Name: ________________________ Partner(s): ________________________

Investigation #13 ________________________

OPTICS

In this investigation, you will become familiar with some of the properties of light. In particular, you will explore color addition and subtraction, the laws of *reflection* and *refraction*, (including *total internal reflection*) and interesting behavior resulting from the *polarization* of light.

To observe all of the phenomena in this investigation, you will rotate through various "stations." Each station will have a series of tasks, measurements and/or observations that you will be instructed to perform. Upon completing a station, you will then rotate to another station. This process continues until you have visited each station. The stations can be visited in any order, but you must be sure to visit each station.

Station #1
Color Addition & Color Subtraction

Recall from a previous laboratory session that different tones consisting of various amplitudes and frequencies can be "added together" to produce any sound that one can perceive. A similar situation exists with light. For example, when red, green and blue light are combined in various amounts, the perception of any color in the visible spectrum can be produced. For this reason, the colors red, green, and blue are called *additive primary colors* of light. When two primary colors of light are combined in equal intensities, the resulting colors are often referred to as the *additive secondary colors* of light. You can refer to your textbook for more details.

Your group will need the following materials/equipment for this part:

- 3 colored light sources (red, green and blue) that can project with equal intensities.
- White background

Procedure

1. Working with your partner(s) in a darkened area, and using the colored lamps provided, go ahead and freely explore the behavior of visible light when different colors are "added." Do this by turning on and turning off different combinations of light sources. (You could just block the light from the different sources if that is easier.) Be sure to shine different color combinations of the light sources onto a white surface and observe the color of the light that appears where the separate source colors overlap. (This is referred to as *color addition*.)
2. Determine the secondary colors by selectively adding the primary colors: red & green, red & blue, blue & green. Record your results in Table 1.1 on the next page.
3. Determine the apparent color of the screen when all three lamps illuminate the screen in equal intensities. Complete Table 1.1.

Note: For your observations, just enter the colors that you perceive. It is okay if you and your partner disagree. Since different individuals have different perceptions of color, just record what YOU see. If you don't know the exact name of the color you see, make up a name that is a reasonably close description.

Table 1.1

Colors of Light "Added"	Apparent Color of Light on White Background
RED + GREEN	
RED + BLUE	
GREEN + BLUE	
RED + GREEN + BLUE	

4. Hold your hand or some object in the light when all three light sources are lit. Observe the colors of the shadows that occur when different light sources are selectively blocked. This can best be done by selectively turning the light sources on and off. Record your observations in Table 1.2 below.

Table 1.2

Color(s) of Light Illuminating Object	Color of Shadow(s) Behind Object		
RED only			
GREEN only			
BLUE only			
GREEN + BLUE			
RED + BLUE			
RED + GREEN			

5. With all three lamps turned on, move your hand or the object toward and away from the screen in order to make different colored shadows overlap. Try to make each combination of shadows overlap. (You may have to move one of the lamps to do this. Be sure to loosen the set screw before trying to maneuver the lamp.)
6. Determine what two shadow colors have to overlap to produce a red shadow. Place your answer in Table 1.3 on the next page.
7. Determine what two shadow colors have to overlap to produce a green shadow. Place your answer in Table 1.3.
8. Determine what two shadow colors have to overlap to produce a blue shadow. Place your answer in Table 1.3.

Table 1.3

Shadow 1	Shadow 2	Resulting Shadow
		RED
		GREEN
		BLUE

Question: When shadows consisting of all three secondary colors overlap, what is the "color" of the shadow that is produced? (Hint: Think about this for a moment. For each secondary color, what color of light is blocked? So if ALL three shadows overlap, which lamps have their light blocked?)

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** _______

Station #2
Transmission, Absorption & Reflection

Your group will need the following materials/equipment for this part:

- 3 colored light sources (red, green and blue) that can project with equal intensities
- Transparent color filters (red, green, blue and "clear")
- Color palettes (red, green, blue, white, black)

1. With the red lamp on and the other two lamps off, hold the each color filter (one at a time) front of the lamp and observe the color of the light that passes through it (if any). Record your observations in Table 2.1 on the next page.
2. Repeat Step 1 with the green lamp on the other lamps off. Complete Table 2.1.
3. Repeat Step 1 with the blue lamp on the other lamps off. Complete Table 2.1.

Table 2.1

Color of Light	Apparent Color of Light Transmitted through each Filter			
	Red Filter	Green Filter	Blue Filter	Clear Filter
RED				
GREEN				
BLUE				

Questions: When white light is shone through a clear transparency filter, is there a particular color of light that passes through the transparency more so than other colors? If so, what color is transmitted more?

