SNELL'S LAW

Objective: To investigate refraction at a boundary of media and use this to determine the index of refraction *n*.

Prelab:

1. Read this lab and Taylor Chapter 7
2. Using figure 1c and 1d below as a reference, redraw each diagram and indicate the angles θ_1, θ_2, and indices n_1, and n_2. For both diagrams, indicate which has the larger *n* value.

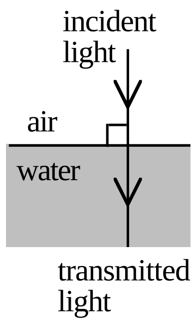


Fig. 1a. Normal Incidence. Air to Water. Reflected ray not shown.

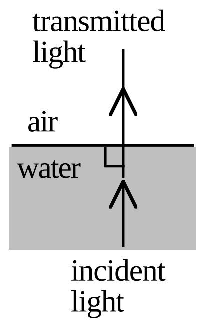


Fig. 1b. Normal Incidence. Water to Air. Reflected ray not shown.

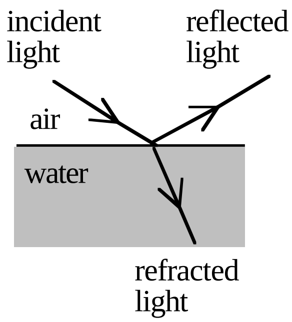


Fig. 1c. Light traveling from air into water.

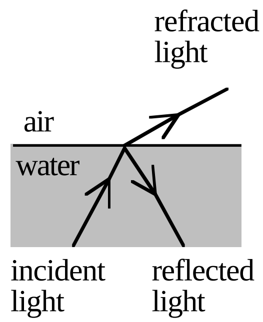


Fig. 1d. Light traveling from water into air.

Apparatus:

Laser, D-shaped water lens, protractor, coffee creamer, mystery fluid.

Introduction:

Light is a wave. For many situations using lenses and mirrors we can simplify our analysis using geometric optics. Geometric optics rests on these simple assumptions:

1. Light travels in straight lines, called rays;
2. Light rays cross each other with no interference between them;
3. Whenever rays strike the interface between two transparent media in which the speed of light is different (e.g., air→glass, glass→air, air→water, etc.), a portion of the light is reflected and a portion is transmitted.
4. The transmitted light rays bend by an amount that depends on the two speeds and on the angle of incidence θ_1. This bending of light rays is called refraction and it is our focus in lab today.

These 4 assumptions have their limits: We know from diffraction that the first assumption does not work when light passes through apertures the size of the wavelength of light. The second assumption is related to the superposition principle that is true for all waves. The fourth assumption is known as "Snell's law," and it states that the angle of refraction is related to the angle of incidence via

$$n_I \sin(q_I) = n_R \sin(q_R) \qquad (1)$$

with n_I and n_R being the index of refraction for the material on the incident side and refracted side, respectively. The index of refraction $n \equiv \frac{c}{v}$ is the ratio of the speed of light in vacuum (c) to the speed of light in the medium (v). (Note that ≡ means "equal by definition".) The geometry is shown in Fig. (1) for light passing from a less dense medium (e.g. air) to more dense (e.g. water).

