PHY 134 Optics: Reflection, Refraction and Images

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There are two parts to this lab that can be done in either order. In Part I you will study the Laws of Reflection and Refraction, measure the index of refraction of glass. In Part II you investigate images produced by lenses.

The PHY 122 version of this lab manual has an embedded video which is (more than slightly as of Spring 2018) slightly out-dated but might be useful. You can find it at http://skipper.physics.sunysb.edu/~physlab/doku.php?id=phy124:raytracing

PART 1

Equipment: Lens and Laser Kit, protractor

When the light beam hits the air - glass boundary, side 1 of the prism in Fig. 2 above, reflection and refraction occurs. A small fraction of the intensity of the incident beam is reflected, leaving a faint reflected ray outside the prism, and the remainder of the intensity is refracted into the prism. The refracted ray hits the glass-air boundary on side 3 of the prism and the ray is again refracted into the air as the "exit" ray in Fig. 2 above. The ray reflected inside the prism on boundary 3 is barely visible.
The law of reflection states that the incident angle $\theta_i$ equals the angle of reflection $\theta_r$

$$\theta_i = \theta_r \quad (1)$$

For refraction, Snell's Law holds. Snell's Law is given in Eq. (2) here:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \quad (2)$$

In our case for boundary 1 $n_1$ is the index of refraction of air (which we assume to be $n=1$, as for vacuum) and $n_2$ is the index of refraction of glass. In this lab $n_2$ is considered to be unknown and you will be measuring it by applying Snell's Law on boundaries 1 and 3.

**Procedure**

Select the center position on the Laser Ray Box to allow for one beam. Align this beam and triangular prism so that $\theta_i$ is well-defined: having the laser beam horizontal and the triangular prism at 45°, for instance. Measure the $\theta_i$ and $\theta_r$ at the first boundary and test whether, within experimental uncertainty, Equation 1 holds. The reflected ray is difficult to see and may require a darkened room.

Now measure the $\theta_1$ and $\theta_2$ for Boundary 1. It may help to trace the prism and rays on paper. Remember that the convention for Equations 1 & 2 is for angles to be measured with respect to the normal (ie. Perpendicular) to a boundary. Next measure the $\theta_1$ and $\theta_2$ for the interior ray and exit ray, ie. at Boundary 3. Use Snell's Law at both boundaries to find the index of refraction for the glass of the prism, then compare.

For a critical angle of incidence $\theta_c$ on the glass-air boundary 3 no refracted intensity is visible, as the full intensity of the incident beam is reflected back into the glass. At the angle when this happens, total internal reflection occurs. Slowly rotate the prism from the position it had for the measurements above. As you rotate the prism you should notice that the exit ray makes smaller and smaller angles with boundary 3. You should also observe a beam exiting boundary 2. Observe the intensity of the beam coming from side 2 as you continue to turn the prism. Rotate the prism until the exit ray disappears completely, while observing the intensity of the new ray from boundary 2. Rotate back and observe a couple of times.

Describe your observations of the intensity of the beam emanating from boundary 2 as you rotate the prism. When the exit ray in Fig 2 disappears, is the intensity of the beam emanating from boundary 2 maximal or minimal? On which boundary do you observe total internal reflection?

**Questions**

The famous image to the right shows that the index of refraction of a material depends slightly on the wavelength of light. Thus, light with different wavelengths (and hence different color) is bent by different angles. This phenomenon is called dispersion. Why did we not observe dispersion in Part 1?
PART 2

**Equipment**

Optical Bench (a rail on which to mount the holders of lenses/screen);

Box with lenses. Use #3 (a 10 cm diverging lens) and

# 4 (a 5 cm converging lens) if possible;

Holders for lenses/screen, screen, lamp, arrow (our object to be imaged)

The purpose of this part is to study images made by lenses and to verify the imaging laws for lenses. The imaging law for the lenses relates the distance of the object ($d_o$) and image ($d_i$) from the lens to the focal length ($f$). This relationship is:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \quad (3)$$

The expression for magnification of the lenses is defined in terms of the heights of the object ($h_o$) and image ($h_i$) and can be related to $d_o$ and $d_i$:

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \quad (4)$$

In equation 4 the object and image heights have the convention that a positive value is upright.

**Procedure**

- **Converging Lens**

Make sure that the lamp and the painted arrow (the object) are placed at one end of the optical bench, with the arrow a few cm in front of the lamp and pointing upward. The arrow and lamp will remain in that position for this part of the experiment. The screen and the lenses will be moved. You will observe two images, one magnified, the other de-magnified, depending on the position of your lens.

Mount the 5 cm (#4) lens in the lens holder. Mount the screen into a holder and place it at ~ 30 cm from the object. Place the lens between the screen (image) and the object, as close to the object as possible. Move the lens towards the screen until you can see a sharp image on the screen. First, observe the size and orientation of the object and of the image. Record them. Next, locate the positions of the image, lens and object and record them. Move the lens away from the object to a new $d_o$, move the screen until you find a sharp image and measure the new $d_o$, $d_i$ and $h_i$. Repeat for a total of five (5 sets) of distance and image heights. Note that the lens is not centered on the lens holder but offset by 0.6 cm. Make sure you correct for the orientation of the lens.
In your analysis, use equation (3) to calculate the focal length \( f \) of the lens from the measured \( d_o \) and \( d_i \) values. Find \( f_{\text{mean}} \) to be the average (mean) of the five values.

To calculate the uncertainty for each value \( f \) (\( \delta f \)) use the fact that the reciprocals \( 1/d_o, 1/d_i \) and \( 1/f \) have the same relative errors as \( d_o, d_i \) and \( f \), and propagate the absolute errors of the reciprocals. The uncertainty in \( f_{\text{mean}} \) can be estimated to be \( \delta f / \sqrt{N} \) or found using the standard deviation of the values (Lab 0, section on Random Errors).

Next, use Equation (4) to find the magnification from the measured heights of the image and object for each of the five measurements. Calculate uncertainty for each value. Then, calculate the magnification (and error) from the measured image and object distances using equation (4). Are the values obtained for the magnification consistent with each other within experimental uncertainty?

- Image and Magnification for the 10 cm Diverging Lens: Qualitative only

Mount the 10 cm (#3) diverging lens in the lens holder. Place the lens as close as possible to the object. Try to make an image on the screen by moving the lens and screen around (verify that you don't in fact produce an image on the screen). Remove the screen and place your eye close to the lens so that you can observe the image the lens produces from the object. Describe whether the image (what you see) appears upright/inverted, magnified/de-magnified with respect to the original object.

Slide the lens away from the object and, keeping your eye close to the lens, observe whether the properties of the image, apart from the size, change as you increase the distance of the lens from the object, i.e. is the image for any object distance upright/inverted, magnified/de-magnified. Is the image real or virtual?

REFERENCES and TOOLS

Chapter 18 of Knight, Jones and Field, College Physics: A Strategic Approach, 2nd Edition
Chapter 32 of Giancoli, Physics for Scientists and Engineers, 4th Edition
Chapter 37 of Katz, Physics for Scientists and Engineers


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