Questions: When white light is shone through the red transparency filter, what color is mostly transmitted through the filter? What color(s) is/are most absorbed by the filter?

4. With the red lamp on and the other two lamps off, hold the color palettes in the red light. Note what color each object appears to be in the red light. Record your observations in Table 2.2.
5. Repeat Step 4 with the green lamp on other two lamps off. Complete Table 2.2.
6. Repeat Step 4 with the blue lamp on other two lamps off. Complete Table 2.2.

Table 2.2

Color of Light	Apparent Color of Light Reflected from each Palette				
	Red Palette	Green Palette	Blue Palette	White Palette	Black Palette
RED					
GREEN					
BLUE					

Questions: When an object is painted white, is there a particular color of light that reflects from that object more than other colors? If so, what color is it?

Questions: When something is painted blue, what color of light is most reflected by the object? What color of light is most absorbed?

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** ______

Station #3
Complementary Colors

When two colors of light that are added together produce white light, the two separate colors are called *complementary colors*.

Your group will need the following materials/equipment for this part:

- Paper of 6 different colors (red, green, blue, yellow, magenta, cyan)
- White background

Procedure

1. Place a small piece of colored paper in the middle of the white background. Focus your eyesight on the black dot corner and stare at the dot for about 20-30 seconds. Try not to let your eyes wander. In order to see the effect, you need to focus—literally!
2. After 20 seconds or so, quickly remove the colored paper and again focus your eyesight on the white background for at least 10 more seconds. You should see an "afterimage" in the region where the colored paper was. Keep your gaze fixed on the white paper in order to see the effect.
3. Repeat Steps 1 and 2 for each piece of colored paper. Record was the color of the afterimage that you observed. Complete Table 3 below.

Table 3

Color of paper	Color of Afterimage
RED	
GREEN	
BLUE	
CYAN (light blue)	
MAGENTA (pink)	
YELLOW	

You see an afterimage because the color receptors in your eye (special cells called *cones*) that are sensitive to the color of the paper will fatigue over time. The white background stimulates all the cones in the eyes, but the fatigued cones send a "weaker" signal to the brain. Thus, the color of the afterimage results from the brain receiving a signal of WHITE – PAPER COLOR. The resulting afterimage should be the complementary color of the paper.

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** _______

Station #4
Reflection and Refraction

Your group will need the following materials/equipment for this part:

- 1 light source with single slit
- 1 ray table with protractor and white paper
- 1 hemi-cylindrical lens
- A darkened area to perform the measurements

Procedure

1. Place the lens at the center of the ray table. Align the light source, slit, and lens so that a narrow beam of light is aimed along the 0° line (the *normal* of the ray table) and strikes the flat side of the lens perpendicular to its surface. The flat side of the lens should lie along the "component line" of the ray table and face the oncoming light ray from the source as shown in Fig 1. You should be able to see a ray that is transmitted through the lens. If not, check that the lens has the rough semicircular surface down. If you are still having difficulties, consult your instructor.

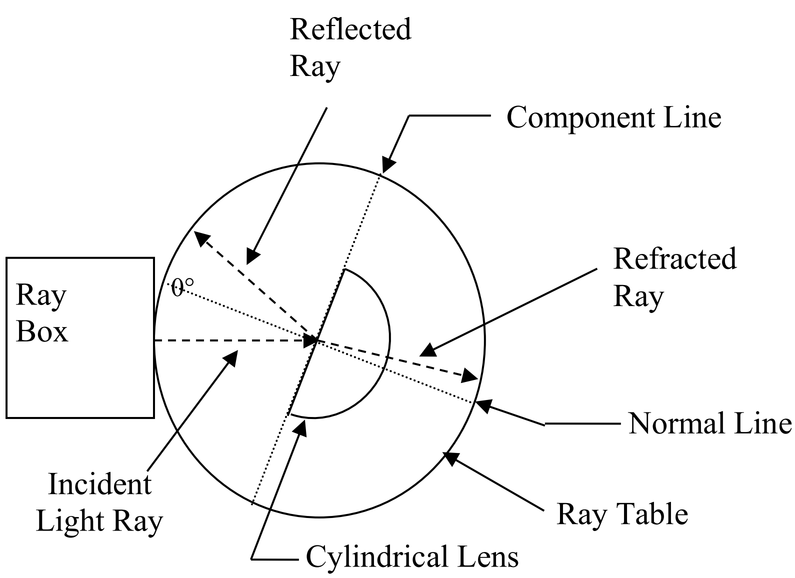

Fig. 1: Overhead view of the ray table station

Note: When the lens is properly aligned, with the flat side along the "component line," an incoming ray directed along the 0° line will pass straight through the lens along the 0° line on the other side. (This is your first data point.)

