Optics: Reflection and Refraction (approx. completion time: 2.5 h) (3/28/11)

Introduction

In this lab you will investigate the reflection and refraction of light. *Reflection* of light from a surface is what allows us to see objects that are not luminous. Different colored objects reflect different colors of light. A mirror is a smooth surface that reflects light in such a way that we can view images of objects. *Refraction* occurs when light changes direction as it passes from one medium to another. For example, a straw in a glass of water may appear bent or disjointed at the surface of the water because the direction of propagation of the light changes when traveling between water, glass, and air.

Equipment

- HeNe laser
- meter stick
- masking tape
- colored pencils
- dim lamp
- plastic half circle
- wooden block with "screen"
- protractor with straight edge
- collimated white light
- square glass slab
- 8.5"x14" blank paper
- pitcher for fetching water
- dilute white paint & eyedropper
- clear plastic cup & straw

Demonstration setups: prism and collimated white light source; laser refraction tank.

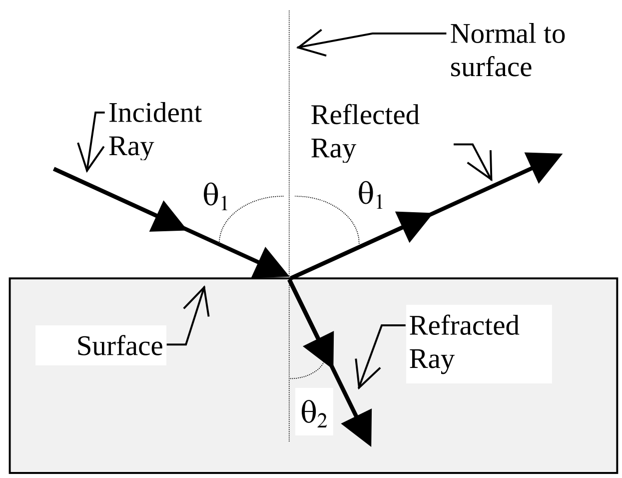
Theory

When a ray of light is reflected from a smooth surface the angle of reflection is equal to the angle of incidence (Law of Reflection):

$\theta_{incident} = \theta_{reflected}$

When light rays pass through a surface from one medium to another (air to water for example) the angles obey the law of refraction, or *Snell's Law:*

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



where n_1 and n_2 are the *indexes of refraction* of the two media (see diagram). The index of refraction is a measure of the way in which the light interacts with the medium. The speed of light in the medium is given by $v = c/n$, where c is the speed of light in vacuum. The index of refraction is always greater than or equal to one. In general, the index of refraction depends on the color (i.e. wavelength, λ) of the light.

Index of refraction for λ=589 nm					
Air	1.000293	Glass, crown	1.52	Polystyrene	1.49
Water	1.333	Glass, flint	1.66	Diamond	2.419

<u>Reflection and Refraction with a HeNe (helium-neon) laser</u>

Obey all instructions regarding laser safety: you do not want to shine the laser in anyone's eye!

Turn off the laser or cover the beam when you are not using it

The direct beam is most hazardous. Make a "block" out of poster board and block the laser beam before it leaves the lab table.

The reflected beam is less dangerous, but you should still keep track of reflections and make sure they do not shine in anyone's eye.

Procedure

Reflection of Light:

Equipment needed: HeNe laser; glass plate; ruler; protractor; paper; beam block

For this experiment you will observe reflection of a laser beam from a piece of plate glass.

Tape a piece of paper onto a level surface and draw a pencil line at the center to use as the baseline for the position of your “mirror”. (see Fig. 1)

Set up the HeNe laser so that the beam is reflected from the glass straight back at the laser. (You may need to turn your laser upside down. If your table is not exactly flat the beam may be high or low when it gets back to the laser).

Obey laser safety instructions and make sure the transmitted beam is blocked.

