PHY/ENS 119 EXPERIMENT NO. 10
REFLECTION, REFRACTION, LENSES AND MIRRORS

Introduction

This laboratory is to show that the very simple principles of reflection and refraction can lead to more sophisticated ideas about optical devices such as curved mirrors and lenses. We begin with a ray box that produces a parallel set of thin laser beams (or "rays" of light). The rays are made visible on a plane surface (a sheet of paper). To make measurements, we will trace the paths of the light rays with a pencil on the sheet of paper lying horizontally, indicating the direction of the rays before and after striking a plane mirror or a glass prism. Then we will progress to the study of curved mirrors and lenses, which are nothing more than reflectors or refractors with curved surfaces. Finally, we will make a precision measurement of the index of refraction of water.

Part 1 -- Light Wave Reflection

A. Use the ray box, a mirror, and protractor to verify that $\theta_{inc} = \theta_{refl}$. See Figure 1. Do this for at least three different incident angles.

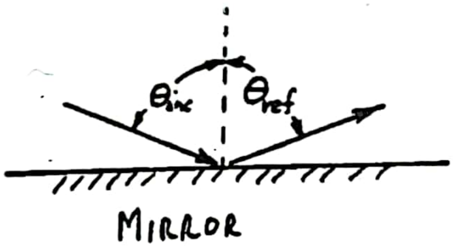


Figure 1.

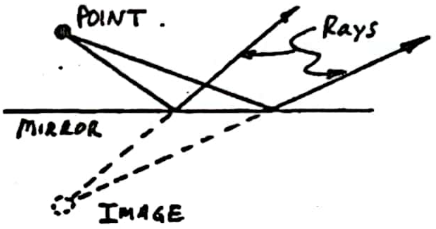


Figure 2.

B. Show that the (virtua1) image produced by a mirror is located as far behind the mirror as the object is in front of the mirror. The method is up to you. (Hint: suppose the object consists of a point. Thus the image of the point is located where two reflected rays from the point intersect.) See Fig. 2.

Part 2 -- Light Wave Refraction

A. Snell's Law

Use the ray box, a glass prism and a protractor to verify Snell's Law of refraction:

$$n_{\text{inc}}\sin\theta_{\text{inc}} = n_{\text{refr}}\sin\theta_{\text{refr}}$$

Where n_{inc} and n_{refr} are the refractive indices of the incident and refracting media, respectively. Take $n_{\text{inc}} = 1$ and $n_{\text{refr}} \approx 1.5$ for glass. Verify the law for at least two different values of θ_{inc}.

B. Critical angles

Snell's law also tells us that if we reverse things, i.e., if we let a light ray hit the glass-air boundary starting from the *glass* side, then

x 1.5

$$(\sin\theta_{\text{inc}})/(\sin\theta_{\text{refr}}) = n_{\text{air}}/n_{\text{glass}} = 1/n_{\text{glass}}$$

Now $\sin\theta_{\text{refr}}$ can never be greater than 1, and is maximum for $\theta_{\text{refr}} = 90^\circ$. The incident angle θ_{crit} for which this happens is called the *critical angle*, and has a value given by

$$\sin\theta_{\text{crit}} = 1/n_{\text{glass}}$$

For any value of θ_{inc} that exceeds θ_{crit}, $\sin\theta_{\text{refr}}$ would have to be greater than 1. Since this is impossible (for any real angle θ), the light beam would only be totally reflected within the glass; no light could be refracted into the air. Use your prism to find θ_{crit}, and compare your measured value with what you would expect from the equation above.

Part 3 -- Lenses and Mirrors

Study and sketch the ray patterns produced by the convex and concave mirrors and lenses in your kit. Determine the focal length of each. Remember that the focal lengths of concave lenses or convex mirrors are *negative*, whereas the focal lengths of convex lenses and concave mirrors are *positive*.

