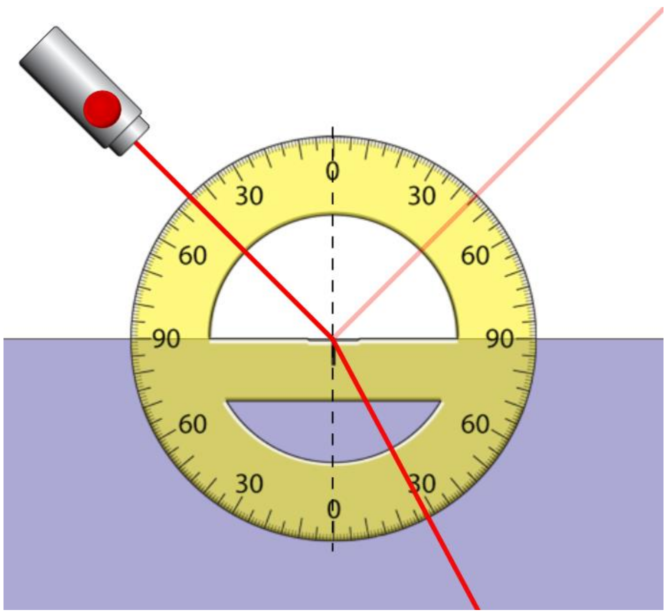
Lab 10: Snell's Law and Refraction

- Gain understanding about the behavior of light as it passes from one medium to another
- Compare least time travel to the rules of refraction
- Use Snell's Law to calculate the index of refraction of water and compare it to 1.33.
- To identify the requirements for total internal reflection

Exploration 1: Refraction!!

In a real lab we would use a refraction tank to do a very similar experiment to this!! We will be shining a laser light from one medium (usually air) into another and recording how changes in incident angle and medium affect the angle of refraction, angle of reflection, and the brightness of each.

1. Open the interactive lab: https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html
2. Hit the red button on the laser to turn it on. At the point where the laser intersects the water, place the center of your protractor as shown.



3. Drag the protractor such that it lines up as indicated. Make sure the horizontal surface of the water is lined up with the 90° mark, and the 0° mark is lined up with the normal.
4. Make sure the top material is set to Air and the bottom material is set to Water.
5. Move the laser between 0° and 90° and **record all observations.** Be sure to include the following:
   - Brightness of the refracted and reflected ray
   - The change in angle of the reflected and refracted wave as the incident angle (your laser) is increased.

   Record ALL your observations on a separate sheet of paper!!
6. Let's examine how a change of material affects the angle of refraction.
   - Put the laser at 50°.
   - Move the bottom material slider from air to the maximum Index of Refraction (1.60)
   - **Record any observations.** Include in your observations the following:
     - How does the *refracted* ray and its angle change as you go from low to high Index of Refraction?
     - How does the *reflected* ray and its angle change as you go from low to high Index of Refraction?
7. We have thus far looked at light passing from low index of refraction to higher. Let's reverse that and see what happens!!
   - Change the top material to Index of Refraction 1.60
   - Repeat Step 6.

8. Answer the following questions on a separate sheet of paper.

   a) *Describe how the reflected light behaves as you move the laser from 0° through 90°. Your answer should include how the angle and brightness vary.*

   b) *Describe the behavior of the laser light as it passes from a low Index of Refraction to high. You should include in your answer everything you learned from the above exploration!!*

   c) *Describe the behavior of the laser light as it passes from a high Index of Refraction to low. You should include in your answer everything you learned from the above exploration!!*

Exploration 2: Calculating Index of Refraction!!

We will use Snell's Law to calculate the index of refraction of water and compare it to the book value of 1.33.

1. Using the same link as above, set the top material to Air and the bottom material to Water.
2. Complete the table by moving the laser to each incident angle, θ_i, and recording the angle of refraction, θ_r. Try to read as precise an angle as possible!!
3. Calculate the sine of each angle.

*****If you don't have a calculator with sine, ask Google for a "trig calculator". On my computer, the calculator came up in the search results!!**

θ_i (deg)	θ_r (deg)	Sin(θi)	Sin(θr)	$\frac{\text{Sin}(\theta_i)}{\text{Sin}(\theta_r)}$
20				
40				
60				
80				

4. Calculate the ratio of sines in the last column.
5. Calculate the average of the last column.
6. Snell's Law:

   Snell's Law provides the relationship between index of refraction and the angles of incidence and refraction. Since the index of refraction, n_i, of air is 1, the equation reduces to:

   $$n_r = \frac{\sin \theta i}{\sin \theta r}$$

   Based on your calculations, what is your calculated value of n_r, the index of refraction of water?

