

Reflection and Refraction

1. Introduction

A. Reflection

When light strikes the surface of a material, some of the light is reflected. The reflection of light rays from a plane surface like a glass plate or a plane mirror is described by the law of reflection: "The angle of reflection is equal to the angle of incidence", or

$$\theta_i = \theta_r$$

These angles are measured from a line perpendicular or normal to the reflecting surface at the point of incidence, Fig. 1.

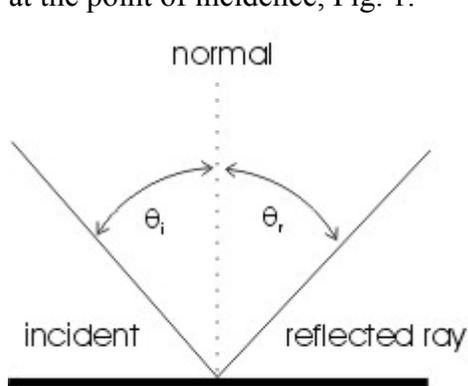


Fig. 1. Reflection

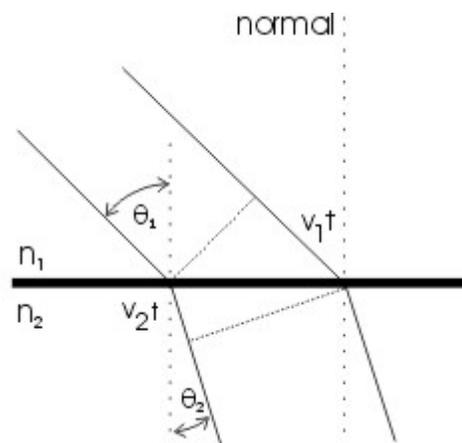


Fig. 2. Refraction

B. Refraction

When light passes from one medium into an optically different medium at an angle other than normal to the surface, it is "bent" or undergoes a change in direction, as shown in Fig. 2. This is due to the different velocities of light in the different media. For θ_1 , the angle of incidence, and θ_2 , the angle of refraction, we have

$$\sin \Theta_1 = \frac{v_1 t}{d} \quad \text{and} \quad \sin \Theta_2 = \frac{v_2 t}{d}$$

or

$$\frac{\sin \Theta_1}{\sin \Theta_2} = \frac{v_1 t}{v_2 t} = n_{12}$$

where the ratio of velocities is called the relative index of refraction. For light traveling initially in a vacuum, the relative index of refraction is called the absolute index of refraction or simply the index of refraction, and

$$n = v/c$$

where c is speed of light in a vacuum and v the speed of light in the medium. Snell's Law can then be written

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

where n_1 and n_2 are the indices of refraction of medium 1 and 2, respectively.

2. Procedure

You will do three different experiments, listed below as A, B, and C. You may use a photometer and the fiber optic probe (recommended) or use your eye to detect maximum intensity of light. The laser or an incandescent light source can also be used in all three methods. When the laser is used no aperture mask is then needed. If you decide to use the laser, do not look into the beam. Observe reflected and transmitted light using a piece of paper. In the following sections we will assume that you will use the laser source, but if you or the lab assistant decide to use an incandescent lamp, follow the same steps but simply replace "laser" with "lamp" when appropriate.

A. Angles of Incidence and Reflection

i) Position the laser (the incandescent light source) on the left end of the optical bench, and place the angular translator about 25 cm from the end of the laser (or light source housing). Make sure the 0° and 180° marks lie on a line parallel to the bench. Finally adjust the rotating table so that the scored lines run perpendicular and parallel to the bench.

ii) Attach a viewing screen with a millimeter scale onto the magnetic holder. Switch on the light and adjust the laser so it hits the center of a millimeter scale marked on the screen.

iii) Replace the viewing screen with the flat surface mirror. Make sure that the mirror surface is parallel to the scored line.



