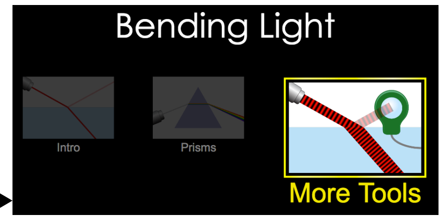
**Experiments in Physics**
**Lab – Snell's Law and total internal reflection**
Name________________________________Score___________________

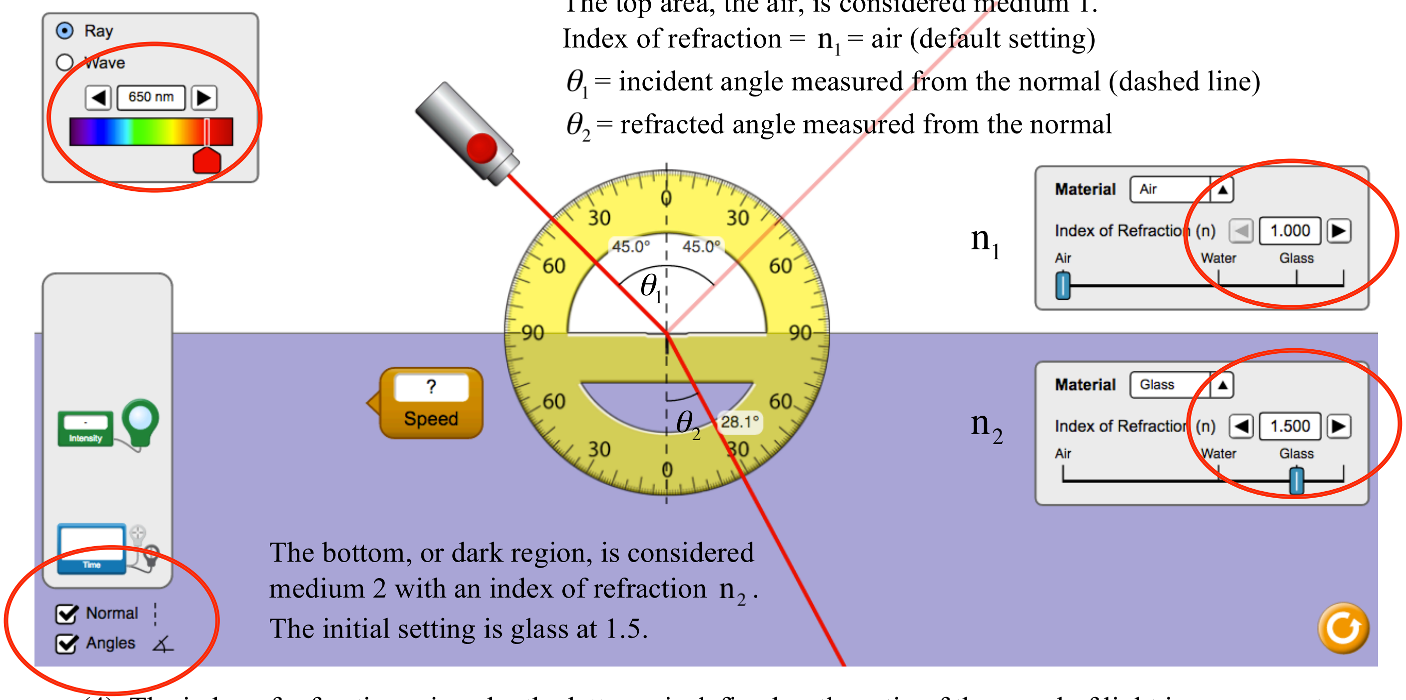
Introduction:
When light travels between two different medium, the velocity and wavelength changes. The result is the "bending" of the light. The "bending" of light is referred to as refraction. The "bending" follows a convenient mathematical relationship called Snell's law, named after Dutch astronomer Willebrord Snellius (1580-1626). The purpose of this lab is to determine the relationship between the incident angle of a light beam and the refracted angle of the light beam as the beam passes from one medium to another. In addition, students will demonstrate the application of Snell's Law. As consequence, students will be able to determine the critical angle for a light beam that travels from a more dense medium to a less dense medium.




**Part I: Discovering Snell's Law with "Bending Light 1.1.1"**

(1) Start the PHeT simulation entitled "Bending Light". The simulation is available at the following website: [https://phet.colorado.edu/](https://phet.colorado.edu/)
(2) Click on the "More Tools" box.
(3) Turn on the laser and drag the circular protractor such that the protractor is centered along the normal line and the boundary between the two mediums. Also, drag the speed indicator tool out from the tools located at the lower left of the simulation. The laser can be dragged to change the incident angle. Play with the simulation and try changing some of the different parameters. Make sure to select "Ray" and check the "Angles" box.

The top area, the air, is considered medium 1.
Index of refraction = $n_1$ = air (default setting)
$\theta_1$ = incident angle measured from the normal (dashed line)
$\theta_2$ = refracted angle measured from the normal




The bottom, or dark region, is considered medium 2 with an index of refraction $n_2$. The initial setting is glass at 1.5.

