Bending Light at an Air/Water Interface (Refraction)

Materials

Flat-sided glass or plastic container filled halfway with dilute starch solution

Circular protractor attached on the outside of one of the walls of the container so that the angles can be viewed through the container from the opposite side and where the center of the circular protractor is at the level of the air/water interface.

White paper standing upright

Straw

Red laser pointer (< 5 mW)
Caution: Avoid direct eye exposure. Do not look or stare directly into the laser beam.

Instructions

1. Take the straw and slowly insert it into the solution at an angle, watching it from the side.

Does the end of the straw go in the path that you expected or does it bend when it enters the solution? In which direction does it bend away from the expected path? Toward or away from the normal (perpedicular) of the air/solution interface?

2. Redo #1, but watch the insertion of the straw from the top of the container. Answer the same questions as in #1.

3. Put the straw aside. Place the upright paper to the left of the container (to block the light from going across the room), and shine the red laser into the solution from the right side and above the top edge of the container. Shine the laser at an angle so that it puts a spot at the air/solution interface that is at the center of the protractor. Draw a line in your mind from the end of the laser pointer to the spot. Then, by looking through the front side of the container and using the protractor on the back, measure the angle of the incident beam relative to the normal at the interface.

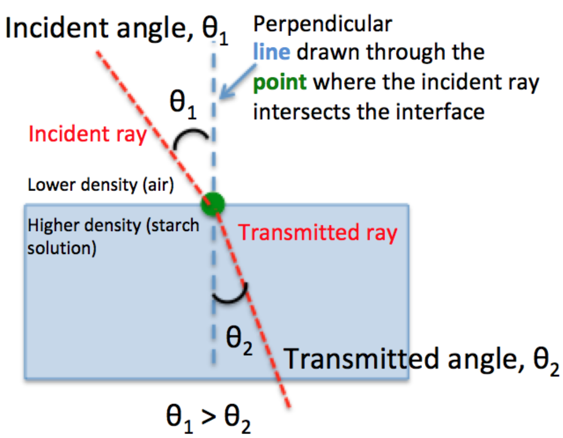
Angle of incident laser beam (in air) relative to the normal of the interface:_____________

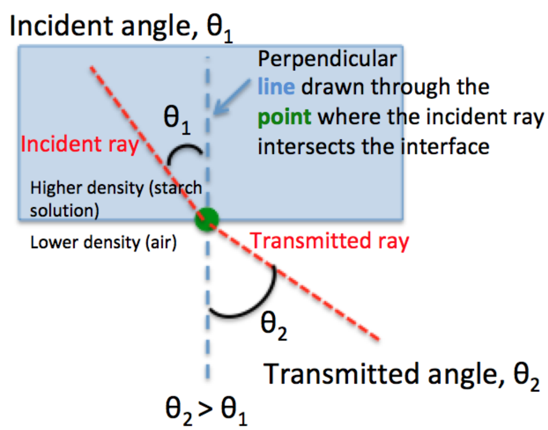
4. Without changing the laser's incident angle, measure the angle of the beam being transmitted into the solution relative to the normal. (There should be enough scattering of the red laser light by the starch in the solution to see the beam in the liquid.)

Angle of transmitted laser beam (in solution) relative to the normal of the interface:_____________

5. When light travels from a less dense medium (air) into a more dense medium (water), its speed slows down and it "bends" toward the perpendicular at the interface. This is called "refraction". (See illustration below).

When light travels from a more dense medium (water) into a less dense medium (air), its speed increases and it "bends" away from the perpendicular at the interface. This is also called "refraction". (See illustration below).





An equation that relates the incident angle (θ_1) and transmitted angle (θ_2) of the light beam to the different speeds of light (v_1 and v_2) in media of two different densities is called Snell's Law:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$$

The speed of light in air is close to that in a vacuum and is 3.00 x 10^8 m/s. Calculate the speed of light in the dilute starch solution.

Speed of red light in the dilute starch solution is:_____________

6. Now, calculate the ratio of the speed of light in the air relative to that in the dilute starch solution:______________________

There is a name given to this ratio. It's called the refractive index, η. Technically, though, the refractive index is really the ratio of the speed of light in a vacuum, c (not to that in air), to that in a medium. However, because the speed of light in air is the same as that in a vacuum to three significant figures, then what we have calculated with our simple experiment is the refractive index of the dilute starch solution (to three or fewer significant figures).

$$\eta = \frac{c}{\mathrm{v}}$$

Note that the refractive index of a medium is inversely proportional to the speed of light in that medium. Therefore, we can further expand Snell's Law to include the ratio of the refractive indices of the two media:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\mathrm{v}_1}{\mathrm{v}_2} = \frac{\eta_2}{\eta_1}$$

7. Can the refractive index of a substance ever be less than 1? Why?

8. Try a different angle of incidence with the solution and predict the angle of transmission using the two refractive indices.

Angle of incident laser beam (in air) relative to the normal of the interface:_____________

Measured angle of transmitted laser beam (in solution) relative to the normal of the interface:_____________

Predicted angle of transmitted laser beam (in solution) relative to the normal of the interface (calculated using Snell's Law and the two refractive indices):_____________

9. Now shine the laser from the side of the container, below the level of the solution, and upward to the air/solution interface. What do you see when viewing the beam from the front of the container as you shine the laser at different angles? Is there a second beam in the solution? How many spots are on the paper as you change the angle?

10. Measure the angle, relative to the normal at the interface, when you see only one spot on the white paper below the level of the solution/air interface.

Angle of laser beam (in solution) relative to the normal of the interface when all the light is “reflected” back into the solution: ____________

This angle is the “critical angle”, above which all light is reflected internally at the interface. This phenomenon is the same one that takes place in fiber optics to send light signals in communications systems. When no light gets out of the fiber optic, it is called “total internal reflection”.

10. You are now ready to explain why the straw appears to bend as observed in #1 and #2. Describe that here….