Light Fountain


NASA

Demonstration

This demonstration shows how light changes paths when travelling through different materials. Snell's Law and the critical angle are explored using lasers and water.

Number of Participants: 2-30

Audience: Elementary (ages 5-10) and up

Duration: 20-30 minutes

Difficulty: Level 2

Materials Required:

- Large, clear plastic bottle
- Sink
- Scotch tape
- Thumbtack or drill
- A laser pointer
- A piece of transparent glass or block of plastic (polycarbonate)
- A transparent glass cup
- A pencil or pen

Setup:

1. Pierce a hole in the lower quarter of the plastic bottle with a thumbtack and widen the diameter to approximately that of a pencil (~6mm). Alternatively, use a drill.
2. Tape over the hole and fill the bottle with water. Leave it in the sink in case of a leak.

Presenter Brief:

Familiarity with introductory optics topics such as Snell's law, reflection, refraction, angle of incidence, and principles of fiber optic cables is recommended. See Additional Resources for details.

Vocabulary:

- Reflection – An abrupt change in the direction of wave propagation when encountering a change in refractive index (barrier).
- Refraction – Bending of a wave when encountering a change in refractive index of the medium.
- Total Internal Reflection – Complete reflection of a wave when striking an index boundary at a narrow angle.
- Critical Angle – The incident angle at which the refracted light ray is parallel to the plane of the index boundary.
- Index of Refraction – A characteristic of transparent materials which describes how light propagates through the medium in relation to space.

Physics & Explanation:

Elementary (ages 5-10):

A reflection occurs when light abruptly changes direction when it encounters a change in medium. However, light can move through objects as well. In refraction, the light's path changes. Usually, when light hits a transparent object, some of the light is reflected and some is refracted.

Describe the difference between reflection and refraction, and ensure the participants can identify the difference. Draw diagrams like Figure 1 and display these effects by reflecting and refracting and refracting laser light with a piece of glass/plastic. Explain that this is why a pen/pencil in a cup of water looks disjointed, as seen in Figure 2.

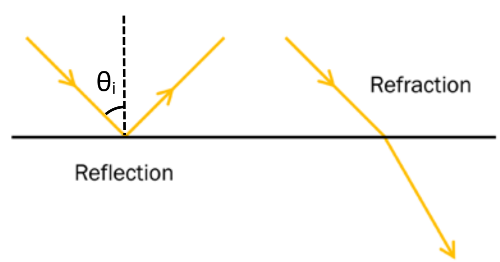

Figure 1

By changing the angle of incidence (θ_i in Figure 1), we can either reflect or refract the laser light.

The principles of reflection and refraction can be used to trap light.

Shine a laser through an empty section of the bottle and a full section of the bottle. Compare how the light moves through the empty bottle vs. through the water. *Note: A clear plastic container works best.*

Figure 2: Bcrowell at the English language Wikipedia [GFDL (http://www.gnu.org/copyleft/fdl.html), CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/), CC BY-SA 1.0 (http://creativecommons.org/licenses/by-sa/1.0) or CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons

Remove the tape covering the hole and shine the laser through the back so that the light enters the spout of water. Show how the laser light bends along with the water. Vary the angle at which you shine the laser to demonstrate how at certain angles, the light escapes the spout. When the light cannot leave the stream, as shown in Figure 3, it is trapped: total internal reflection. Watch the video at https://www.spsnational.org/programs/outreach/light-fountain to better see the phenomenon.

Since water and air are different mediums with different indices of refraction, light can bend abruptly change direction at the boundary between the two.

Middle (ages 11-13) and general public:

Display or recreate Figure 1 to show the difference between reflection and refraction.

Reflection and refraction are ways light behaves when changing mediums.

Snell's Law describes how light is refracted in terms of an angle θ and a refractive index n (see Figure 4).

$$n_i sin\theta_i = n_r sin\theta_r$$

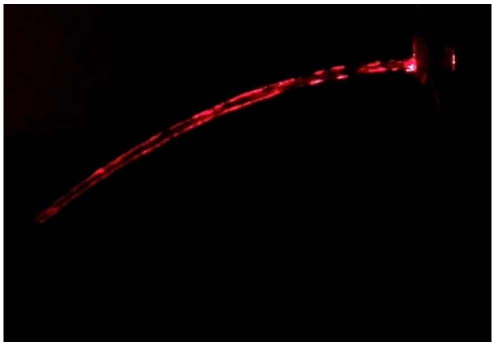

Figure 3

The incident angle of light determines how much of the wave is reflected and how much is refracted.