Fig. 3. The component carrier (left) and the angular translator with the component carrier on the rotating table (right).

iv) Rotate the table a set number of degrees (for example, 30°), and then move the arm until the reflected laser passes through the center of the aperture on the viewing arm. Use a piece of paper or the plastic screen to detect laser light. Record the angle which the arm makes with the mirror. What is the relation between the angle of incidence and the angle of reflection? (Angle of incidence is the angle the incident ray makes with the normal to the reflecting surface; similarly for the angle of reflection.) Repeat for 3 various settings of the incidence angle, fill out Table 1.

v) Replace the flat mirror with a concave or a convex mirror. Repeat point (iv).

Table 1. Angle of incidence vs. angle of reflection

Incidence angle θ_1	Reflection angle θ_2	
	Flat mirror	Spherical mirror

B. Index of Refraction.

i) In this experiment you will need a viewing screen and a square glass plate with two magnetic tapes, one at the top and one at the bottom. In the second part of this experiment you will replace the glass plate with a transparent acrylic plate. Record the thickness of the plates.

ii) Using the same equipment setup as in Experiment A, place the glass plate and the special component carrier on the rotating table. Place the screen attached to another

component carrier on the optical bench, several centimeters behind the angular translator. The millimeter scale on the screen should run horizontally.

iii) Adjust the position of the component carrier until the back surface of the glass plate coincides with one of the two perpendicularly scored lines on the rotating table.

iv) With the glass plate perpendicular to the bench, adjust the position of the laser so that the light strikes the center of the millimeter scale. If the glass does not alter the lights' path, the position of the beam should remain the same although the translator's table is rotated.

v) Rotate the table and record what happens to the previously centered beam. Is the incident ray refracted toward or away from the normal to the glass? Figure 4 shows how to calculate θ_2 and next the index of refraction given the angle of rotation, θ_1 , and the displacement of the image, d . Using this method, a large error is introduced since the definition $\sin \theta_2 = d/t$ is correct only for a right triangle, but the triangle formed by the refracted beam, glass surface and the normal is not a right triangle.

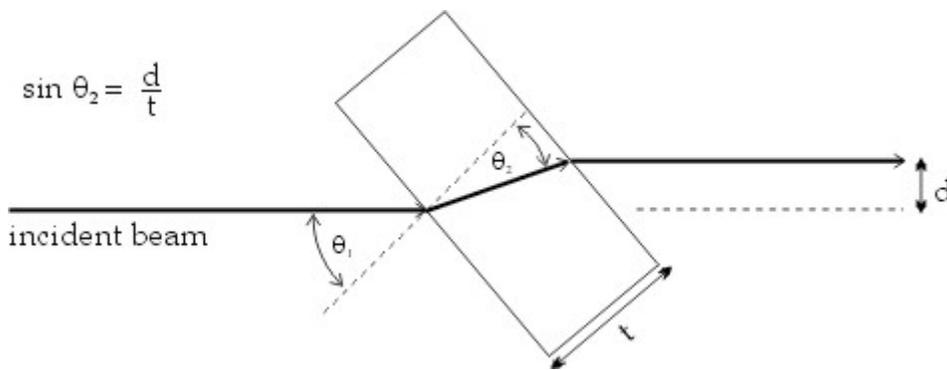


Fig. 4. Refraction by a plate. Note that in Experiment B we assumed that $\sin \theta_2 \approx d/t$.

Since the estimated value of θ_2 is not accurate, the index of refraction calculated from $n = \sin \theta_1 / \sin \theta_2$ can be treated at best as a first approximation.

Repeat measurements N times for different incident angles and fill out Table 2. N should be between 6 and 10. Then find the average index of refraction from $n_{ave} = \sum n_i / N$, where N is the number of measurements and n_i is index of refraction obtained for a specific angle of incidence. Next, estimate the error by calculating variance, σ ,

$$\sigma = \sqrt{\frac{\sum_{i=1}^N n_i^2}{N-1} - n_{ave}^2}$$

vi) Replace the glass plate with the acrylic plate and determine the index of refraction for acrylic.

Table 2. Index of refraction. Record only values of θ_1 and d. You will calculate n and n_{ave} and variance later.

