Light in the Sea

Introduction

In Figure 1, a beam of light strikes a glass surface at an angle. At the interface between the glass and the air, part of the beam is reflected and part enters the glass. Notice that the light entering the glass bends at an angle. This bending is called refraction, and it occurs whenever light crosses—at an angle—the boundary between two media of different densities.

In Figure 1, light is traveling from a medium of low density to one of high density (air to glass). As the light enters the glass, it slows down and refracts toward normal. As $n_2$ (index of refraction) in second medium increases, the angle $\theta_2$ (as measured from the normal) decreases.

![Figure 1](image1.png)

In Figure 2, the opposite occurs. As the light moves from a high density medium to one of low density (glass to air), it speeds up and refracts away from normal. If $n_2$ decreases, then the angle $\theta_2$ increases.

![Figure 2](image2.png)

Willebrord Snell (1591–1626) is credited with the discovery of the relationships involved in refraction. He found that the change in velocity is analytically related to the angles formed at the boundary and the properties of the media through which the light is traveling.

That is,

- $V_2 = \sin \theta_2 = \text{constant}$
- $V_1 = \sin \theta_1$
- $V_2 = \text{velocity of light in second medium}$
- $V_1 = \text{velocity of light in first medium}$

The constant is a dimensionless number called the index of refraction and is represented by the letter "$n$." From the above equation, we get the widely used form of Snell’s Law:

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

- $n_1 = \text{index of refraction in first medium}$
- $n_2 = \text{index of refraction in second medium}$
- $\theta_2 = \text{angle of incidence}$
- $\theta_2 = \text{angle of refraction}$

This is the equation you will use to solve the problems in the following activities.
Activity 1

Bending Light

Purpose

To draw the path a light ray follows as it travels through fresh water and salt water. You will then measure the angles formed and determine the index of refraction for fresh water and salt water.

Materials

glass or plexiglass rectangular box
straight pins
cardboard
white paper
protractor with straight edge
salt water (50 grams of table salt to 1 liter of water)

Procedure

Secure a piece of paper to the cardboard and set it down on a table. Place the glass box on the center of the paper. Trace the outline of the box. Remove the box from the paper.

Find the midpoint on the back of the outline and mark its position (next to the line, not on it) (Figure 3). Label this point B.

Draw a dotted line through point B that is perpendicular to the outline of the box. This represents the normal to the back face of the box.

Draw another line, two centimeters in length, that extends out from point B at a 45-degree angle. Label the point at the end of this line “A” and the angle.

Stick a straight pin into the paper at Point A and another one at Point B (Figure 4). Fill the glass box with fresh water and place it back onto the paper inside the outline.

From the front of the glass box, position yourself so that your line of sight is just above the table top. You should have a clear view of the pins on the other side. Move left or right until the pins at Points A and B appear evenly aligned. (You may close one eye, but do not tilt your head.)

Once aligned, mark a third point, “C,” on the front side as close to the glass box as possible. Stick a straight pin into the paper at Point C. All three pins should appear to be aligned.

Carefully remove the glass box from the paper. Draw a line from point B to point C. Label the angle this line makes with the normal, “θ₂” (Figure 5).

Measure the angle with a protractor.

Using Snell’s Law, calculate the index of refraction for fresh water.

Fill the glass box with salt water and place it back over the outline. Repeat the steps above. Label your new point of alignment, “D,” and the new angle, “θ₂’.”

Calculate the index of refraction for salt water.
Questions

1. The accepted value for the index of refraction in fresh water is 1.33. How does your measured value compare with the accepted value? Express your answer in terms of percent error.

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\% \text{ Error} = \left( \frac{\text{Difference between measured & accepted values}}{\text{accepted value}} \right) \times 100\%
\]

\% \text{ Error} = \underline{\quad} \%

2. Why is there no single accepted value for the index of refraction of seawater?

3. In the experiment, we did not take into account what happens to the light as it passes through the glass. In terms of speed and direction, how does the light behave as it travels from the air to the glass? From the glass to the water? From the water to the glass? And, finally, from the glass to the air again?
ACTIVITY 2
Now You Don't See It, Now You Do

Purpose
To observe the difference in refraction for air, fresh water, and salt water and relate those observations to practical applications.

