Reflection and Refraction of Light

Goals and Introduction

When a source creates light, it is common that the there is no preferential direction in which the light is emitted. And yet, we find that while light travels in a medium, unobstructed by any obstacles, it will travel in a straight line, called a *ray*. This means that if we could follow the light back along the path it has traveled, we could locate the *point of divergence* of the light, or the location of the source. With a minimum of two rays of light from a source, we could back trace along their directions of travel and determine where they intersect. This should be where they originated, or at least is the point from which they both diverged.

In the case where a traveling ray of light does encounter an obstacle while traveling in a medium the light often undergoes two processes – *reflection* and *refraction*. Some percentage of the light will reflect from the surface of the obstacle and the remaining light will transmit into the material, or refract. Each of these events is governed by a law that can be derived by examining the wave nature of light.

In the *law of reflection,* a ray of light that is incident on a surface can be said to be traveling with some *angle of incidence* to the surface. This angle is measured from the normal to the reflecting surface (a line that is perpendicular to the surface). After the ray reflects from the surface, we can also measure the *angle of reflection*, again, as measured from the normal to the reflecting surface (Figure 1). The law of reflection states that after the light ray is reflected, it will be traveling in a direction away from the surface such that the angle of reflection is equal to the angle of incidence (Eq. 1).

$\theta_i = \theta_r$ (Eq. 1)

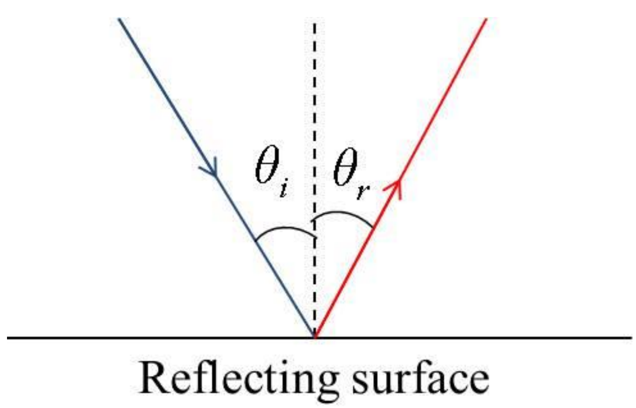

Figure 1

In the *law of refraction*, a ray of light that is incident on a surface can, again, be said to be traveling with some angle of incidence to the surface. Here, the surface acts as a boundary between two media. Within each medium the speed of light is different. One way in which we note this difference is by defining an *index of refraction*, *n*, for each medium. The index of refraction is equal to the ratio of the speed of light in a vacuum to the speed of light in that medium (Eq. 2).

$$n = c/v \qquad \text{(Eq. 2)}$$

Because of the speed difference between the two media, as a light ray crosses the boundary and is transmitted into the next medium, the direction the ray is traveling will change. Refraction is the bending of the light ray, or the change in direction.

There are two possibilities in this scenario, where a ray of light travels across the boundary between two media: (1) the transmitted ray is pulled towards the normal to the surface if the transmitted medium has a higher index of refraction than the incident medium, or (2) the transmitted ray is pulled away from the normal to the surface if the transmitted medium has a lower index of refraction than the incident medium. One example of the refraction process for a ray is shown in Figure 2. The relationship between these quantities is captured in Snell's Law (Eq. 3).