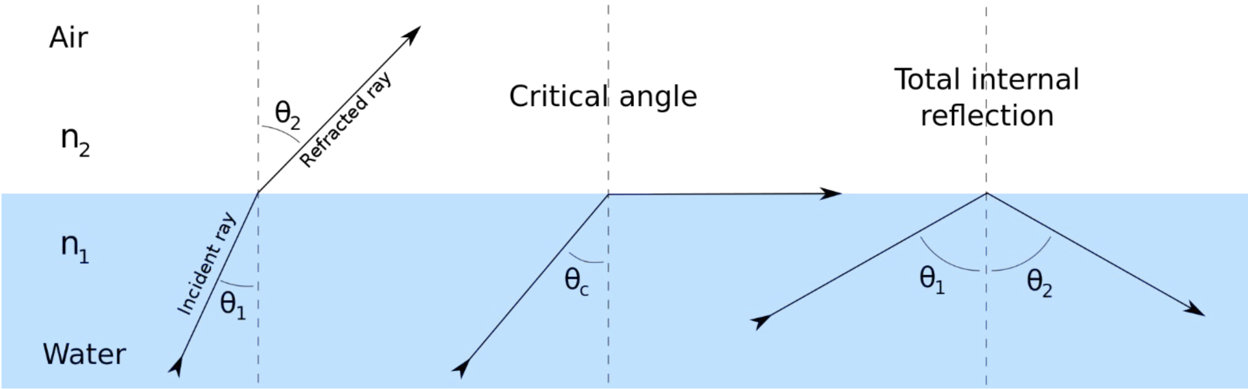

Figure 4: By Josell7 (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons

Explain that light can be reflected and refracted at an interface, meaning that some light is transmitted (refracted) and some is redirected (reflected) into the same medium.

In optical fibers, very little refraction takes place. This is by design: an inner transparent core is surrounded by an outer cladding with a lower index of refraction.

Shine the laser through the water spout as described previously. The air surrounding the water has a lower index of refraction than the water. If the laser enters at the right angle, it will reflect inside the water stream as shown in Figure 3.

Highschool (14 +):

Fiber optics transmit digital information at very high speeds. These fibers work on the principle of total internal reflection.

In reflection, the light bounces off the index barrier and continues to propagate through the same medium.

Total internal reflection occurs in an enclosed, symmetrical passage: the light never strikes an index boundary at an angle extreme enough to cause refraction. Instead, all the light is reflected into the passageway.

Demonstrate refraction and reflection between water and air as outlined previously. Point out the angle at which refraction and reflection switch.

The critical angle is the angle at which incident light is refracted along the plane of the index barrier. For reflection to occur, the light must strike the barrier at an angle smaller than θ_c.

Return to Snell's Law understanding the condition for total internal reflection ($\theta_r = 90°$). Now, θ_i becomes the critical angle, θ_c. Solve for the critical angle.

$$\theta_c = sin^{-1}(n_r/n_i)$$

Have students determine the critical angle between water ($n_r = 1.003$) and air ($n_i = 1.33$)[1].

The incident ray of light must be at an angle smaller than the critical angle (θ_c).

Additional Resources:

- MIT course slides: https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-007-electromagnetic-energy-from-motors-to-lasers-spring-2011/lecture-notes/MIT6_007S11_lec32.pdf

- MIT demonstration video: https://www.youtube.com/watch?v=s7w1Z1FCgwA
- BBC Two: Total internal reflection and the Light Fountain in action https://www.youtube.com/watch?v=lYgej5gvzUs
- Milonni, Peter W. Eberly, Joseph H. *LASERS*, 1988. (p 609 – 618)
- Jenkins, Francis A. White, Harvey E. *Fundamentals of Optics*, 1976. (p 11 – 13)
- [1]CRC Handbook of Chemistry and Physics

Useful Equations:

Snell's Law	$n_i sin\theta_i = n_r sin\theta_r$
Critical angle	$\theta_c = \sin^{-1}\left(\frac{n_r}{n_i}\right)$

$n = index\ of\ refraction\ incident\ medium\ (n_i), refractive\ medium\ (n_r)$

$\theta = angle\ of\ incidence\ (\theta_i), refraction\ (\theta_r)$