7. Calculate the Percent Error assuming the Index of Refraction of Water is 1.33.

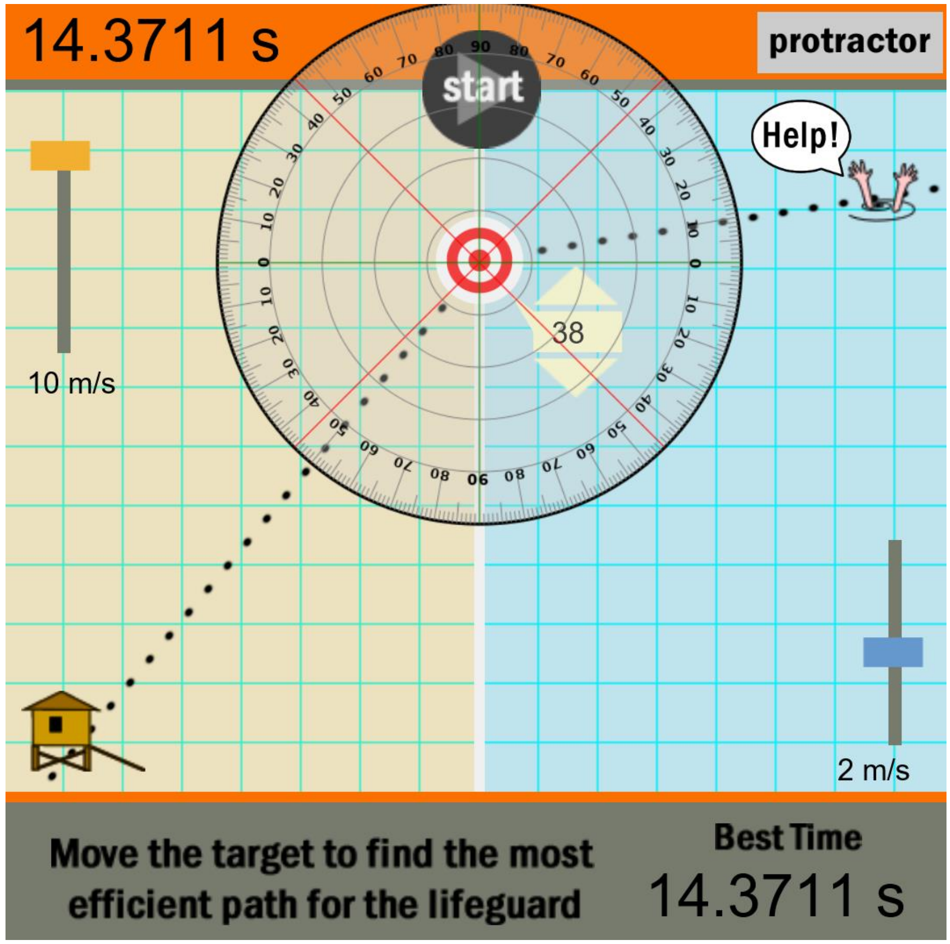
   $$\textit{Percent error} = 100 * \frac{|Calculated\ average - 1.33|}{1.33}$$

8. *Were you able to accurately calculate the index of refraction of water? Provide supporting evidence to back up your claim.*

Exploration 3: Least Time

A light wave will refract (i.e., bend) as it passes from one medium into another medium. The tendency of a light wave to do this is often explained by the Least Time Principle. This principle states that *of all the possible paths that light might take to get from one point to another, it always takes the path that requires the least amount of time.*

In our scenario, the lifeguard must reach the swimmer in as little time as possible. Keeping in mind that the lifeguard can run faster on the sand than swim in the water, our task is to determine the optimal entry point into the water in order to reach the drowning swimmer in *the least amount of time*.



1. Open the program: https://www.physicsclassroom.com/Physics-Interactives/Refraction-and-Lenses/Least-Time-Principle/Least-Time-Principle-Interactive and expand to the full screen.
2. Adjust V_{sand} to 10m/s, and V_{water} to 2m/s. Move the target until you get the least time traveled. There is usually a fireworks explosion when you reach it!!
3. When you find the correct point, hit the protractor button and put the center of the protractor at the bullseye. The 0° mark should be horizontal. You want to read from the horizontal 0° normal as shown in the diagram.

   For Example: The readings here are θ_s=50° and θ_w=9°
4. In Table 1 (next page) record the following: θ_s, θ_w, and time.
5. Repeat step 2 – 4 for the remainder of the velocities given in Table 1.
6. Calculate the following and place in Table 2: The ratio v_{sand}/v_{water}, $\sin(\theta_1)$, $\sin(\theta_2)$, and the ratio of $\sin(\theta_s)/\sin(\theta_w)$.

