Snell’s Law: The Equation of Refraction

Light travels at different speeds in different substances. Light travels faster in water than in diamond, it travels faster in air than in water, and it travels the fastest in a vacuum. One way of indicating how fast the speed of light is in a particular substance is to give that substance’s ***index of refraction***, denoted *n*. The index of refraction for a substance is defined as the ratio of the speed of light in a vacuum to the speed of light in that substance:

nsubstance = c/vsubstance

For example, the index of refraction for water is 1.33. This means that light travels 1.33 times faster in vacuum than water.

When light travels from one medium into another, the path of the light will bend if two things are true:

* The media have different indices of refraction
* The path of the light makes a non-zero angle with the normal to the boundary.

The following equation, called ***Snell’s Law***, shows the relationship between the angle of incidence, the angle of refraction, and the indices of refraction of the two substances involved.

Normal

na sin θi = nb sin θr

θi

where na = Index of refraction

Substance A

for substance A

nb = Index of refraction

Substance B

for substance B

θi = Angle of incidence

θr

θr = Angle of refraction

**Procedure:**

You will work in groups of three. Each student will include in his/her lab report 2 drawings on graph paper, one for Part I, and one for Part II.

**Part I: The Index of Refraction for Glass.**

1. Obtain a small slab of frosted glass. Place it ontop of a piece of graph paper. Align the glass with the grid lines on the paper. Trace the shape of the glass on the paper.
2. Obtain a laser, and shine the laser into the glass at an angle. Make pencil marks on the paper indicating where the laser beam is starting, where it enters the glass, and where it leaves the glass. Turn off the laser, and remove the glass from your graph paper. Connect the dots you made with straight line segments to illustrate the path of the laser beam.
3. Draw the normal to the point where the laser hit the glass. Use a protractor to measure the angles of incidence and refraction. Record this information in Table 1.
4. Use Snell’s Law, and the fact that the index of refraction for air is 1.0003, to calculate the index of refraction for glass. Record this information in Table 1. (Make sure your calculator is in *degree mode*!)
5. Have each lab partner repeat steps 1-4, shining the laser into the glass *at a different angle.*
6. Find the average value for the index of refraction of glass using your three trials. Record this in Table 1.

Table 1

|  |  |  |  |
| --- | --- | --- | --- |
| Student | Angle of Inc. (θi) | Angle of Ref. (θr) | Index of Ref. (n)  For Glass |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
| Average | \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\* | \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\* |  |

**Part II: The Speed of Light in Jello.**

1. Obtain a dish of jello. Place it on top of a piece of graph paper. Align the straight face of the dish with the grid lines. Trace the shape of the dish on the paper.
2. Shine the laser into the straight face of the dish at an angle. Make pencil marks on the paper indicating where the laser beam is starting, where it enters the dish, and where it leaves the dish. Turn off the laser, and remove the dish from your graph paper. Connect the dots you made with straight line segments to illustrate the path of the laser beam.
3. Draw the normal to the point where the laser hit the dish. Use a protractor to measure the angles of incidence and refraction. Record this information in Table 2.
4. Use Snell’s Law, and the fact that the index of refraction for air is 1.0003, to calculate the index of refraction for jello. Record this information in Table 2.
5. Use the definition of *index of refraction* (see “Background”) to calculate the speed of light in jello. (Hint: c = 3.00 x 108 m/s)
6. Have each lab partner repeat steps 7-11, shining the laser into the dish *at a different angle.*
7. Find the average value for both index of refraction and the speed of light in Jello using your three trials. Record this in Table 2.

Table 2

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Student | Angle of Inc. θi | Angle of Ref.  θr | Index of ref.  N | Speed of light in jello |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
| Average | \*\*\*\*\*\*\*\*\*\*\*\*\* | \*\*\*\*\*\*\*\*\*\*\*\*\* |  |  |

**Part III: Confirming the index of refraction of Jello using total internal reflection.**

1. Obtain another piece of graph paper. Position your laser that so that it is now shining *directly* into *curved* face of the Jello.
2. Determine, experimentally the *smallest* angle of incidence, within the Jello, such that the laser totally internally reflects off of the flat surface of the Jello. This is the *critical angle for total internal reflection.*  Record below:

*θcritical* = \_\_\_\_\_\_\_\_\_\_\_\_\_\_

*θcritical*

Analysis Questions.

1. Why does light bend, or refract, when it moves from one substance into another?
2. What was your average value for the index of refraction of glass?
3. The actual value for the index of refraction in glass in 1.52. Calculate your percent error using the formula:

% error = |actual – calculated|/actual x 100%

Be sure to discuss possible sources of error in your summary.

1. What was your average value for the index of refraction of jello?
2. Why were you instructed to shine the laser into the glass and Jell-O at an angle, instead of straight on?
3. Why were you initally instructed to shine the laser into the straight face of the jello dish instead of the curved face?
4. If an angle of incidence is exactly at the critical angle for total internal reflection, what is the value of the angle of refraction *θr*?
5. Use your answer to #7, and your experimentally found value for *θcritical* to recalculate the index of refraction for Jello.
6. Find the %-difference between your answer to #8 and the average value you found in Table 2.

# Extension Question

A laser begins underwater and is directed towards the surface. When the laser strikes the surface (above which there is air), it makes a 71° angle with the normal. What happens when you try to use Snell’s Law to predict the angle the laser makes when it passes into the air. Explain what physically happens to the laser beam.