Hold a pencil or a straight edge vertically down from the laser beam near the edge of the paper. (Let the laser beam hit the center of the pencil, or graze the edge of the ruler.) Mark a point on the paper directly beneath the beam. Make another point on the paper beneath the point where the beam hits the glass. Draw a line representing the incident beam.

Measure the angle between the glass and the beam and confirm that it is 90°.

Making sure the laser beam remains aligned, remove the glass and draw and label lines at 30°, 45° and 60° to the line representing the initial position of the surface of the glass, through the point where the beam hit the glass. From the same point, draw and label a dashed line *normal* to each of these lines.

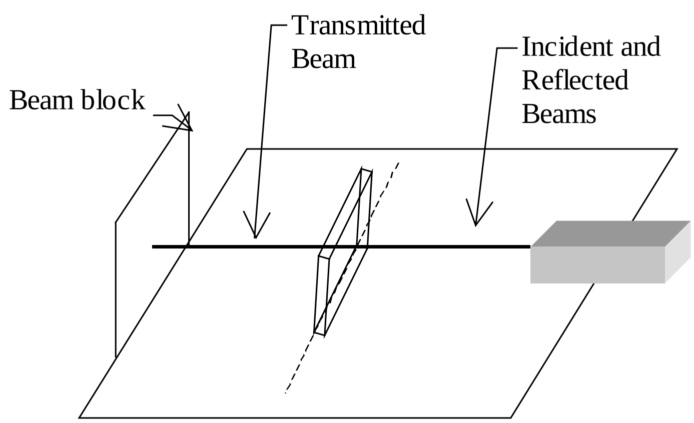


Figure 1: Reflection of 90° incident beam

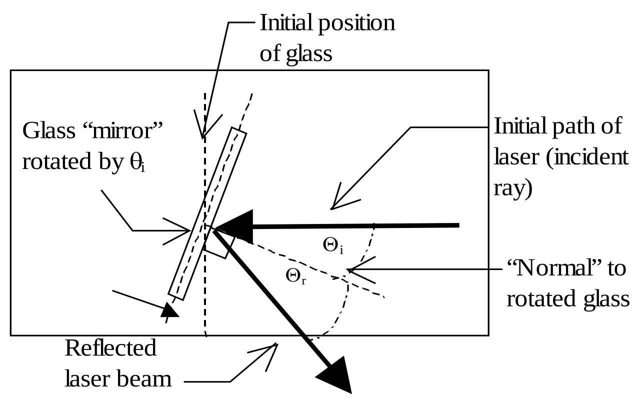


Figure 2: Lines drawn on paper during measurements. The incident and reflected

Replace the glass with its reflecting surface along the 30° line, mark points under the reflected laser beam, and draw and label a line representing the beam reflected from the external (laser side) surface.

Measure and label the *angle of incidence* and the *angle of reflection* (from the normal to the surface).

Repeat for angles of 45° and 60°. Record your data in the table below. (For the final report each member may keep one drawing or trace a drawing and write their own labels).

Angle of Incidence	Angle of Reflection

Summarize your data and discuss whether it agrees with the law of reflection.

Refraction of Light:

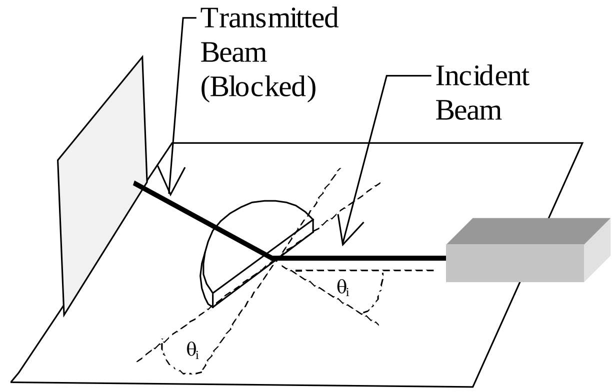


Figure 3: Refraction of a laser beam in

Equipment needed: plastic, half-circle dish; beam block; laser; ruler; paper.