2. Slowly rotate the ray table and observe the behavior of the rays that reflect off the flat surface of the lens and that refract through the lens. (The reflected rays may be very dim until the table is rotated past 10° or so.) Once you have made some qualitative observations, collect data for incident angles that vary from 0° to 80° in increments of 10°. Complete the Table 4.1 on the next page.

Note: Be sure that you measure all angles with respect to 0° line on whichever side of the ray table the light ray is. If you are having difficulties, consult your instructor.

Table 4.1

Angle of Incidence (°)	Angle of Reflection (°)	Angle of Refraction (°)
0		
10		
20		
30		
40		
50		
60		
70		
80		

Question: Based on your observations, qualitatively describe how the angle of reflection compares to the angle of incidence for each trial?

Question: Based on your observations, qualitatively describe how the angle of refraction compares to the angle of incidence for each trial?

3. Reverse the position of the lens so that the flat side of the lens is again aligned along the "component line" of the ray table, only now, the incoming beam initially strikes the curved side of the lens as shown in Fig. 2 on the next page.

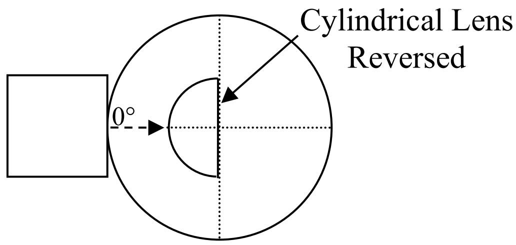

Fig. 2: Repeating previous measurements with lens reversed.

4. Again starting at 0°, slowly rotate the ray table and observe the angle that the refracted ray makes with the "normal." Complete Table 4.2 below.

Table 4.2

Angle of Incidence (°)	Angle of Reflection (°)	Angle of Refraction (°)
0		
10		
20		
30		
40		
50		

Question: Qualitatively describe how the angle of refraction compares to the angle of incidence.

Questions: Was there an angle of incidence where the refracted ray seemed to vanish completely? If so, go back and measure the angle (to the nearest degree) that the incoming ray makes with the interface when this occurs.

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** _______

Station #5
Polarization

Your group will need the following materials/equipment for this part:

- 1 white light source
- 3 Polaroid filters

Procedure

1. Turn on the light source and orient Polaroid filter *A* so that its plane is perpendicular to the direction of the incoming light. Note the intensity of the filtered light as compared to the unfiltered light.
2. Next, place Polaroid filter *B* directly on top of the first and slowly rotate the second filter until the intensity of the transmitted light is a maximum. Note the orientation of the two filters when the transmitted light in a maximum. When the intensity of the transmitted light is a maximum, the filters are said to be "aligned."
3. With filters *A* and *B* aligned with each other, slowly rotate filter *B* until the intensity becomes a minimum. Note that the intensity of the transmitted light drops essentially to zero. When the intensity of the transmitted light is at a minimum, the filters are said to be "crossed."

Question: Through what angle did you have to rotate the filter *B* from the "maximum intensity position" in order to achieve minimum intensity?

Angle of rotation from maximum intensity to minimum intensity = ______^{o}

4. With filters *A* and *B* crossed, carefully insert filter *C* between the filters *A* and *B*. Try to insert filter *C* so that it is aligned with filter *A*. (Since filters *A* and *B* were already crossed, filter *C* should also be crossed with filter *B* after insertion.)

Question: When filter *C* (the middle one) is aligned with the first (and therefore crossed with the second), is there any light transmitted through the entire system of filters? Record your observation by placing a check in the appropriate space.

______ Yes, light was transmitted through the 3-filter combination.

______ No light was transmitted through the 3-filter combination.

5. Slowly rotate the third filter and observe the behavior of the transmitted light. Again, be careful that filters *A* and *B* remain crossed.

Questions: Did light pass through all three filters at any time? Check the box.

______ Yes, light was transmitted through the 3-filter combination.

______ No light was transmitted through the 3-filter combination.

Question: The filters used in this investigation "polarize" the light. This means that they force a component of the light to vibrate along a particular direction. Do these observations support the notion that light is a transverse wave or a longitudinal wave?

Checkpoint: Consult with your instructor before proceeding. **Instructor's OK:** ______

Station #6
Prisms, Mirrors and Lenses

Your group will need the following materials/equipment for this part:

- 1 light source with adjustable slit numbers
- 1 triangular prism
- 1 metric ruler
- Assortment of cylindrical mirrors and lenses
- A darkened area to perform the measurements
- White paper and curvature measurement guides

Procedure

1. Lay the white paper on your table and adjust the ray box so that a single narrow beam of light is directed along the paper.
2. Place the sharp corner of the prism in the path of the light ray as shown in Fig. 3 below.
3. Rotate the prism until you obtain an easily discernable spread of colors.

