Index of Refraction and Total Internal Reflection

Name:

Group Members:

Date:

TA's Name:

Materials: Ray box, two different transparent blocks, two letter size white pages, pencil, protractor, two nails, and graph paper.

Objectives:
1. Understanding image formation due to refraction.
2. Finding the index of refraction of a transparent material.
3. Observing total internal reflection and experimentally finding critical angle.

Part 1: Introduction and Predictions
Take a look at the transparent cube in which you find a vertical strip on one of its sides. If you look through the opposite side of the cube as shown in the side view below, you see the strip (image of the strip) appear to be closer to you than the actual strip (object) because the light coming from the strip is refracted as it exits the cube to get to your eye. We will use the method of parallax as you used in the tutorial to locate the image and compare the location of the image with the location of the object.

Vertical strip   observer
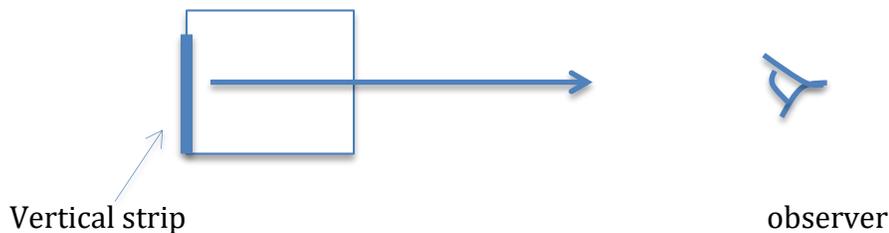
Light scattering off of the strip (the object) first travels through the block (medium 1) and then travels through the air (medium 2) to get to your eye.

1.   What is the index of refraction of air?

2.   Is the index of refraction in medium 1 (block) larger or smaller than medium 2 (air)?

3.   Do you think the image appears to be closer to you or farther away than the object?

4.   Do you think the image is real or virtual? Why?

5.   Do you think that the image is formed because light is being reflected or because light is being refracted?

6.   Let's test our answers by constructing a ray diagram below (viewed from above looking down at the block on the table). The diagram shows rays of light leaving the vertical strip in three directions. These rays travel through the cube. Predict what happens to the rays when they pass from the cube into the air. Draw the path of the three rays after they pass from the cube to air, that is, show the path of each ray starting at the arrow head in the drawing and going in some direction in the air. We have drawn the normal (perpendicular line) at each of point that our rays arrive at the surface. Use reasoning from Snell's law to decide the direction for each ray, that is, if the ray moves to a region of smaller index of refraction, does the angle increase, decrease or stay the same.
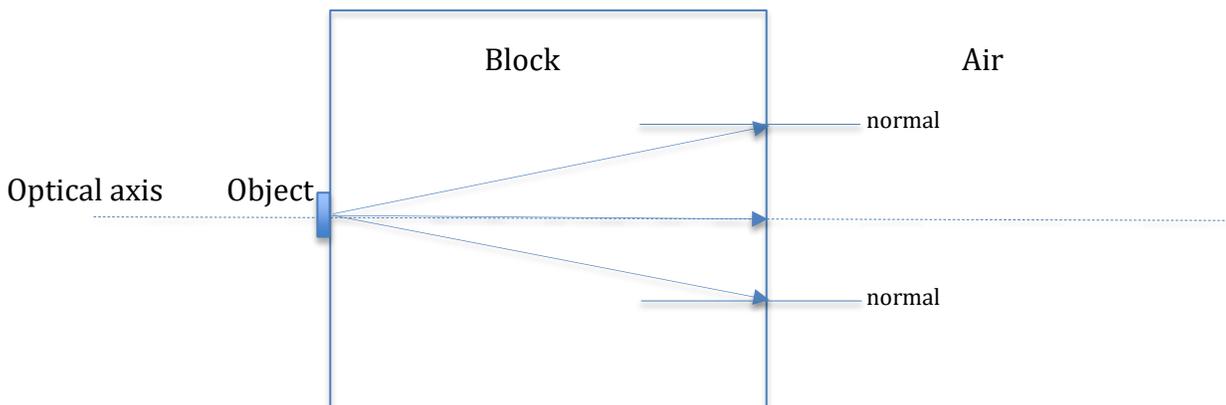

7.   Now we will determine a prediction for the location of the image formed by the emerging rays. The question we are asking is "where do the rays appear to be coming from?" Use a straight edge to extend your predictions of the rays in air back through the cube. Find the location where they cross (or nearly cross). This is the location of the image. Mark it with an "I." This is your prediction of where the image is located.

