Extension Activity – Water

Title of Activity - Refraction of Light

Concepts/Principles Covered –

Light is used every day to see objects. Depending on the object's properties, light may behave quite differently. Light can either be absorbed, reflected, or transmitted. If light is **absorbed**, it is transferred to the object, mostly as heat. When light is **reflected** it is bouncing off the object, like a mirror. Lastly, light can be **transmitted**, or move through an object, such as glass.

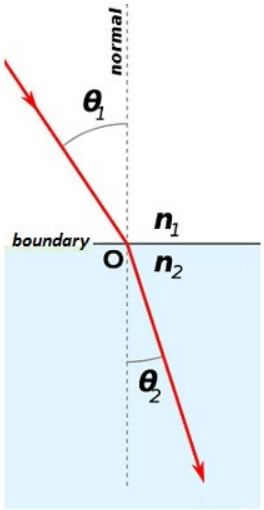
Light behaves differently due to the nature of the object. An object is classified as **opaque** if light cannot pass through, meaning that light is only absorbed or reflected. **Translucent** objects are slightly see-through, like wax paper, and act in all three ways: absorption, reflection, and transmission. Lastly, an object can be **transparent**, or completely see-through, so light moves entirely through the object.

Light will slow down when it goes from one medium to another. In water, light is slower than in air, and is even slowest when moving through a solid. This is because the atoms are more spaced apart in gases than liquid and solids and are not blocking the light from moving.

Each object has its own **index of refraction**, a value 'n', used to determine what angle the light will bend when it comes into contact with it. The index of refraction in a vacuum is $n_{vacuum} = 1$. Air is fairly close to this value with $n_{air} = 1.000277$.

Indices of refraction are related to both the angles of incident (incoming) and refraction (scattered) using Snell's Law,

$$\frac{n_1}{n_2} = \frac{sin\ sin\ \theta\ _2}{sin\ sin\ \theta_1}$$



where, n_1 = the index of refraction of the first object, n_2 = the index of refraction of the second object,

Θ_1 = the angle of refraction in the first object, and Θ_2 = the angle of refraction in the second object.

Snell's Law can also be written as:

$$sin\ sin\ \theta_1 \quad = sin\ sin\ \theta_2 \ .$$

Short Description –

Experimentally determine the index of refraction of water and demonstrate the principle of light refraction. Specifically, the students will measure the incident angle of light in air and the refracted angle of light in water, plot a graph of the sine of the angles and determine the refraction index of water from the best fit line, and calculate water's refraction index algebraically using Snell's Law.

Standards Covered -

MS-PS4-2: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

CCSS.MATH.CONTENT.7.G.B.5: Use facts about supplementary, complementary, vertical, and adjacent angles in a multi-step problem to write and solve simple equations for an unknown angle in a figure.

HS-PS4-3: Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

CCSS.MATH.CONTENT.HSG.SRT.D.10: Prove the Laws of Sines and Cosines and use them to solve problems.

Length - 2-3 hours

Age Group – Grades 6-12

Materials and Supplies -

- Glass container (small aquarium or square/rectangular shaped clear bin) filled slightly more than halfway with water
- Laser pointer or strong flashlight
- Clear transparent paper or plastic sheet
- Markers
- Protractors
- Milk or baby powder (optional)

CAUTION

Do not look directly at the laser beam.

Step-by-step Instructions -

Divers are specifically trained to endure diving deep underwater in order to repair the ships and perform other aquatic duties. In water, objects may be located in a different spot than they appear from land. A diver uses light refraction to determine more accurate locations of objects underwater before jumping from the air and into the water. You are placed in charge of operating an aquatic remotely operated vehicle (ROV). You want to shine some light from your ship onto the spot where the ROV is exploring in the water. You need to determine the index of refraction of water so that you can shine the light in the correct location in the water.

PART ONE: Determining the Angles of Incidence and Refraction

- Fill a small aquarium tank halfway with water.
- Place a few drops of milk or baby powder into the water to better see the light's path.
- Fix a light at an unknown angle outside of the tank so that it shines from the air into the water. This is the incident, or incoming, angle, θ_1.

- Using a transparent piece of paper or plastic, draw the path of the light as it moves from air through water using the dry erase markers.
- Draw a boundary line where air stops and water begins on the transparency.
- Draw a perpendicular line (known as the normal and seen in the image above) to the boundary where air intersects water.
- Using a protractor, measures the angle of incidence, θ_1, in air between the path of light to the normal line and the angle of refraction, θ_2, between the path of light in water and the normal.
- Repeat Steps 3-7 for four trials, using different incident angles (air) each time, and record all the trials' data in the table below. Also, calculate the sine of each angle measured and the overall averages.

Trial	Θ_1 (Incidence: AIR)	sin Θ_1	Θ_2 (Refraction: WATER)	sin Θ_2
1				
2				
3				
4				
AVERAGE				

PART TWO: Graphically Measure Indices of Refraction

- To determine the index of refraction, n_2, of water, revise the Snell's Law equation to solve for n_2.

$n_2 =$

- We can assume that the index of refraction for air is close to 1. Assuming this, rewrite the equation for n_2 where $n_1 = 1$.

$n_2 =$

- Plot a graph of sin Θ_2 (x-coordinate) verses sin Θ_1 (y-coordinate) from the table above using the graph paper below:

- Determine the slope of the line (y = mx + b) in order to graphically calculate the index of refraction for water. Record the value: n_2 = ________________

Note: You could determine the slope using the slope equation of y = mx + b, where m is slope and b is the y-intercept. Another method is to take slope, m, as "rise over run" or the change in the y-coordinate values divided by the change in the x-coordinate values. Draw a line that connects most of the points (a line of best fit) and pick two points that fall near or on that line. To determine the slope between those two points, solve the following slope equation:

$$m = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1} = n_2$$

PART THREE: Calculate the Index of Refraction Using Snell's Law

- Rewrite the equation derived in Step 9 for n_2 below:

n_2 =

- Calculate the index of refraction for water, n_2, if the accepted index of refraction in air, n_1, is 1.000277. Use the averages for sin θ_1 and sin θ_2.

  Index of refraction or water, n_2 = ______________________

- The actual index of refraction, n_2, of water is equal to 1.3330. This value is known as the accepted value. Calculate the percent error between the accepted value of n_2 (1.3330) and the value you algebraically measured in Step 14:

$$Percent\ error = \left(\frac{|accepted - measured|}{accepted}\right) \times 100$$

Percent error =_________% from calculation

- Next, calculate the percent error between the accepted value of n_2 (1.3330) and the value of n_2 that you graphically measured in Step 12.

$$Percent\ error = \left(\frac{|accepted - measured|}{accepted}\right) \times 100$$

Percent error =_________% from slope

- Was the percent error higher in the graphically measured index of refraction or the algebraically calculated index of refraction? Why do you think that is? What could you do to lower your percent error in the future?

OR For Younger Students

- Put a pencil or stick into a glass of water and have students observe how it appears bent.
- Shine different colored light into water. Does light color change the angle? Can you notice light scattering in the water?
- Try shining a light through something opaque, something transparent, and something translucent. Can the light always make it through the object?

Sources

http://www.exploratorium.edu

https://www.teachengineering.org

Photos a) NOAA’s ROV Hercules exploring underwater, b) A Navy deep-sea diver prepares to enter the water, c) A Naval petty officer brings the American flag to his underwater salvage unit