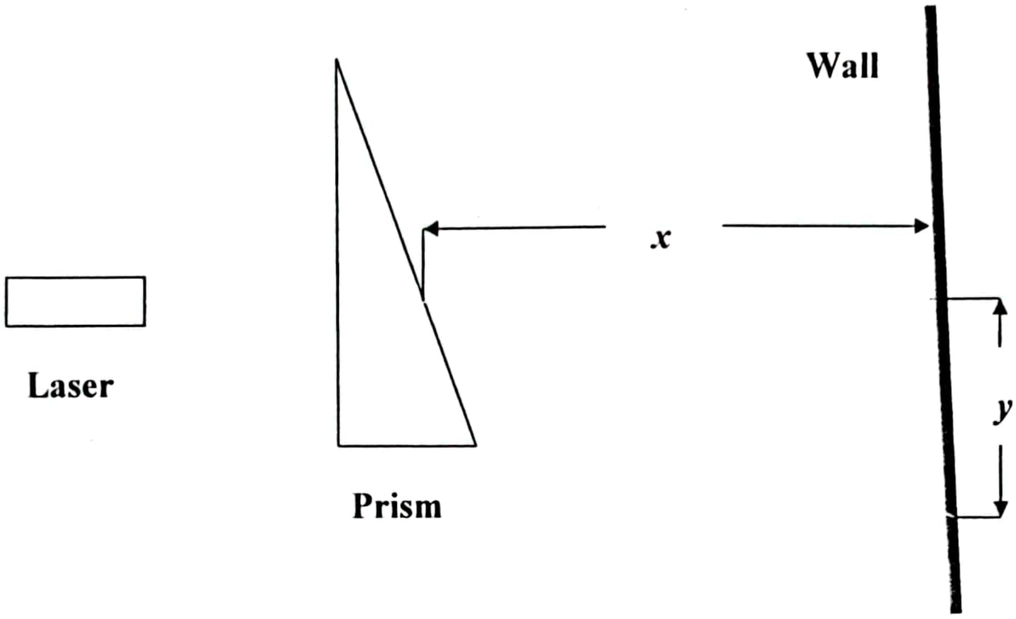
Part 4 -- Precision Measurement of the Index of Refraction of Water

In this part, a plastic prism-shaped container and a laser are used to measure the index of refraction of water.

Equipment

Laser, prismatic plastic container of triangular cross-section, meter stick, masking tape.

CAUTION! This experiment uses a laser. *NEVER* stare directly into a laser beam or its reflection!



Procedure

1. Direct a laser beam so that it strikes perpendicular to a wall about 1.5 meters away. Mark the spot on the wall with masking tape and a pen or pencil.

2. The prism container is (nominally) shaped as a 30-60-90° triangle. Place the (empty) container so that the laser beam strikes perpendicular to the triangle, on the side opposite the 60° angle as shown in the diagram. How will you know when the beam is perpendicular?

3. Check to make sure the spot on the wall has not moved, or re-mark it if it has. Measure the distance x as precisely as possible with a meter stick. It may be convenient to adjust the position of the container so that x is 1.000 m.

4. When you are certain that x is accurately measured, and that the laser beam is perpendicular to the side of the prism and to the wall, and that the laser spot is accurately marked on the masking tape on the wall, fill the prism with water. The laser beam should now pass through the water and be refracted, causing the spot to move to a new position on the wall, a distance y from its original position. Mark the new spot and measure y as precisely as possible.

5. Carefully measure the angles of your prism by tracing its outline with a sharp pencil on a piece of graph paper. Is it strictly 30-60-90°? If not, determine what the actual angles are.

yes

Report

For Parts 1, 2 and 3, show your drawings and determine the asked-for quantities. For Part 4, determine the index of refraction n of the water from your data. **[NOTE: The angle determined by x and y in step (4) of part (4) above is *NOT* the angle of refraction by itself.]**

Do a *careful* error analysis to determine your uncertainty in n. Does your value of n agree with published values to within your experimental uncertainty? If the prism was not strictly a 30-60-90° triangle in cross-section, what effect did this have on your determination of n? Make corrections as necessary, and discuss your procedure *thoroughly*.