Glass plate			Acrylic plate		
Incident angle θ_1	Displacement d [mm]	$n = \sin \theta_1 / \sin \theta_2$ $\approx (t/d) \sin \theta_1$	Incident angle θ_1	Displacement d [mm]	$n = \sin \theta_1 / \sin \theta_2$ $\approx (t/d) \sin \theta_1$

C. Index of Refraction. This method is more precise than that in part B.

i) Place the glass plate attached to the component carrier at the center of the rotating table. Place a square piece of paper about 5 centimeters on a side with a millimeter scale across the middle between the glass plate and the component carrier. Align the component carrier so the back surface of the glass plate is parallel to the scored line on the table. Place the viewing screen with the millimeter scale on the viewing arm. Turn the laser on and rotate the table to a convenient angle. You should see least two reflections on the screen as indicated in Fig. 5.

Light is refracted toward the normal when passing from air to glass. Is the same true when light propagates from glass to air? By observing the positions of the image on the viewing screen, you can see that the refraction must be away from the normal at a glass-air interface. (See Fig. 5).

ii) Observe on the screen two reflected laser beams from the plate. Measure the distance between them. You can measure the distance between the two images observed on the back of the plate using the paper with the millimeter scale or in the front of the plate on the screen placed on the viewing arm. Using the following symbols: D - the distance separating the laser spots on the back of the plate; t - the plate thickness; θ_1 - the angle of incidence; and θ_2 the angle of refraction, we have $\tan \theta_2 = D/(2t)$

Repeat measurement N times for different angles of incidence. Calculate θ_2 for various θ_1 . Then calculate n from $n = \sin \theta_1 / \sin \theta_2$ and average value of n and variance.

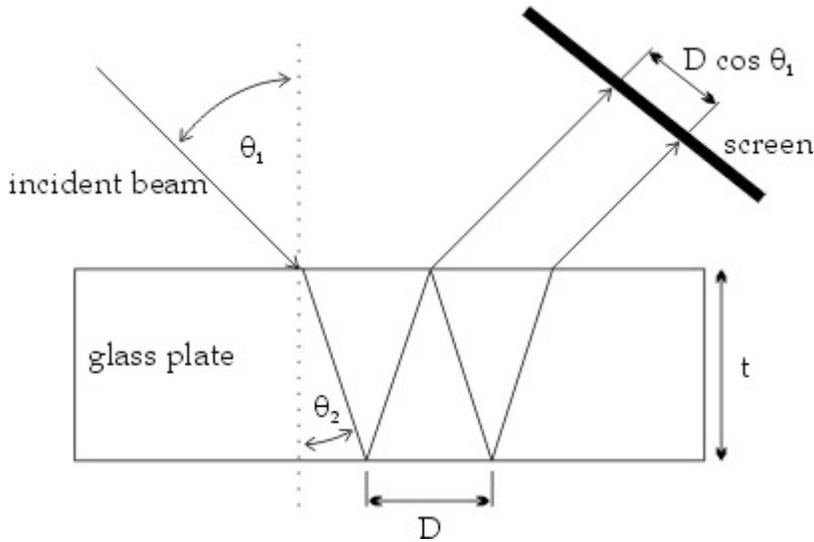


Fig. 5. Secondary reflections

iii) Repeat for the acrylic plate.

Table 3. Index of refraction. In class record only values of θ_1 and D . You will calculate values of n , n_{ave} , and variance σ later.

Glass plate				Acrylic plate			
Incident angle θ_1	D [mm]	θ_2	$n = \sin\theta_1 / \sin\theta_2$	Incident angle θ_1	D [mm]	θ_2	$n = \sin\theta_1 / \sin\theta_2$

3. Report

1. In the introduction discuss the total internal reflection and its applications. You may want to read a section in your textbook on total internal reflection.
2. In the result section present data in Tables 1, 2 and 3.
3. Calculate the average values of n and experimental errors, σ .
4. Index of refraction of glass varies between 1.50 and 1.80 depending on glass composition and the wavelength of light. Index of refraction of acrylic also varies with the wavelength, and for the red laser it is about 1.49. Compare your results with the expected values and discuss possible deviations.

5. In the conclusion section comment about relationship between reflection angle and incident angle for flat and spherical mirrors.