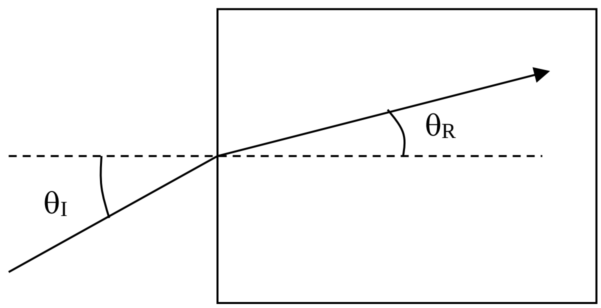


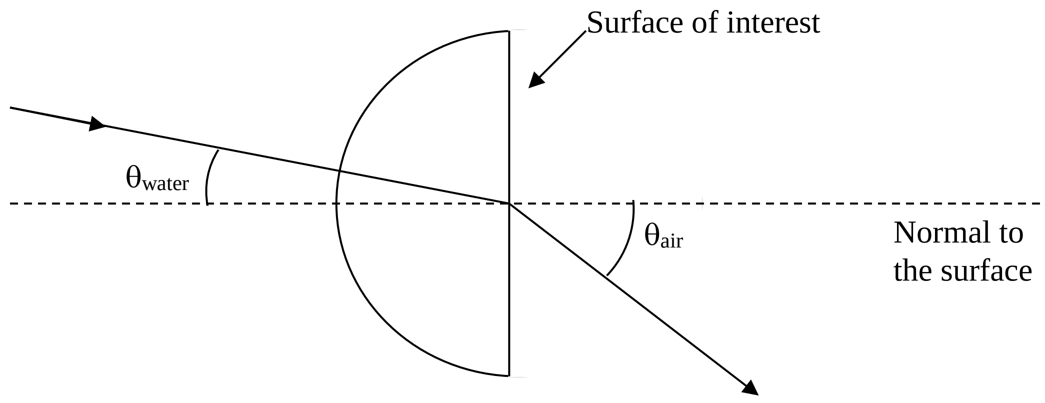
Fig. 1: Snell's Law. Angles are measured relative to the normal (dotted line).

Part I: Data

Refraction refers to the bending of light when it crosses an interface between two materials. We will discuss this from a wave point of view in class, but for now we will consider it experimentally.

(1) Arrange your laser and D shaped water dish as explained by your instructor. We are interested in looking at refraction as the light passes from water-to-air. Using Eq. (1) show that the light does not bend when it crosses a surface along the normal (perpendicular) to the surface. The beam must hit the dish at normal incidence – *perpendicular to the surface*- so there is no bending of the light at the air-to-water interface. Align the dish so that its straight edge is along the protractor axis and the dish is centered on the protractor. Align the laser so that it is centered and perpendicular to the axis of the protractor. (What happens if either of these two conditions is not met? Is there an experimental technique you can use to minimize the effect of even a small misalignment?)

Qualitatively describe what happens to θ_{air} as θ_{water} increases from 0 to 90 degrees. Now measure θ_{air} as a function of θ_{water}. For each point, estimate the uncertainty in your measured values.



(2) As in Eq. (1) Snell's law of refraction states that $n\sin(\theta)$ is constant across an interface so

$$n_{\text{water}}\sin(\theta_{\text{water}}) = n_{\text{air}}\sin(\theta_{\text{air}}) \tag{2}$$

where n_{water} and n_{air} are the index of refraction for water and air, and θ_{water} and θ_{air} are defined in the diagram above. For each point find n_{water} using $n_{\text{air}} = 1.00029 \sim 1$. Plot n_{water} vs. θ_{water}. Is the plot what you expect?

We also need the uncertainty in the index of refraction *for each point*. We'll call this δn_{water}. Looking at Eq. (2) we see that to compute δn_{water} at each point we need to find the uncertainty in a ratio of sines. With Excel compute the uncertainty at each point. What do you notice about the size of the uncertainty as the angle increases?

Part II: Results

(1) Include error bars in your graph of n_{water} as a function of θ_{water}. As always, be sure to save a copy in case you need it in the future (perhaps the postlab).

(2) Do you see any evidence for a systematic error in the graph?

(3) Compute your value for n_{water} and its uncertainty using a weighted average.

Part III: Total internal reflection

What happens at large angles of incidence? Experimentally explore the angles around the point where the amount of transmission changes drastically. This angle is called the critical angle. What is the condition for the critical angle? Find an expression for the critical angle in terms of the index of refraction of water. Compare your expression to a measured value.

Part IV: Measuring refractive index

While a particular index of refraction does not uniquely determine a material, it can help you find out what you have. With your lab group, devise a simple method using the equipment you have to determine the index of refraction of a mystery material. Once you have a satisfactory method ask your instructor for the mystery material. Determine the index of refraction. Individually write up your results in a concise summary. Please include: (1) A description of your procedure (2) Your result with uncertainty in standard form.

(3) Using the list of refractive indices on Wikipedia, what do you think the mystery material might be?