Tape a piece of paper onto a level surface and draw a pencil line at the center to use as the baseline for the initial position of your refracting surface. Draw and label lines rotated 30°, 45° and 60° to the baseline and intersecting the center of the baseline. (Suggestion: Use different colored pencils for different angles.)

Draw and label dashed lines normal to each of these lines. (Use same color code.)

Set up the half-circle dish (open side up) with the flat side along the baseline and towards the laser. Line up the laser so its flat surface is normal to the flat surface of the dish and mark the path of the incident laser beam.

Make sure the transmitted beam is blocked.

Leave the laser fixed and rotate the dish by 30° and mark the new position of the flat side. Notice if anything happens to the transmitted beam.

Fill the dish with water and notice if anything happens to the transmitted laser beam.

The laser beam should be visible in the water. (Adding a few drops of dilute white paint will help.)

Put the top on the plastic dish and use the protractor to measure the angle of the refracted beam from the flat side of the dish.

Remove the plastic dish and draw the line representing the refracted beam on the paper using the angle you measured. (Continue to use your color code.) Label all lines clearly.

Repeat for angles of 45° and 60°. Each lab partner should have a sketch that they have labeled for their final report.

Use the following table to summarize your data (angles of incidence and angles of refraction).

In the third and forth columns of the table, calculate the angles of refraction using Snell's Law and the percent difference from your experimental observation. Discuss your results.

Angle of Incidence	Angle of Refraction	Angle of Refraction (from Snell's Law)	% Difference

Refraction and Internal Reflection (water and air):

Equipment needed: plastic half-circle dish; water; laser block; laser; ruler; paper.

Line up the half-circle dish so that the laser refracts through the second surface but is normally incident on the first surface, as shown in Fig. 4. Find the transmitted beam. Fill the dish with water and observe what happens to the transmitted beam. If necessary, adjust the angle of the second surface until you can see the transmitted beam.

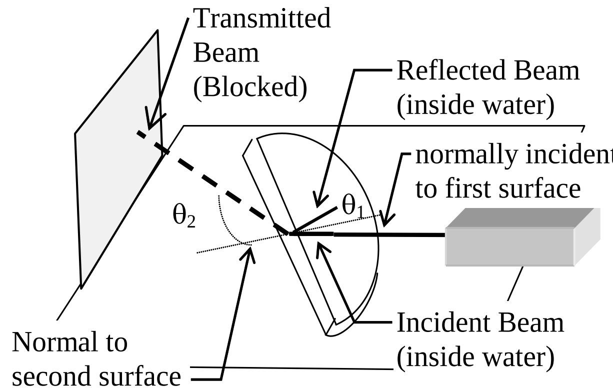


Figure 4: Internal reflection inside the semi-circular dish

You will be looking at reflection from the second surface (inside the water).

Now the incident angle, θ_1, is the angle inside the water and θ_2 is the angle in the air as the beam leaves the second surface of the dish.

Based on Snell's law, which would you expect to be greater, θ_1 or θ_2?

Carefully measure both of these angles (relative to the normal). Which is bigger θ_1 or θ_2?

In the water you should see *internal reflection* from the second surface (i.e. water to air interface). Slowly rotate the dish and observe the intensity of both the reflected and transmitted beams. How do the intensities of the transmitted light and the internally reflected light change with angle?

In *total internal reflection* there is no transmitted light. Can you observe this by rotating your prism?

What is the minimum value of θ_1, the angle of the incident beam (hitting the second surface from inside the water) for which total internal reflection just occurs?

Use this minimum value of θ_1 and Snell's Law to calculate the index of refraction of water. (Hint: What is the value of θ_2 when total internal reflection occurs?) Compare your calculated value to the value given in the table (1.333).

Refraction & "Dispersion" by a Prism:

Equipment needed: a source of collimated white light and a prism.

