

Name: _____ Book: ___ Period: ___ Due Date: _____
 Lab Partners: _____

FINDING THE INDEX OF REFRACTION - WebAssign

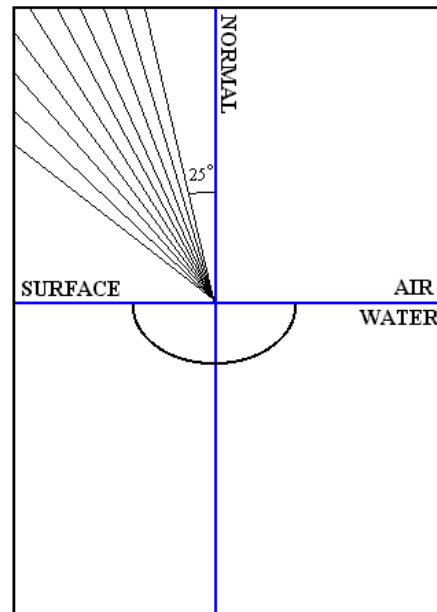
Purpose: The theme in this lab is the interaction between light and matter. Matter and light seem very different yet there must be an underlying connection at some level, because, as you will observe, they interact with each other all the time. If there was no interaction we could not see anything. Interaction implies some commonality in their nature. To observe and verify that an interaction occurs between light and matter we will:

- (1) Determine the index of refraction of water.
- (2) Determine the critical angle of water.
- (3) Observe and measure chromatic dispersion of white light by a diffracting medium.

PART ONE: Finding the Index of Refraction of water

Procedure:

1. Prepare your Data Sheet. Draw a line across the middle of a large sheet of paper with a pencil and meter stick. This represents the surface of the liquid. Label it **SURFACE**. Above the line write **AIR** and below it **WATER**. Use a protractor, pencil, and meter stick to construct a line down the length of the paper **perpendicular** to the **SURFACE** line. Label it **NORMAL**. It must be **precisely** perpendicular to the surface line.
2. Use a protractor, pencil, and ruler to construct lines on the **AIR**-side of the **SURFACE** line at the following angles measured counter-clockwise from the **NORMAL** line: 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°
3. Orient the paper so the laser beam is traveling above and parallel to the **NORMAL** line. Blocks with vertical sides can be used to align the beam along the **NORMAL** line. The instructor will show you how to accomplish this. Once aligned, make sure the paper does not move while you complete step 4.
4. Fill the semicircular plastic tray with water and place it on the large sheet of paper with the flat edge along and parallel to the **SURFACE** line. Make sure the water is on the "water" side of the **SURFACE** line. The arc near the middle of the figure shows the approximate location of the tray. Reflections off the front and back surfaces of the tray can be used to properly orient the tray with respect to the laser and to the paper. Pay careful attention to your instructor's demonstration. Once the tray is located on the paper, it is all right to move the paper slowly. Do not let the tray slide on the paper, however.
5. Slide and rotate the paper, with the water and tray on top, until the laser beam travels along the 25-degree line and hits the **center of the flat side of the tray**. The beam will refract into the liquid. You can be certain that you are aligned correctly when some light from the beam reflects off the inner surface of the circular side of the tray and returns to the center of the flat face of the tray.



6. Mark the point where the refracted beam reaches the edge of the paper after it exits through the circular back wall of the tray. Repeat the process for incident angles from 30° to 70°, for a total of 10 points on the paper Data Sheet.
7. Draw lines from the center of the data sheet to the points marking the refracted beams. Measure the angles of all the incident and refracted rays. Write the angles on the data sheet next to each line. Read the angles to the nearest 1/10th of a degree. The incident angles are likely different from the angles you intended to draw. Measure them all, and enter the measured angles in the Data Table below.
8. Calculate the index of refraction of water from the angles of the incident and refracted rays using Snell's Law. Record your values for n_{water} in the Data Table and calculate the average value of $n_{\text{water-Avg}}$.

$$n_{\text{water}} \sin \theta_{\text{water}} = n_{\text{air}} \sin \theta_{\text{air}}$$

n for air is 1.00029

If any of your answers are not within 10% of the true value, repeat them until they all agree to within 10% of the average value.