(4) The index of refraction, given by the letter n, is defined as the ratio of the speed of light in a vacuum to the speed of light in a medium: $n = \frac{c}{v}$, where c = $3.0 \times 10^8$ m/s. As light travels into different substances, the velocity of light is lower. *For our purposes the speed of light in a vacuum will be the same as that of air.* Use the speed tool to measure the velocity of light in the glass. Write the velocity in terms of c.
____________________________________.
(5) Use the definition for the index of refraction to verify that the index of refraction for glass is 1.5. Show all your work in the box below.

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(6) The relationship between the velocity, frequency, and wavelength of a wave is given by $v = f\lambda$. Since the frequency remains constant when light travels between different media, an expression can be written to solve for $\lambda_2$.

For medium 1, $v_1 = f\lambda_1$ and for medium 2, $v_2 = f\lambda_2$. By making an appropriate substitution, write a mathematical expression for $\lambda_2$, in terms of $v_1, v_2$, and $\lambda_1$. Show all your work.

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(7) Set the following initial data parameters and complete the table below. **Write all velocities in terms of the speed of light, c. Record your values for $\sin\theta_1$ and $\sin\theta_2$ to three significant figures. Record your values for $\lambda_2$ in nanometers.**

| Data Set 1 | Data Set 2 | Data Set 3 |
|---|---|---|
| $\lambda_1 = 650nm$ | $\lambda_1 = 460nm$ | $\lambda_1 = 542nm$ |
| $n_1 = 1.250$ | $n_1 = 1.000$ | $n_1 = 1.500$ |
| $n_2 = 1.548$ | $n_2 = 1.333$ | $n_2 = 1.224$ |
| $\theta_1 = 55.0°$ | $\theta_1 = 35.0°$ | $\theta_1 = 40.0°$ |

| Data Set | $\theta_2$ | $v_1$ | $v_2$ | $\sin\theta_1$ | $\sin\theta_2$ | $\lambda_2$ |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |

(8) Use the above data and complete the table below for the ratio's given. **Record your values to 3 sig. figs.**

| Data Set | $\frac{\sin\theta_1}{\sin\theta_2}$ | $\frac{n_2}{n_1}$ | $\frac{v_1}{v_2}$ | $\frac{\lambda_1}{\lambda_2}$ |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

(9) Based upon the pattern you see above for the ratios across different data sets, write a complete mathematical expression for Snell's Law. Verify your expression by looking up Snell's Law in your textbook, the internet, or by asking your instructor.

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(10) All of the ratios have medium 1 values in the numerator. Using the definition for the index of refraction, write expressions for $n_1$ and $n_2$ in term of $c, v_1$, and $v_2$. Using the expressions, show that $\frac{n_2}{n_1} = \frac{v_1}{v_2}$.

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**Part II – Total internal reflection or TIR**

(1) As you may have seen in your observations (such as in Data Set 3), when light travels from a more dense medium, such as water (n = 1.33) to a less dense medium, such as air (n = 1.00), the light ray bends **away** from the normal (the dashed line). At a specific angle, called the **critical angle**, the light ray will bend 90 degrees from the normal. Set the following initial data parameters and complete the table below.

Data Set

$\lambda_1 = 650nm$

$n_1 = 1.333$

$n_2 = 1.000$

| $\theta_1$ / degrees | $\theta_2$ / degrees | **Reflected angle** /degrees |
|---|---|---|
| 20 | | |
| 40 | | |
| 60 | | |
| 80 | | |

(2) What happens when the refracted angle approaches 90 degrees? ____________________

(3) Based upon what happens, estimate the **critical angle**, $\theta_{critical}$, for the water-air interface.

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(4) Use Snell's Law to derive a formula for the critical angle in terms of $n_1, n_2,$ and $\sin\theta_c$ where $\sin\theta_2 = \sin 90°$ and $\sin\theta_1 = \sin\theta_c$. Verify your formula using your textbook, the internet, or by asking your instructor. Show all your work.

For questions 5 to 7, use a laser wavelength of 650 nm.

(5) Estimate the critical angle for a glass ($n_1$ =1.500) – air ($n_2$ = 1.000) using the simulation. ______________

(6) Calculate the critical angle for the glass-air boundary. ____________________

(7) Calculate the critical angle for a "Mystery A" – air boundary. ____________________

(8) Using the internet or a table from your textbook, determine what "Mystery A" might be.

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**Part III – Problem solving using Snell's Law**

(1) A scuba diver on a boat (index of refraction = 1.000) shines a violet light (415 nm) towards the water (index of refraction = 1.336) to illuminate some phosphorescent coral. With what wavelength in nanometers does the light strike the coral? What is the velocity of the light when it strikes the coral, in terms of c? (Hint: the velocity of light in air is 1.00c)

(2) A double pane surface consists of a layer of oil on top of a layer of water (index o1.333). A red laser beam (650nm) moves between the two surfaces, passing through the oil at a speed of 0.71c and into the water at a speed of 0.75c. The incident angle from the oil to the water boundary is 32 degrees. What is the index of refraction for the oil? What is the refracted angle, measured from the normal, for the red laser beam going into the water?