**EXPERIMENT: GEOMETRICAL OPTICS**

[Equipment list: LED Light (white), Optics Track, Image Screen, 100mm lens, 200mm lens, -150mm lens, Cork Board, Plate Glass, Push Pins (4), Protractor, Ruler]

**Overview:**

Lenses are of two general types: convergent and divergent. A convergent lens is one that causes all rays parallel to the axis of symmetry of the lens to converge to a single point, called the principal focal point, after passing through the lens. The distance between the center of the lens and this focal point is the focal length f of the lens. A divergent lens causes parallel rays of light to diverge after passing through the lens. If these divergent rays are traced backwards in a straight line, they appear to come from a common point on the "object" side of the lens. The focal length, measured from the lens to this focal point, is negative for the divergent lens. This is in accordance with the usual sign convention for object and image distances:

"Measure the object distance from the object to the lens, and the image distance from the lens to the image. The value of either measurement is negative if this is counter to the direction of the light path."

F

F

f

f

o

i

o

i

figure 1

Consider the two diagrams in figure 1 that illustrate image formations for converging and diverging lenses. The object distance is labeled o and the image distance is labeled i. In each case the object and image positions are so related that they may be interchanged. Such points are called conjugate foci. From a consideration of the similar triangles in either figure, we can derive the thin lens formula

where the sign convention stated above is used. The image formed by the divergent lens illustrates a virtual image. Whereas a real image (i > 0, image distance positive) can be found by placing a screen in the correct position, a virtual image (i < 0, image distance negative) can be seen only by looking back through the lens into the light.

**PART 1: SNELL'S LAW**

A ray of light passing from one clear material and incident upon another clear material of a different index of refraction from the first at some angle other than 90° to the surface will refract. The angle at which the light ray refracts will be different from the angle that the light ray had before it entered the second material. Snell’s Law relates these two angles and these two indices of refraction using equation (1). A Rectangular plate glass will be available in the lab for you to use to show this relationship. You will represent a light ray which is traveling through air at some angle approximately 30° to 40° incident upon the glass block’s surface by using pins. Start by placing the glass block on a sheet of paper, centering the glass block upon the paper. Trace about the perimeter of the glass black with a pen or pencil. Put two pins upright in the paper to define an incident ray. Sight edgewise through the glass and put two more pins in the paper in such a way that the second set of two pins are in line with the images of the first two pins viewed through the glass. Make sure that you have only one of your eyes open when doing this.

Light Path

Pins

Pins

Glass Block

figure 2

(1)

Remove the glass and pins, and from the pinholes trace a light ray through the outline of the rectangle.

Ɵ1

Ɵ1

Ɵ2

Ɵ2

figure 3

Due to the Law of Reversibility (refer to figure 3) you can measure two angles of incidence (Ɵ1) and two angles of refraction (Ɵ2). Measure the angles of incidence and the angles of refraction and write these values in the designated cells on the Excel Worksheet. Average the two angles of incidence together resulting in an average Ɵ1. Then average the two angles of refraction together resulting in an average Ɵ2.

Determine the index of refraction of the glass using these two average angles and the index of refraction in air using the Excel Worksheet.

Calculate the speed of light inside the glass block on the Excel worksheet.

Scan, or photograph, the drawing of the glass block and rays of light, complete with measured values of angles and include it in this report. Compare your experimentally found index of refraction of the glass plate to the manufacturer’s value of 1.5 using the % Difference equation.

Determine the percent difference between your experimentally determined index of refraction to that of the manufacturer’s on the Excel worksheet.

Calculate the Speed of Light in glass on the Excel worksheet using your experimentally determined index of refraction.

(2)

**PART 2: 10 cm CONVERGING LENS**

Set the light source at the 1-centimeter mark on the track and place and place the 10 cm converging lens at the appropriate positions on the track such that the distance between the light source and the lens is equal to the Object Distances stated in Table 1. Move the screen to a position that shows to have the sharpest image formed upon it. Measure the distance from the lens to the screen position…this is your image distance. Record the image distance in Table 1. Using equation 1 from above and the Object Distance and corresponding Image Distance determine the Focal Length of the lens and record it in Table 1.

For each of the object distances, state in Table 1 on the Excel worksheet whether the Image formed is Real or Virtual, whether the Image is Inverted or Upright. Also, determine mathematically the Magnification of the Image formed. Magnification is equal to the negative of the ratio of the Image Distance divided by the Object Distance ( ).