DATA TABLE

PART ONE: Finding the index of refraction of water

Trial	θ_{air}	θ_{water}	$\sin \theta_{\text{air}}$	$\sin \theta_{\text{water}}$	n_{water}	%Error
1	25° = _____	_____ °	_____	_____	_____	_____ %
2	30° = _____	_____ °	_____	_____	_____	_____ %
3	35° = _____	_____ °	_____	_____	_____	_____ %
4	40° = _____	_____ °	_____	_____	_____	_____ %
5	45° = _____	_____ °	_____	_____	_____	_____ %
6	50° = _____	_____ °	_____	_____	_____	_____ %
7	55° = _____	_____ °	_____	_____	_____	_____ %
8	60° = _____	_____ °	_____	_____	_____	_____ %
9	65° = _____	_____ °	_____	_____	_____	_____ %
10	70° = _____	_____ °	_____	_____	_____	_____ %

Average of all you measurements: $n_{\text{water-Avg}} =$ _____ %

Reminder: %Error is: $100\% \times |\text{your answer} - \text{correct answer}| / (\text{correct answer})$.

You will need to look up the correct value for the index of refraction of water before you can attempt the %Error calculations. This is truly a %Error calculation because the true value is known.

9. Using only data from Part I, create a graph; call it Graph #1; $\sin \theta_{\text{air}}$ vs $\sin \theta_{\text{water}}$. (Which is vertical and which is horizontal?)

This graph should yield a straight line through the origin with a slope equal to $n_{\text{water}}/n_{\text{air}}$, or $n_{\text{water}}/1.00029$.

Fit it to a straight line **through the origin** ($y=Ax$). From the slope of the straight line through the origin calculate n_{water} . Report the slope of the line and the index of refraction of water derived from the slope.

The index of refraction of water derived from the slope of the line is your “**First Graphical Estimate**”.

Slope of the line through the origin in Graph #1 = _____

Calculate the index of refraction of water from the slope. Then calculate the %Error in that result. Even with our rather crude apparatus this should prove to be a very accurate method for determining the index of refraction of almost any liquid. Good technique is critical to an accurate result; work carefully.

Since the slope of Graph #1 = $n_{\text{water}}/1.00029$, the index of refraction of water, estimated from this graph, is

First Graphical Estimate of $n_{\text{water-1}}$ = _____; %Error = _____%

10. Using only data from Part I, Create another graph; call it Graph #2; θ_{air} vs θ_{water} . (Which is vertical and which is horizontal?)

Before you begin this graph, check the settings in the File – Settings menu to make sure that “degrees” is the default angular measure. The points in this graph can be fit with some difficulty to the following equation.

$$\theta_{\text{air}} = \sin^{-1}((n_{\text{water}}/n_{\text{air}})*\sin \theta_{\text{water}})$$

Let $n_{\text{air}} = 1.00029$.

You can define this function in the Curve Fit menu under the Analyze menu. Assuming the θ_{water} axis has the short name of x , this fitting function is defined as follows, where N is the sought after index of refraction of water:

$$\text{asin}((N/1.00029)*\sin(x))$$

The index of refraction of water derived from this equation is your “**Second Graphical Estimate**”.

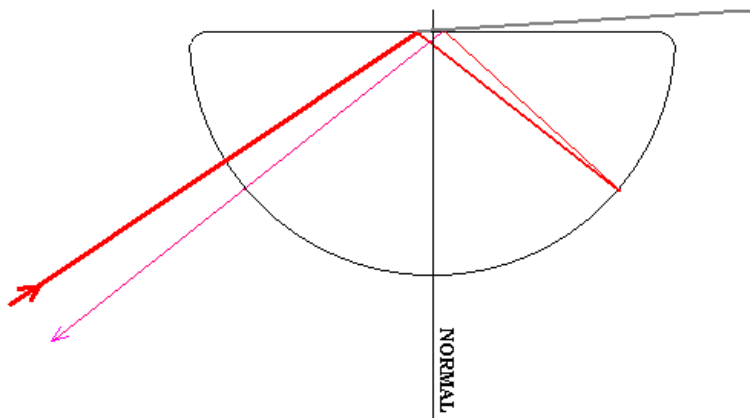
Second Graphical Estimate of $n_{\text{water-2}}$ = _____; %Error = _____%

Be sure to print Graph #2, showing the Second Graphical Estimate of the index of refraction of water, and save it in your folder before you create Graph #3 in the next section. Graph #2 and Graph #3 are not identical and both must be submitted attached to your final lab write-up.