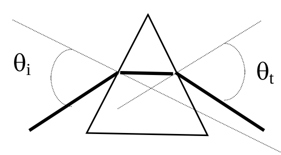


Figure 5: Refraction by a prism

Figure 5 shows a single color of light being refracted by a 60°, equilateral triangle, glass prism. Because the prism has an index of refraction greater than air the light is bent "inward" when passing from air to glass.

Your instructor will make a similar setup using a prism and a source of collimated white light. Make a sketch of what you see, noting the colors.

When the different colors of light in an incident beam are refracted by different amounts, they are said to be *dispersed.* The phenomenon you have observed is known as the *dispersion* of white light into its component colors. According to your observations, is blue light refracted more or less than red light by the prism?

Is the index of refraction for blue light greater or less than for red light?

Index of refraction of glass:

Equipment needed: square glass slab; laser beam block; laser; meter stick.

Set up the laser so that it hits a meter stick (positioned on its edge) perpendicularly. Mark a line under the laser beam representing the undeflected path of the beam.

Draw two lines at ±45° to the undeflected path and place a square glass slab, flat, at a 45° angle to the laser beam, with the beam passing through the clear (polished) edges. (Note: You may need to prop the glass on a plastic top.) Observe what happens to the transmitted beam as you insert the glass. (See Figure 6.)

Is the laser beam being deflected at an angle (in which case the distance of deflection gets larger as you move farther from the glass), or is it simply displaced a constant distance (in which case it travels parallel to the undeflected path but displaced to the side)? Trace the path of the transmitted laser beam until you understand what is happening.

Measure the distance of deflection and the width of the glass slab. Make sure you have an accurate measure of the angle of incidence on the glass slab.

Make a sketch of the path of the laser beam through the glass and label the angle of incidence, θ_1, the width, h, and the deflection distance, d.

Use Snell's Law, your glass width, h, the incident angle, θ_1, and a value of n = 1.5 to calculate the deflection distance, d, through the glass. Does your glass have an index of refraction greater or less than 1.5? Does the deflection increase or decrease with increasing index of refraction?

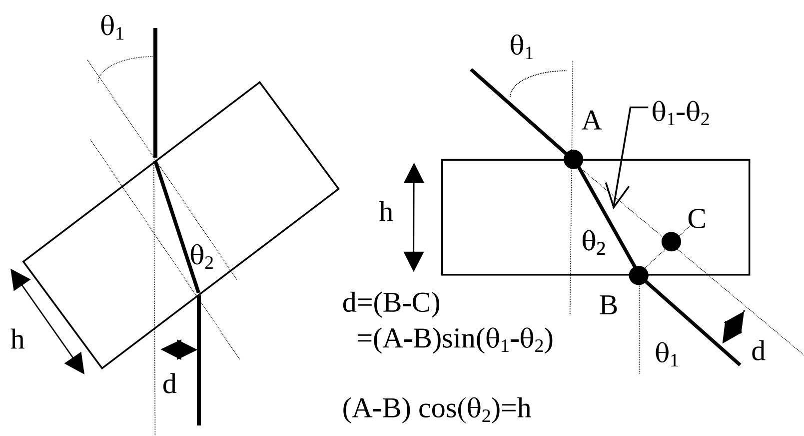


Figure 6: Refraction in glass (two views). For a slab of glass with parallel sides the emerging angle is equal to the incident angle and the beam of light is simply displaced a distance d.

Checking your understanding (optional essay):

Now, back to that straw in the glass of water! Take a clear, plastic cup, fill it with water, and stick a straw into it. Observe and record your observations when looking at the straw from above at different angles. (Suggestion: Make sketches.) Also, look at the straw from the side, through the cup, and describe what you observe. Discuss your observations and interpretations with your lab partner(s). Based on your understanding of the law of refraction, explain why you see what you see. (i.e. What's happening?)