Materials
soup bowl
penny
saltwater solution (50 grams of table salt to 1 liter of fresh water)

Procedure
Place a penny in center of a bowl. Hold the bowl straight out from your chest at arm's length. The penny should not be visible.

Mark a spot on the wall or blackboard to indicate the level to which you raised the bowl. Return the bowl to this height for each procedure.

Add ¼ cup of water to the bowl, making sure the penny stays in the center. Again, hold the bowl at arm's length. Do you see the penny? If not, begin adding as many tablespoons of water as necessary to make the penny visible. How many additional tablespoons did it require?

Repeat the procedure using salt water. How many tablespoons of salt water did it require?

Questions
1. Which medium—air, fresh water or salt water—has the highest index of refraction? Explain.

2. In this experiment, light rays reflect off the penny and travel toward the observer’s eyes. Figure 6 shows a light ray traveling through air. Draw the light rays for Figure 7 and Figure 8. (Remember the light ray bends as it breaks the surface of the water, not when it reaches the top of the bowl.)
3. A tropical fish collector was rowing along the shore when he spotted a rare fish he wanted. The fish was swimming 8 feet below the surface of the water. Given that the angle of refraction (as the light travels from the fish to the collector's eyes) is 40 degrees, draw a ray diagram on Figure 9 below. Show the real and apparent positions of the fish.

To calculate the apparent position, first use Snell's Law to determine the angle of incidence. Then use the given angle of refraction (40 degrees) and the angle of incidence you calculated above. Hint: You will need to use basic trigonometry to solve this problem, i.e., relationships between angles.

Figure 9 Fish 8 feet below water surface

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normal

8 feet

actual position of fish
ACTIVITY 3
Absorption and Scattering

Purpose
To observe the effects of scattering and absorption on light waves in water.

Background
Many songs and stories suggest the ocean is blue. In fact, the ocean appears to be a variety of colors and hues, depending on your point of observation. From the beach, the ocean seems green or even gray. Water around a coral reef is a brilliant aquamarine, and a sunset casts a fiery red glare on the ocean’s surface.

These changes in colors are related to reflection, absorption and scattering of light waves, which also affect the depth of solar light penetration, photosynthesis and the temperature of surface water.

Particles in the water, as well as plant life and animal life, absorb or scatter light as it enters the ocean. Thus, white light is separated into distinct colors. Some of these colors are absorbed, some scattered and others reflected back to the surface, creating the variations in the color of the ocean.

Materials
2 to 3 clear glass containers
flashlight
toilet paper roll
cardboard
2 to 3 pipettes or eyedroppers
milk
mud

Procedure
To intensify the light source, make a collimator (Figure 10). Take your toilet paper roll and cut two pieces of cardboard into circles for end pieces. Cut a vertical slit \( \frac{1}{4} \) inch wide in each of the circular ends. Glue the ends to the toilet paper roll, aligning the vertical slits.

Fill the glass containers with water. Shine the light through the containers. (Note: Place the collimator between the flashlight and the glass container. It will focus the light into a more concentrated beam.) Because tapwater contains little particulate matter, not much light will be scattered or absorbed.

Add one to two drops of milk to the container and stir well. Shine the light through the container.

Look at the water in the container from the top or from a side perpendicular to the beam of light. (You should see blue.)

Look at the water in the container from the side opposite the flashlight. (You should see red.)

Place additional glass containers behind the first to accentuate the redness.

Repeat the above procedure using mud.

Questions
1. In the above activity, what is the color of the water if you observe it from the top or side?

2. When you added mud to the glass, what is the color of water from the top, looking down and at the sides?

3. What appears to cause the color of the water? What general statement might you make about what is in the ocean water when it is blue? Green?
Competency Factors/References

Competency Indicators

Physics/Academic—
5.3 know how to investigate and describe light in a quantified manner

References


"Light in the Sea," Oceans Alive. 1990. Environmental Media, Chapel Hill, NC. (A series of 60, five-minute video programs designed to supplement life and physical science lessons.)