PART TWO: Finding the Critical Angle of an Air-Water Surface

1. This time aim the laser beam into the water through the curved back wall of the tray. You are aligned correctly when the beam reflected from the curved surface bounces directly back to the laser and the beam passes directly through the center of the flat side of the tray. Rotate the paper until the refracted beam on the **AIR**-side makes a 90-degree angle with the normal. Mark the path of the incident ray on the **WATER**-side of the surface and measure the angle this ray makes with the normal. Record this angle as the critical angle in the space reserved below.

The figure below shows the incident ray and internal reflections that can be used for alignment. The beam is not yet aligned in the figure. When the beam and the tray are aligned, both reflections will take place at the center of the flat face and the reflected ray will coincide with the incident ray. The refracted ray exits from the front face of the tray traveling slightly upward and to the right. When the tray is aligned at the critical angle, the internal reflections will all coincide and the refracted beam will be traveling parallel to the flat face of the tray.



2. Calculate the index of refraction of water using your critical angle and Snell's Law. Record this estimate for $n_{\text{water-C}}$ below.

$$n_{\text{air}} \sin \theta_{\text{air}} = n_{\text{water}} \sin \theta_{\text{water, critical angle}}$$

n_{air} is 1.00029 and θ_{air} is 90 degrees when θ_{water} is at the critical angle.

(Measure the critical angle for the water-air surface. Use that result to calculate the index of refraction of water. If your answer is **not within 10% of the correct value**, repeat the procedure until it is.)

Critical angle _____°

$N_{\text{water-C}}$ (estimated from the critical angle) = _____; %Error = _____%

3. Create a new page in **LoggerPRO3**. Call the new graph "Graph #3". Add the new θ_{water} and θ_{air} from Part Two to the earlier data used to create Graph #2. Graph #3 will look like Graph #2 with an extra data point. Make sure the square brackets defining the data in the fit include the new point. Sort the data so that **Curve Fit** will work. Make sure the vertical axis goes from 0° to 100° and make sure the horizontal axis goes from 0° to 60°. The new data point will change the estimate of the index of refraction for water, if only slightly.

Call this your Third Graphical Estimate of $n_{\text{water-3}}$ = _____; %Error = _____%

Submit all three printed graphs showing the three graphical estimates of the index of refraction of water.

PART THREE: The Rainbow

This is a group demonstration of how a spectrum of different colors is created from a white light source using a diffracting medium. In this case it's water. What we perceive as white light is actually a mixture of all the colors our eyes are capable of registering. These all fall in the wavelength range of the peak output of our sun. No doubt, if we had evolved under the glare of a different star our eyes would register its particular mix of wavelengths as white light.

Using a white light source and a card with a pinhole or a vertical slight between two pieces of paper, create a beam of white light and shine it onto the center of the flat face of the water filled semicircle used in Parts I and II. Out of the curved back of the dish you will see a rainbow of colors from red to violet. Set the angle of incidence near 50° and measure the minimum and maximum angles of refraction. This can be a little tricky.

Angle of incidence (*in class demonstration*) = _____ $^\circ$

Red light (wavelength ~ 700 nm) angle of refraction = _____ $^\circ$

Violet light (wavelength ~ 400 nm) angle of refraction = _____ $^\circ$

- A. Given an incident angle near 50° , which color is bent more (farther toward the normal line?)
(Circle one: Red or Violet)
- B. Which color has the longer wavelength?
(Circle one: Red or Violet)
- C. Use relationships in the textbook to calculate the frequency range of visible light.