$$n_i \sin\theta_i = n_t \sin\theta_t \qquad \text{(Eq. 3)}$$

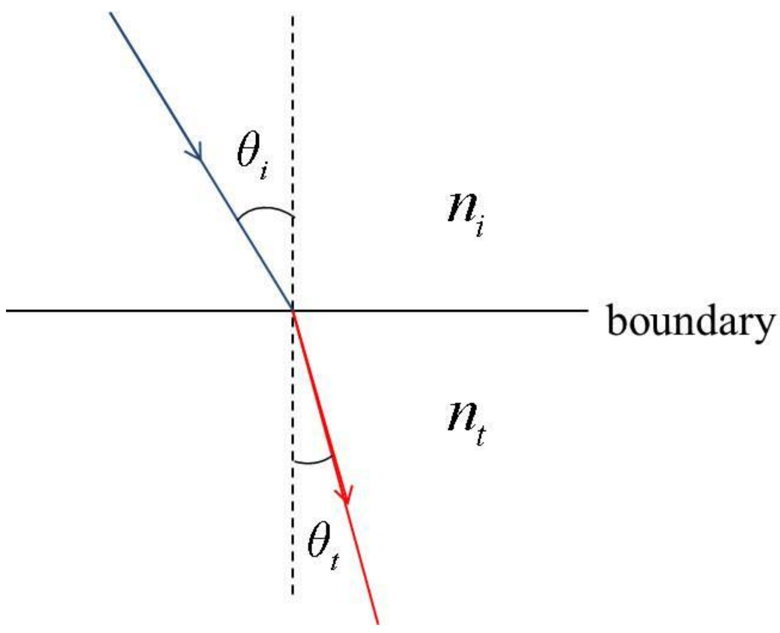

Figure 2

In today's lab, you will trace rays of light and use your traces to locate the point of divergence, or the source of the light. You will also verify the law of reflection of light from a surface. Lastly, you will verify that light refracts as it passes through a boundary between two media and use your measurements to determine the index of refraction of a material. To perform many of these measurements and sketches accurately, you may require a good deal of paper. Be sure to use a ruler, or some form of straight edge and include these sketches in your lab report as figures to which you can refer in your conclusion, as necessary.

Goals: (1) Determine the point of divergence for a set of light rays
(2) Measure and verify the law of reflection
(3) Measure and verify the refraction of light
(4) Use Snell's Law to determine the index of refraction of a medium

Procedure

Equipment – mini-optics bench, light source, slit mask aperture, slit plate, one component carrier, straight-edge, or ruler, circular ray table with base, paper for ray tracing, ray optics mirror, cylindrical lens

NOTE: The room lights should be turned down during the rest of the experiment.

1) Lay out the lab optics bench from the kit box. Note that the rulers on the sides are in units of mm. You can place components of this lab on this bench during the experiment. Some are magnetic and will be held in place when you place them on the bench.

2) Place the light source from the kit box onto the optics bench at the far end. Be sure to turn the knob on the top of the light source so that the bulb is aligned with its reflector to project light forward. The dot on the knob should be facing forward, in the direction the light will travel from the bulb along the bench. **Record** the location of the bulb in the box, as measured using the ruler on the bench.

3) Place the base for the circular ray table on the optics bench and then place the ray table on top of the base. The table should be tilted towards the light source, as it sits on the base.

4) Attach the slit plate to the component carrier so that the slits are vertical, and place it on the optics bench between the light source and the ray table. Move the carrier so that the slits are about 5 cm in front of the light source. Then, slide the base holding the ray table until it touches the component carrier's base. **Record** the location of the center of the ray table, as measured using the ruler on the bench.

5) Turn on the light source and verify that you see the rays coming through the slit plate and striking the ray table. Then, fold a piece of paper so that you can draw on just the top half of the page. Lay the paper on the ray table.

6) Using a straight-edge, or ruler, center the paper on the ray table, **mark** the center of the ray table on the paper, and **trace** the path of the rays, noting the direction the light is traveling. Then, unfold the paper and, off to the side, use the ruler to **back-trace**, each of the rays to find the location where they appear to intersect. Use additional paper, by taping it to the bottom of your page, is necessary. On your paper, **measure and record** the distance from the center of the ray table to where the rays intersect. **Include** this sketch in your lab report.

7) Now, orient the ray table so that the "normal" line is pointing towards the light source, and the "component" line is perpendicular to the optics bench. Place the ray optics mirror on the ray table so that the flat face of the mirror faces the light source and lies along the "component" line on the ray table.

8) Align the slit plate by sliding it around on the carrier so that the center ray is traveling along the "normal" line on the ray table. Though there are other rays coming through the slit plate and hitting the mirror, we will only use the center ray for measurements in this part of the experiment.

9) Observe that as you rotate the ray table, the reflected rays change direction. In particular, observe that the center reflected ray becomes clearly visible when the table has been rotated so the center ray is no longer normally incident. Angles of incidence and reflection are measured relative to the "normal" line on the ray table.

Question 1: Given our setup and available equipment, why is it important to only use the center ray for measuring angles in this part of the experiment? Does this mean that the other rays do not obey the law of reflection? Explain why or why not.

10) Begin by rotating the ray table so that the incident center ray is traveling along a direction about 5° from the "normal" line. **Measure and record** the angle of incidence (should be near 5°, but make sure). Then, **measure and record** the angle of reflection.

11) Repeat step 10 by increasing the angle by 5° from the previous angle. The final angle of incidence you should consider is 85°.

