Magic Water

For Ages: 4-99

Description: This activity will demonstrate total internal reflection phenomenon, an introduction to light reflection and refraction, and critical angle.

Materials

- Hard paper or plastic sheet with a picture printed on it, like fish or a smiley face. Paper or plastic sheet should not be flexible, in order to keep stable while entering into the water
- Plastic bag, ziplock plastic bag recommended
- Waterproof marker
- Water (normal, clean)
- Container for water.

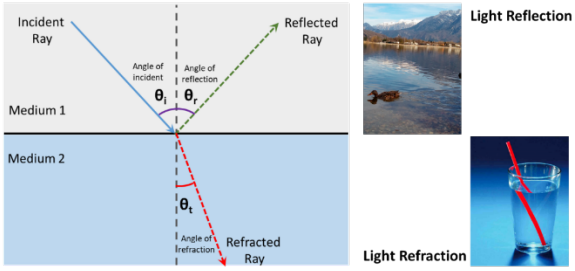
Background and Misconceptions

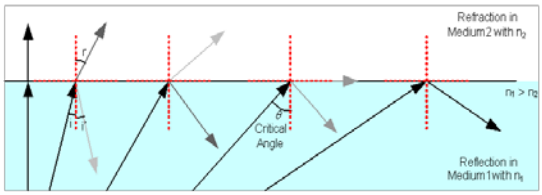
Reflection is the abrupt change in the direction of propagation of a wave that strikes the boundary between two different media. At least some part of the incoming wave remains in the same medium. Assume the incoming light ray makes an angle θ_i with the normal of a plane tangent to the boundary. Then the reflected ray makes an angle θ_r with this normal and lies in the same plane as the incident ray and the normal.
Law of reflection: $\theta_i = \theta_r$

Refraction is the change in direction of propagation of a wave when the wave passes from one medium into another with refractive indexes n_i and n_t, and changes its speed. Light waves are refracted when crossing the boundary from one transparent medium into another because the speed of light is different in different media. Assume the incoming light ray makes an angle θ_i with the normal of a plane tangent to the boundary. Then the refracted ray makes an angle θ_t with this normal and lies in the same plane as the incident ray and the normal.
Snell's law (or law of refraction): $n_i \sin\theta_i = n_t \sin\theta_t$

Total internal reflection

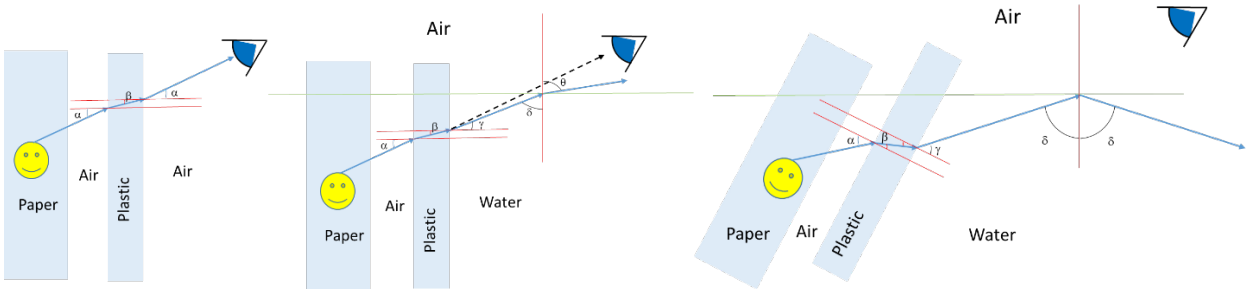
When light leaves a medium of higher index n_1 and enters one of lower index n_2, the angle of refraction will be larger than the angle of incidence. Hence, the outgoing ray will be bent towards the surface. As the angle of incidence is increased, the angle of refraction will eventually reach 90 degrees. Beyond that angle of incidence, Snell's law requires $\sin\theta_2$ to be greater than unity. When that occurs, there is no mathematical solution for the outgoing angle, and hence there is no refracted ray at all. Instead, all of the light (instead of just some of it) is reflected from the surface. To solve for this critical angle of incidence θ1, consider Snell's law with $\sin\theta_2$ set equal to unity:
This gives a formula for the critical angle θc $n_1 \sin\theta_1 = n_2$ $\sin\theta_c = \frac{n_2}{n_1}$





http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_8_4_TotalInternalReflection.html

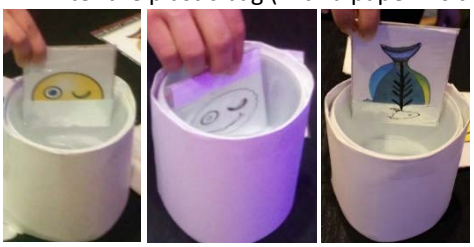
When we insert the plastic bag into the water, the beams reflected from the image on the paper bend due to the fact that the plastic-water-air ($n_{plastic} > n_{water} > n_{air}$) media change. Therefore, the beams do not enter into the eye of the observer. Approaching the water surface with the eye, it is possible to see again the picture, because we are intercepting again those beams. However, if we rotate the plastic bag in the water, again we stop seeing the image. The reason is that the beams approach now the water-air surface with an angle exceeding the critical angle, and so they undergo the total internal reflection phenomenon. Rotating again the plastic bag, at a certain point we stop seeing also the drawings outside the plastic bag, because also those beams exceed the critical angle.



Guided Activity

1. Take the hard paper or plastic sheet with the picture (in our example we used a fish and a smiley face).
2. Put the paper inside the plastic bag.
3. If the image on the paper is a smiley face, then on the plastic bag draw borders of the smile. In a case there is a picture of a fish, it is recommended to draw its skeleton.

4. Enter the plastic bag (with a paper inside) into the container full of water under different angles.



Teacher Guided Questions Inquiry

Use these questions to get the students started on their own inquiry.

1. **What are the refractive indexes of air, water and plastic bag?**
   $n_{air}=1$, $n_{water}=1.33$, $n_{plastic}=1.49$
2. **Why under the certain angle is the image on the paper not visible?**
   When we insert the plastic bag into the water, the beams reflected from the image on the paper bend due to the plastic-water-air medium changes and do not incident into the eye.
3. **Why do we see the image only from the plastic bag?**
   We see the image from the plastic bag because reflected rays from the plastic pass only water-air mediums and still incident into the eye.