Frequency of Red light (wavelength ~ 700 nm) = _____

Frequency of Violet light (wavelength ~ 400 nm) = _____

Which color has the higher frequency?
(Circle one: Red or Violet)

- D. Use the angle of incidence and the two measured angles of refraction to estimate values of the index of refraction of each end of the visible spectrum. You know the incident angle, which is the same for both colors since they both arrived in the same beam of white light and traveled along the same path. You know the refracted angle for each end of the visible spectrum. Now calculate the index of refraction for the red and violet ends of the visible spectrum.

Index of refraction for Red light (wavelength ~ 700 nm) = _____

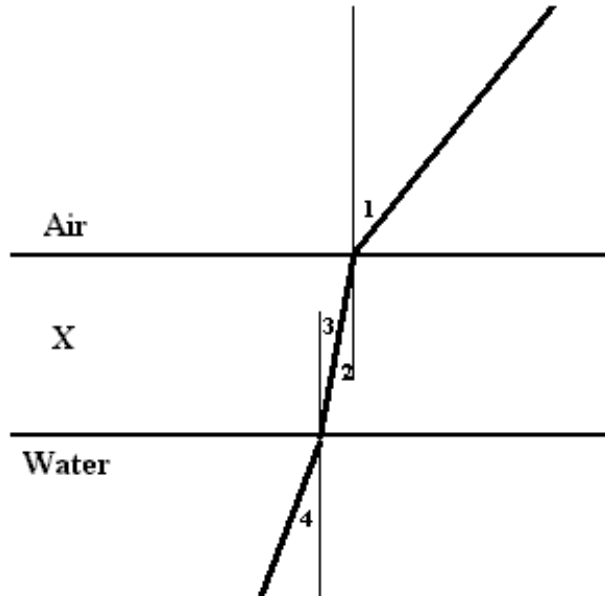
Index of refraction for Violet light (wavelength ~ 400 nm) = _____

- E. For which color is the index of refraction in water larger?
(Circle one: Red or Violet)
- F. Which color is slowed more when entering the water?
(Circle one: Red or Violet)
- G. Use the measured spread in the index of refraction between red and violet light to estimate the difference in the index of refraction between light with a wavelength of 633 nm and light with a wavelength of 589 nm. {The brightest monochromatic light source available prior to the advent of the laser was the sodium vapor lamp; $\lambda = 589$ nm. Thus, in most tables of values the index of refraction is still reported at 589 nm. Our HeNe laser, on the other hand, operates at a wavelength of 633 nm.}

$n_{589 \text{ nm}} - n_{633 \text{ nm}} = \underline{\hspace{2cm}} - \underline{\hspace{2cm}} = \underline{\hspace{2cm}}$

Questions for Analysis: (Answer questions 1 - 6 on WebAssign, which we be due at a later date. Answer question 7 on this page, now, and attach your answer to the write-up, if you use additional paper.)

7. In our experiments, the beam of light actually passes through three different media; air, plastic and water. We have not justified our implicit assumption that we can ignore the plastic. Is that a fair and reasonable thing to do? Let's examine that question with a simple example problem. Imagine three media in layers as shown in the figure below. The beam passes from air into medium X and then from medium X into water. There are four angles to measure.



Assume the two surfaces are parallel to each other. What is the relationship between angle 2 and angle 3? (This is a purely geometric question. The answer depends only on the property of light that it travels in a straight line within a transparent, homogeneous material.)

$$\theta_2 = \text{_____} \times \theta_3$$

Now, use that result and Snell's Law to find the relationship between angles 1 and 4. To accomplish this, write Snell's Law for each surface and then eliminate the index of refraction for material X using algebra.

Show your derivation of the Snell's Law relationship between angle 1 and angle 4. (Remember what you already know the relationship between angles 2 and 3.)

Given the Snell's Law relationship between angle 1 and angle 4 derived above, do we need to know the index of refraction of X, or any of its other properties? (Think of it this way: How important is it to find the index of refraction of X, given that we know the index of refract of air and all we really want to know is the index of refraction of water?)