12) Now, replace the ray optics mirror with the cylindrical lens, which is made of acrylic plastic. Align the flat face of the lens so that it lies along the "component" line on the ray table. Again, align the slit plate by sliding it around on the carrier so that the center ray is traveling along the "normal" line on the ray table. Though there are other rays coming through the slit plate and hitting the lens, we will only use the center ray for measurements in this part of the experiment.

13) Observe that as you rotate the ray table slightly, you can see that the center ray travels in a different direction within the plastic lens. You need to look within the plastic to see the change in direction that occurs when the light hits the flat face of the plastic. There is a miniature scale for measuring angle within the plastic (or just on the rim of the curved portion) that you will use for determining the angle of refraction in each case.

Question 2: Given our setup and available equipment, why is it important to only use the center ray for measuring angles in this part of the experiment? Does this mean that the other rays do not obey the law of refraction? Explain why or why not.

14) Begin by rotating the ray table so that the incident center ray is traveling along a direction about 10° from the "normal" line. **Measure and record** the angle of incidence (should be near 10°, but make sure). Then, **measure and record** the angle of refraction that is occurring where the light hits the front, flat face of the plastic.

15) Repeat step 14 by increasing the angle by 5° from the previous angle. The final angle of incidence you must consider is 40°.

As always, be sure to organize your data records for presentation in your lab report, using tables and labels where appropriate.

Data Analysis

Calculate the distance between the center of the ray table and the light source by using your measurements in steps 2 and 4.

Assume the index of refraction in air is equal to 1. Using Snell's Law, calculate the index of refraction for each angle of incidence that you used in steps 14 and 15.

Calculate the mean value of the index of refraction, based on your data.

Research and find a value for the expected index of refraction for acrylic plastic.

Error Analysis

Calculate the percent error for the distance between the light source and ray table, comparing the value you found in the Data Analysis section and the value from your sketch.

$$\%diff = \frac{|d_{\text{calc}} - d_{\text{sketch}}|}{d_{\text{calc}} + d_{\text{sketch}} \,/2} \times 100\%$$

Calculate the percent difference for each law of reflection measurement using the angle of incidence and reflection you recorded in each case.

$$\%diff = \frac{|\theta_i - \theta_r|}{\theta_i + \theta_r \,/2} \times 100\%$$

Question 3: Was the law of reflection verified? Explain your answer given the percent differences you calculated.

Calculate the percent error between the mean value of index of refraction you found from your data and the value you researched.

$$\%error = \frac{|n_{\text{experimental}} - n_{\text{predict}}|}{n_{\text{predict}}} \times 100\%$$

Question 4: The lab equipment manufacturer claims that the plastic is acrylic plastic. Based on your results and the percent error calculation, what is your assessment of this claim? Explain your answer.

Questions and Conclusions

Be sure to address Questions 1 through 4 and describe what has been verified and tested by this experiment. What are the likely sources of error? Where might the physics principles investigated in this lab manifest in everyday life, or in a job setting?

Pre-Lab Questions

Please read through all the instructions for this experiment to acquaint yourself with the experimental setup and procedures, and develop any questions you may want to discuss with your lab partner or TA before you begin. Then answer the following questions and type your answers into the Canvas quiz tool for "Electromagnetic Waves – Intensity and Polarization of Light," and submit it before the start of your lab section on the day this experiment is to be run.

PL-1) A ray of light strikes a flat surface with an angle of incidence of 25°. What is the angle of reflection? Express your answer in degrees.

PL-2) Selma and Igor are working on measuring the reflected light from the flat face of the mirror. Igor made a mistake and measured the angle of incidence as if it were between the light and the flat face of the mirror, rather than the "normal" line. He should,

A) just subtract the angle he measured from 180° because that would basically be the angle of incidence and that's okay.

B) just subtract the angle he measured from 90° because that would basically be the angle of incidence and that's okay.

C) start over and repeat the experiment measuring the proper angle.

D) use that angle because it is basically the same thing.

PL-3) Selma measures an angle of incidence in air of 40° (n_{air} = 1), as a ray strikes the front, flat face of the plastic. If she measures an angle of refraction of 23°. What is the index of refraction of the plastic that she will calculate?

PL-4) Selma measures an angle of incidence in air of 40° (n_{air} = 1), as a ray strikes the front, flat face of the plastic. If she measures an angle of refraction of 23°. She notices that while some of the light did transmit into the plastic, some of it reflected from the flat surface. What is angle of reflection?

PL-5) Igor has measured an index of refraction for the plastic of 1.7. He would like to predict the angle of incidence that would result in an angle of refraction of 10°. What is the angle of incidence? Express your answer in degrees and assume n_{air} = 1.