*****If you don't have a calculator with sine, ask Google for a "trig calculator". On my computer, the calculator came up in the search results!!**

Exploration 3: Least Time Data, Calculations and Questions

Table 1

V_{sand} (m/s)	V_{water} (m/s)	θs (deg)	θw (deg)	Time (s)
10	2			
10	4			
10	5			
9	4			

Table 2

$\frac{V_{sand}}{V_{water}}$	Sin(θs)	Sin(θw)	$\frac{\text{Sin}(\theta s)}{\text{Sin}(\theta w)}$

1. *We often think that the straightest path from here to there is also the quickest. What does this exercise show you? Do you find it surprising?*

2. *Does there seem to be a relationship between the ratio of velocities, V_{sand} /V_{water} and the ratio of sines, Sin(ϑ_s) /Sin(ϑ_w)? Explain.*

3. *Can you relate these finding to the full version of Snell's Law shown below? Give it a try!!*

$$\frac{n_r}{n_i} = \frac{\sin \theta i}{\sin \theta r}$$

Exploration 4: Total Internal Reflection!!

Total internal reflection is the physics behind fiber optic fibers and a diamonds brilliance to name a few. The goal of this exploration is to identify the requirements for total internal reflection and determine the critical angle for water.

1. Open the program: https://www.physicsclassroom.com/Physics-Interactives/Refraction-and-Lenses/Refraction/Refraction-Interactive and then expand to full screen.
2. Place the laser beneath the water and hit the green ”go” button. Then place the protractor as shown below.
3. We are searching for the critical angle. It is the angle at which the refracted light (in air in this case) disappears. Figure a shows the region before the critical angle is reached.   Figure b shows the region beyond the critical angle where total internal reflection occurs. We need to find the angle that is the boundary between a refracted ray being seen (a) and no longer being seen (b).

Figure a: Showing dim reflected light and dark refracted light.

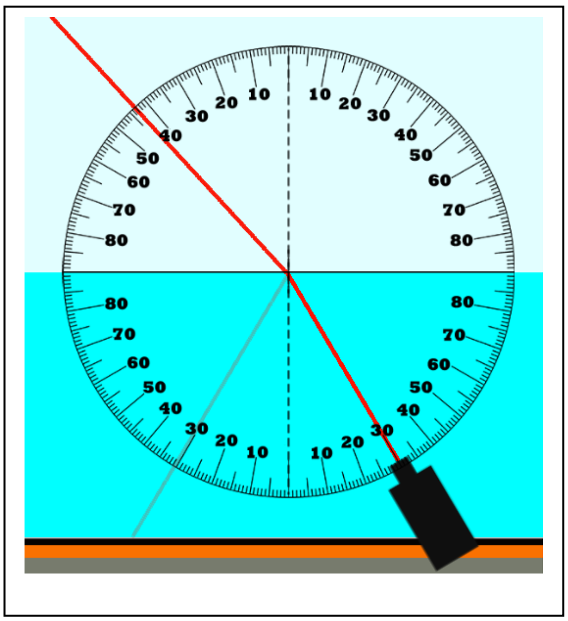
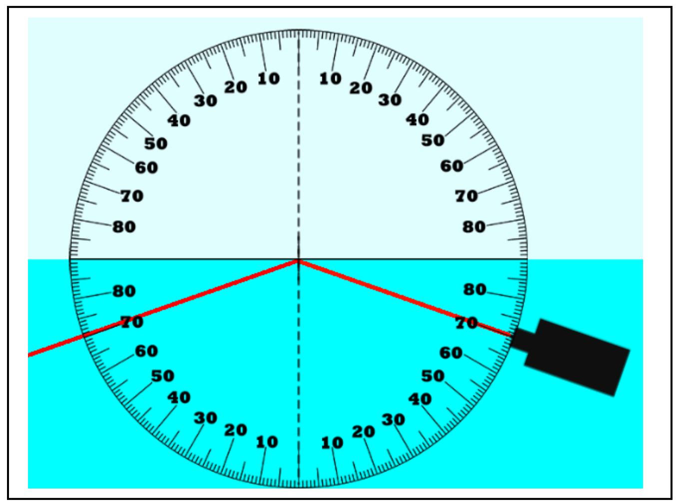


Figure b: Showing only reflected light



4. Determine the critical angle for water.
5. Answer the following questions on a separate sheet of paper.

   a) Look up the critical angle for water on Google. Compare to the number you found. How closely does your angle align to that found on Google?

   b) What do you notice about the refracted ray (in air)? Does it bend toward the normal (vertical line) or away?

   c) Complete this sentence. In order to see total internal reflection, light needs to pass a) from higher index of refraction to lower b) from lower index of refraction to higher   c) it doesn’t matter.