8.   Look back at your answers for prediction questions 3, 4, and 5 and see if they are consistent with your drawing above. Don't change your original answers but comment here if you think there is a better answer for any of those questions or if you are satisfied with your previous answers. For this to be a real image, the rays reaching your eye must pass through the image location. Does that change your answer?

Part 2: Image formed by refraction

9.   Put the transparent cube on clean white paper. Draw the block outline on the paper. Put a mark on the paper where the vertical strip is located and label that with an "O" since this is the object location. Indicate the optical axis which goes through the center of the strip and which is perpendicular to the front and back surfaces of the cube (see the dotted line on our figure in Question 6).   Now we will experimentally find the location of the image of the vertical strip using the method of parallax you practiced in the tutorial session. Use the same nails you used in the tutorial. To use the method of parallax keep the block steady. Then look at the image of the strip with one eye closed with your head on the right side of the optical axis at about 10^0-20^0 angle. Place one nail close to the block so that it lines up with where you see the vertical strip. Place the other nail at the near edge of the paper closer to you so that it lines up with where you see the vertical strip. Now mark the location of the nails on the paper and then use a ruler to draw a straight line between those two points and extending to the surface of the block. Now do the same thing with your head at the left side of the optical axis.
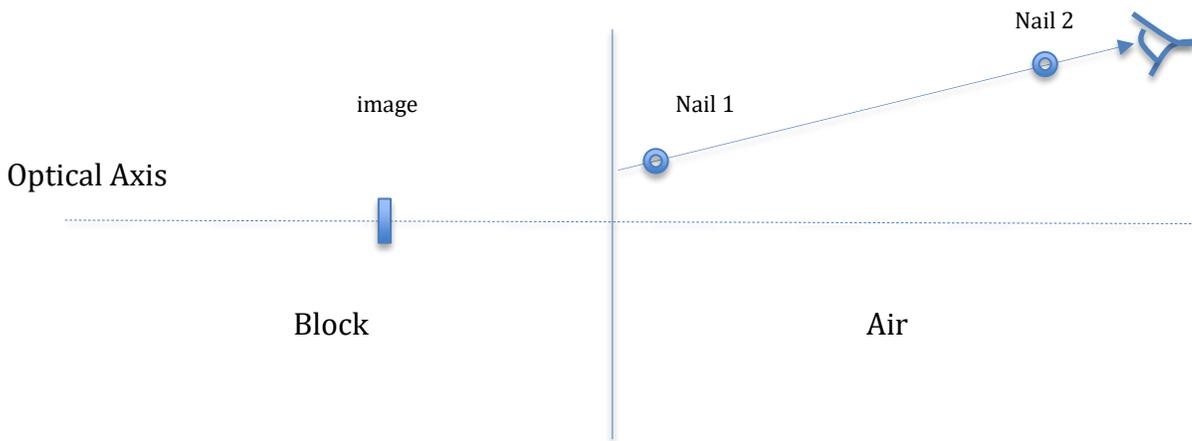
10.   Now remove the block from the paper and use the ruler to extend the two rays back through the outline of the block. Where these two extended rays cross is the image location. Mark it with an "I".

11.   Now use the ruler to measure the distance from the vertical strip (object) to the front surface of the block. Also measure the shortest distance from the image location on your paper to the front surface of the block. Enter those values below.

Object distance from the front surface S (cm)	Image distance from the front surface S' (cm)

12.   For each parallax measurement (each emerging ray on both sides of the optical axis) draw a straight line on the paper from the object to the point where light emerges from the block. Identify on your paper the angle from the normal or optical axis and then denote the incident angle θ_1. Also identify the refracted angle from the normal (this is the line you determined using the nails) and label it θ_2.

13.   Using a protractor measure the incident angle and the refracted angle for one of the two rays you used to locate the image.

	Incident angle, θ_1	Refracted angle, θ_2
Ray 1		
Ray 2		

14.   Use Snell's law, $n_1 \sin \theta_1 = n_2 \sin \theta_2$, to calculate the index of refraction of the block from your data. Show your calculations below. Use angles obtained from both rays.