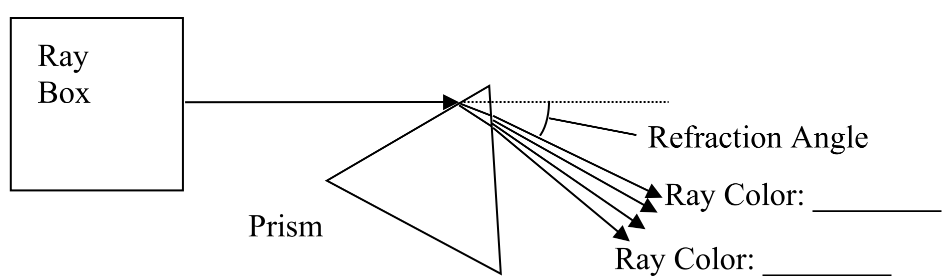

Fig. 3: The dispersion of white light into its color spectrum.

Note: Have the light ray intercept the prism near a sharp corner in order to maximize the amount of transmitted light. Also, view the spectrum while looking along the surface of the paper should make the spectrum easier to see.

Questions: What colors do you see and in what order do you see them? Label the color of the least refracted ray and the color of the most refracted ray in the respective spaces provided in Fig. 3 on the previous page.

Question: How much a particular color refracts depend on *the index of refraction* of the prism. The greater this refractive index, the greater the refraction or bending. According to your results, for which color does the prism appear to have the highest index of refraction? For which color is the index of refraction the least?

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4. Remove the prism and adjust the ray box so that three or four light rays emerge along the piece of paper.
5. Position a *concave* (curved inward) mirror so that the middle ray is reflected straight back upon itself.
6. On the paper, trace the surface of the mirror and the incoming and outgoing light rays. Be sure to include arrows to indicate the directions of the light rays.
7. On the paper, locate the points where the three light rays intercept the mirror and the point where the reflected rays appear to cross each other. (See Fig. 4 below.)

Note: Use a ruler or straightedge to draw your all of your light rays!

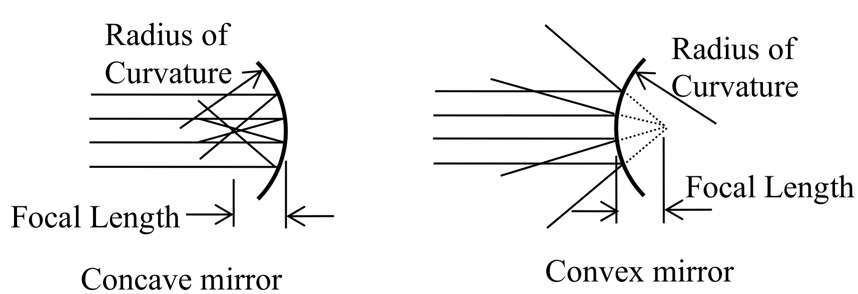

Fig. 4: The focal length and radii of curvature for the curved mirrors.

8. Along the middle ray, measure the distance from the mirror surface to the point where the five rays cross each other. This is the *focal length* of the mirror. Record your result:

Focal length of the concave mirror = ______ cm

9. Determine the radius of curvature by comparing your mirror to the radius of curvature measurement sheet and then record the result:

Radius of curvature of the concave mirror = ______ cm

10. Remove the concave mirror and repeat Steps 4-9 with the *convex* (curved outward) mirror on the other side of the white paper. Record the focal length and radius of curvature:

Focal length of the convex mirror = _______ cm

Radius of curvature of the convex mirror = _______ cm

Note: For the convex mirror, you will have to trace the rays back behind the mirror in order to locate the focal point. (See Fig. 4.)

Questions: By what approximate numeric factor are the focal length and the radius of curvature for the concave mirror related? What about for the convex mirror?

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11. Remove the convex mirror and repeat only Steps 4-8 using the double convex and double concave lenses. (You do not have to find the radius of curvature for the lenses.)

Focal length of the convex lens = ________ cm

Focal length of the concave lens = ________ cm

At this point you should have four sketches: the two curved mirrors and the two lenses. Each sketch should be neatly drawn (using a ruler), titled, and show the focal lengths. Both mirror sketches should show radius of curvature of each mirror as well.

Question: Which mirror focusses the light rays and which mirror spreads them out?

Focusses: __________ Spreads: ___________

Question: Which lens focusses the light rays and which lens spreads them out?

Focuses: ___________ Spreads: ___________

Checkout: Consult with your instructor before leaving the lab. **Instructor's OK:** ______