Compare the average focal length found from calculation to the manufacturer’s stated focal length using the % Difference equation. Calculate this on the Excel worksheet.

**PART 3: 20 cm CONVERGING LENS**

Set the light source at the 1-centimeter mark on the track and place and place the 20 cm converging lens at the appropriate positions on the track such that the distance between the light source and the lens is equal to the Object Distances stated in Table 2. Move the screen to a position that shows to have the sharpest image formed upon it. Measure the distance from the lens to the screen position…this is your image distance. Record the image distance in Table 2. Using equation 1 from above and the Object Distance and corresponding Image Distance determine the Focal Length of the lens and record it in Table 1.

For each of the object distances, state in Table 2 whether the Image formed is Real or Virtual, whether the Image is Inverted or Upright. Also, determine mathematically the Magnification of the Image formed. Magnification is equal to the negative of the ratio of the Image Distance divided by the Object Distance ( ).

**Ray Diagrams:** (Copy this page and include it in your report. Use the drawing application in Word to draw the rays and the imaged formed. Use a different color of your choice to draw with.)

Obj. > 2f

2f

f

f

2f > Obj. > f

f

f

2f

f > Obj.

f

f

2f

**PART 4: -15 cm DIVERGING LENS**

Determine an approximate focal length of a diverging lens by allowing the light from a distant light source (set light source at 1 cm mark) to shine through the diverging lens and onto the screen (set screen at 121 cm mark). There will not be an image formed on the screen, just a circle of light due to the diverging effect of the lens. Start by measuring the diameter of the physical stop on the stand that you will place the diverging lens. On the screen you will see a vertical line with hatch marks along its length. Measure the entire length of the line. Then place the diverging lens in front of the screen **with the physical stop on the screen side** and align the screen and lens to the light source. Adjust the distance between the lens and the screen until the diameter of the circle of light on the screen is the same size as the full length of the vertical line on the screen. Using geometry determine the focal length of the diverging lens. Make calculations on the Excel worksheet.

Diameter of Physical Stop = \_\_\_\_\_\_\_\_\_\_\_\_ Length of Vertical Line on Screen = \_\_\_\_\_\_\_\_\_\_\_\_

Physical Stop

Screen

Focal Length

X

There is a small space between the center of the lens and the physical stop, but we are going to ignore this small space and determine an approximate focal length of the diverging lens.

Determine the focal length of the diverging lens using similar triangles. Show work on the Excel worksheet.

Compare the average focal length found from calculation to the manufacturer’s stated focal length.

**PART 5: COMPOUND LENS SYSTEM**

A. Using the converging lens from Part 2 and the diverging lens from Part 4 set up a compound lens system to form an image on the screen. Place the converging lens 25 centimeters away from the light source and the diverging lens 35 centimeters from the light source (10 centimeters from the converging lens). Adjust the screen until you achieve the sharpest image and record the position of this image on the Excel worksheet.

B. Using the manufacturer’s values for the focal length of the converging lens from Part 2 and the focal length of the diverging lens from Part 4 mathematically (using the thin lens equation) determine the image distance as measured from the diverging lens. You must show all step-by-step work in the Results section of your lab report. Record the calculated image distance on the Excel worksheet.

Compare the measured image distance to the mathematically determined image distance using the percent difference formula.

**Results: This part of the lab report tells us how well you understand the experiment. Type the results for each part (at least one paragraph) in the Results section of your report, numbering each with the corresponding section number.**

**Answer the Questions for Further Discussion (below) in complete sentences. Restate your results to support your answers.**

1. What are the sources of uncertainty (both random uncertainties and systematic uncertainties) associated with determining the index of refraction of glass in Part 1? Review the uncertainty analysis instructions on Pilot to help you answer this question.

2. What are the sources of uncertainty (yes, both random and systematic) associated with determining the focal length of the 10 cm focal length lens in Part 2?

3. Spherical lenses, like the ones used in this experiment, inherent with their shape and the material that they are made have several possible types of aberrations. Spherical aberration and chromatic aberration are two common ones. Describe these two aberrations associated with spherical lenses.

4. A simple telescope could be made with the two converging lenses from parts 2 and 3 of this experiment. Using your experimentally determined focal lengths of these two lenses what would be the magnification of this telescope?