Part 3: Total Internal Reflection

You learned in class that fiber optics cables transmit light over a long distance without much loss using "total internal reflection." Next we will investigate this phenomenon. The figure below shows a semicircular piece of transparent plastic block. Two light rays enter into the plastic radially toward the center of the piece. Since the rays are perpendicular to the surface of the plastic each ray refracts with zero angle of refraction. Those two rays meet the plastic-air interface with different incident angles.
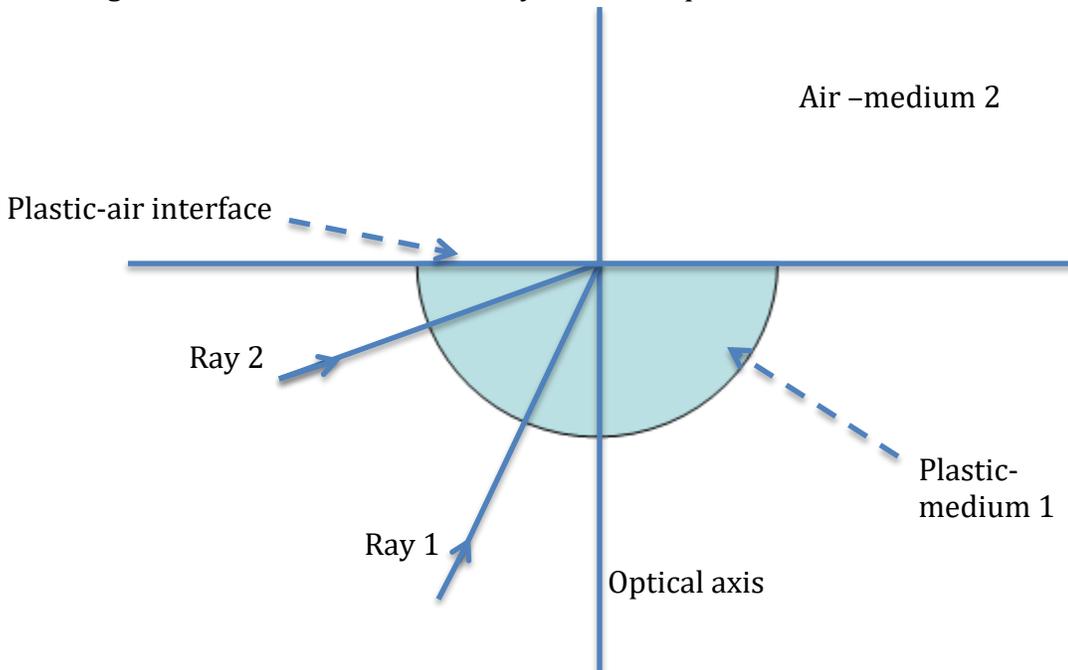
15.   Discuss with your group members what will happen to Ray 1 (reflect or refract or both or neither) at the plastic-air interface. Then sketch on the figure what you expect. Mark the rays to indicate they are from incident Ray 1.

16.   Ray 2 strikes the interface at a steeper angle. Discuss and decide if the same thing will happen to Ray 2 (reflect or refract or both or neither) at the plastic to air interface. Then sketch what you expect. Mark the rays to indicate they are from incident Ray 2.

You are provided a semicircular piece of plastic and a letter size paper. Draw the optical axis and plastic-air interface line on the paper. Put the semicircular piece of plastic on the paper as shown above. Arrange the ray box such that it emits only a single ray using the black "ray selector" piece. You will need to adjust the ray box by sliding the top part of the box back and forth to get a good a nice focused ray.

17.   First send a ray along optical axis and trace the ray. Does the refracted ray from the plastic-air interface show any deviation from the original path of the ray?

18.   Then send a ray toward plastic–air interface with a small incident angle (10^0-15^0 from the optical axis) similar to Ray 1 in the drawing and observe what happens to the incident ray at the plastic air interface. Does it reflect, refract, neither or both?

19.   Investigate what happens to the refracted and reflected rays at the plastic-air interface by increasing the incident angle at plastic-air interface. Increase the incident angle at least up to 60^0. Make sure that the incident ray is perpendicular to the circular surface by sending the ray radially toward the center of the semicircular piece. Describe your observations below of how the behavior of light striking the interface changes as the angle is changed.

20.   Trace the ray for which you get a refracted angle of 90°. The corresponding incident angle is called the *critical angle* for the plastic –air interface. Measure and record the critical angle.

θ_c = _____

21.   Now using Snell's law applied at the critical angle find the refractive index of the plastic. Show your work below.

$n =$ _____

22.   Make the following calculation. Increase the incident angle 5° more than critical angle you found ($\theta_1 = \theta_c + 5°$) and apply Snell's law to determine the **refracted** angle θ_2. Use the refractive index you found in Question 21 for the calculation. Show your work below.

23.   Explain why you got the answer you did in question 22. How does this make sense?

24.   Now try it experimentally. Create a ray where the incident angle is 5° more than critical angle ($\theta_i = \theta_c + 5°$). Does it reflect, refract, neither or both?

25.   If the plastic had a refractive index greater than what you found do you expect the critical angle to be greater than, less than or remain the same for plastic-air interface?

Please remember to attach both ray tracing papers to your lab report for grading.