Observation Experiments: Light Bending

Go to: http://phet.colorado.edu/en/simulation/bending-light

You have a laser beam (press the button to turn it on!) that is shining from air into some other material such as water, glass, mystery material A, or mystery material B. Use water for part 1 of this lab.

Part 1: Observational Experiments

Grab the protractor from the toolbox and set it up so that you can easily measure the angle at which the laser beam strikes the water (relative to the normal line) and the angle that it makes with the normal line once it is in the water.

1. What happens to the laser beam as it enters the water?

2. Do you notice a second, lighter ray that is reflected off the water? Explain the path of this ray.

3. In “Laser View” - click on “wave”. Pose an explanation that explains why the light bends when it enters the water.
4. Collect the following data to help you find the relationship between the *incident ray* (the incoming laser beam from the air) and the *refracted ray* (the laser beam after it is bent by the water). Measure your angles relative to the normal.

<table>
<thead>
<tr>
<th>Angle of Incident Ray, $\Theta_1$</th>
<th>$\sin(\Theta_1)$</th>
<th>$\cos(\Theta_1)$</th>
<th>Angle of Refracted Ray, $\Theta_2$</th>
<th>$\sin(\Theta_2)$</th>
<th>$\cos(\Theta_2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Create a relationship between two or more of the physical quantities above. *Hint: See if a ratio of two of the quantities remains constant between runs of the experiment.*

6. You may have noticed this box on the right hand side that allows you to change the “Index of Refraction (n)”. Notice the values for “n” for air and water.

   Do you notice anything interesting as it relates to your equation in (5)?

7. Move the slider to change the index of refraction for both materials. What happens? How would you describe what the index of refraction is?

8. Rewrite your equation from (5) so that it incorporates $n_1$, the index of refraction for the first material and $n_2$, the index of refraction for the second material.

**Part 2: Testing Experiment**

9. Create an experiment that uses the simulation to test your equation from (8). Use your equation to try to predict something!

Laboratory Investigation adapted from Daubert
Part 3: Summarize and review - Snell's law of Refraction

Snell’s law relates the incident angle and the refracted angle of a beam of light to the indices of refraction of the two media through which the light travels:

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

Where:
- \( n_1 \) = refractive index of the incident medium
- \( n_2 \) = refractive index of the refracting medium
- \( \theta_1 \) = incident angle (relative to the normal line)
- \( \theta_2 \) = refracted angle (relative to the normal line)

The "index of refraction" is an intrinsic property of the medium. The index of refraction of air is 1.0, water is about 1.33, and glass is about 1.5.

10. Predict and test We observed earlier that light moving from air to glass or to a liquid bends (refracts) toward a normal line that is perpendicular to that surface. Also, light moving in a glass or liquid into air bends away from a line that is perpendicular to that surface. Use this idea to predict qualitatively what happens to a laser beam in each of the experiments below. Hint: Do not forget to draw a normal line to the border of two different media at the location where the light beam hits the border. Use a solid glass prism and a hollow glass prism to complete the table that follows.

<table>
<thead>
<tr>
<th>Illustration of the experiment</th>
<th>Use your knowledge of refraction to predict qualitatively the path of the beam.</th>
<th>Perform the experiment and record the results (i.e., the path of the beam).</th>
<th>Discuss whether your prediction was successful or if the relationship needs to be modified.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid glass prism in air</td>
<td>Laser beam from air to glass. Note that the light bends toward the perpendicular line in going from water to glass, and vice versa in going from glass to water.</td>
<td>Perform the experiment and record the results (i.e., the path of the beam).</td>
<td>Discuss whether your prediction was successful or if the relationship needs to be modified.</td>
</tr>
<tr>
<td>Hollow glass prism in water</td>
<td>Laser beam from water to glass. Note that the light bends away from the perpendicular line in going from air to water, and vice versa in going from water to air.</td>
<td>Perform the experiment and record the results (i.e., the path of the beam).</td>
<td>Discuss whether your prediction was successful or if the relationship needs to be modified.</td>
</tr>
</tbody>
</table>

Snell's law: \( n_1 \sin \theta_1 = n_2 \sin \theta_2 \)

incident medium

refractive index \( n_1 \)

refractive medium

refractive index \( n_2 \)
Index of Refraction and Total Internal Reflection

11. Reason and Explain Different colors of light have different indexes of refraction.

<table>
<thead>
<tr>
<th>Color</th>
<th>Index of Refraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>1.613</td>
</tr>
<tr>
<td>Yellow</td>
<td>1.621</td>
</tr>
<tr>
<td>Green</td>
<td>1.628</td>
</tr>
<tr>
<td>Blue</td>
<td>1.636</td>
</tr>
<tr>
<td>Violet</td>
<td>1.661</td>
</tr>
</tbody>
</table>

How can this information qualitatively explain why we see a rainbow when it rains? Think of where the sun is located with respect to an observer when the observer sees a rainbow. What assumption about the shape of the water droplets in the air can we make?

12. Reason and Explain Explain why an asphalt or concrete road sometimes looks wet on a hot day (hint: think about the air).

13. Total Internal Reflection While scuba diving, Will shines a laser pointer from beneath the surface of the water (n=1.33) up towards the air (n=1)

a. If Will shines the laser pointer at an angle of 20° with respect to the normal, what angle should the light enter the air at? Be sure to include a picture of the situation along with your mathematical reasoning.

b. If Will shines the laser pointer at an angle of 70° with respect to the normal, what angle should the light enter the air at? Be sure to include a picture of the situation along with your mathematical reasoning. *(were you unsuccessful in finding the angle? what happened? what do you think this could mean?)*
14. Practice

a. Allison sees a coin at the bottom of her swimming pool at an angle of 40 degrees to the normal and she dives in to retrieve it. However, Allison doesn’t like to open her eyes in the water so she must rely on her initial observation of the coin made in the air. At what angle does the light from the coin travel as it moves toward the surface? \(n_{\text{water}} = 1.33\)

b. Here’s an interesting trick to try. Place a penny in the bottom of a cup and stand so that the penny is just out of sight as shown. Then pour water into the cup. Without moving, you will suddenly see the penny magically appear. If you look into the cup at an angle of 70 degrees to the normal, at what angle to the normal must the penny be located in order for it to appear in the bottom of the cup when the cup is filled with water?

c. Rohit makes his girlfriend a romantic candlelight dinner and tops it off with a dessert of gelatin filled with blueberries. If a blueberry that appear at an angle of 44 degrees to the normal in air is really located at 30 degrees to the normal in the gelatin, what is the index of refraction of the gelatin?

d. A jeweler must decide whether the stone in Mrs. Smigelski’s rig is a real diamond or a less-precious zircon. He measures the critical angle of the gem and finds that it is 31.3 degrees. Is the stone really a diamond or just a good imitation? \(n_{\text{diamond}} = 2.41, n_{\text{zircon}} = 1.92\)

e. Heather is snorkeling in Oahu’s Hanauma Bay when she looks up through the water at a palm tree on the shore. If the index of refraction of the water is 1.33 and Heather sees the palm tree at an angle of 45 degrees, at what angle is the palm tree really located with respect to the normal?

f. In her bedroom, Mia has a fiber optic light that glows as hundreds of fiber optic cables are lit from below. A) If each fiber optic cable has an index of refraction of 1.48, at what critical angle must light enter the cable in order for total internal reflection to occur? B) Explain why total internal reflection is important to a fiber optic lamp.