUE		
RED+GREEN+BLUE		

Q: How well did your predictions agree with your results? Explain any differences.

5. **Subtractive color addition**: Now we will see how subtractive color addition works differently. Here we will use the white light boxes located in the middle of the lab bench. By stacking several color filters on top of each other, we can see what the resultant color is. This light is *very* bright so you may want to cover up the rest of the light box (where the filters don't cover) with a book or piece of paper to see the results clearly. Some of the filters are not very efficient (as we saw earlier) so you may want to use more than one of the same color (i.e.: in the first one, stack two reds and two blues together)

MIXTURE	PREDICTED COLOR	PERCEIVED COLOR
RED+BLUE		
RED+GREEN		
CYAN+MAGENTA		
CYAN+YELLOW		
MAGENTA+YELLOW		
CYAN+MAGENTA+YELLOW		

Q: Why does the red+green and red+blue give different results in this part of the experiment than in part 4? Explain what caused the results for RED + GREEN to be different in each case (that is, explain how each case worked).

Q: Explain the results for cyan+yellow.

Q: Explain any differences between predicted and perceived

Q Describe the qualitative difference between additive and subtractive color mixing with a practical example from everyday life of each.

Q: Why is it harder to think of examples of additive color mixing?

6. Test your color vision by using the color-plates provided in the lab. The plates have different numbers or patterns on them, testing for specific color perception. If you can read the number or see the design (usually a wavy line) then you can correctly identify the plate. If you are unable to see the number or design your eyes have trouble distinguishing between two specific shades of color.

- Number of color-plates correctly identified:____________________
- Number of color-plates incorrectly identified: __________________
- Comment on your color vision: