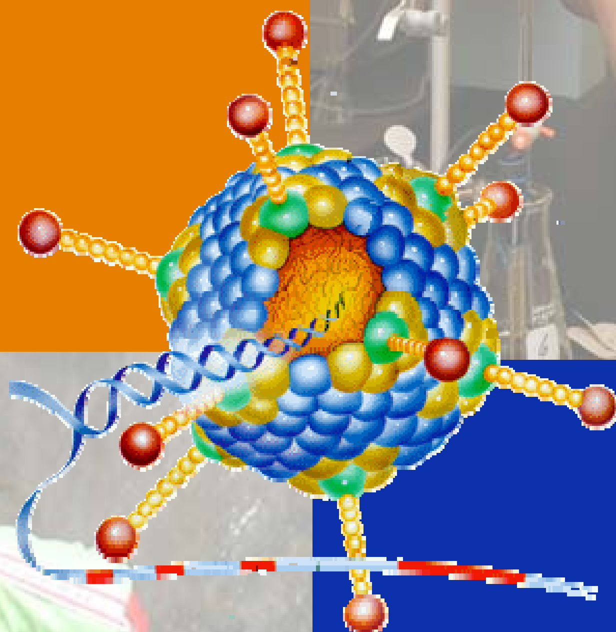
Refraction and Reflection

Lab Book



The waterCAMPWS
Center for Advanced Materials
for Purification of Water with Systems

The WaterCAMPWS Center for Advanced Materials for Purification of Water with Systems
University of Illinois at Urbana-Champaign

Overview

This lab introduces the basic concepts of refraction and reflection of electromagnetic waves. You will be provided with water, vinegar, and an unknown solution. A laser pen will act as the wave source. By using trigonometric identities and Snell's Law, you will be able to identify the index of refraction of these solutions. It is important to record each measurement as accurately as possible, for it will greatly affect your accuracy during the calculation for the unknown. The second part of the experiment allows you to identify the critical angle for total internal reflection in which only reflection on the interface will be observed.

In completion of the lab, each group will calculate the index of refraction of water and vinegar respectively. With these results, you will be able to find a range of values in which the unknown index of refraction resides.

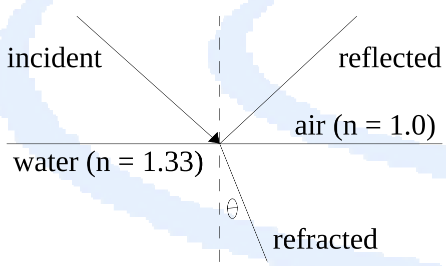
Although safety goggles are not required for this experiment, the laser source is still a potential hazard that can cause serious injury. Always use with caution and NEVER look directly into the laser. Laser can be reflected or refracted when shone on the Plexiglas. The reflected or refracted beam may be as intense as the incident laser. Always be alert and never stare at the same spot for extended period of time.

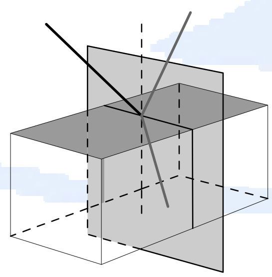
Recall:

Index of refraction is one of the various important properties of matters. A common way to determine the index of refraction is by applying the concept of the Snell's Law

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad (1)$$

Where θ is the angle between the incident ray and the plane perpendicular to the surface, also known as the angle of refraction. Then n is the index of refraction.





Since the interface of interest in this experiment would always be that of air ($n \approx 1$) and a solution, the index of refraction of the solution can be easily found. For example, if the Snell's Law is equated into the form:

$$n_2 = \frac{(\sin\theta_1)(n_1)}{\sin\theta_2} \text{ or simply, } n_{sol} = \frac{(\sin\theta_{air})(n_{air})}{\sin\theta_{sol}} \qquad (2)$$

The angles can be determined by using the property of arctangent, the distance between the intersection of the incident ray and the interface is the "adjacent" and the distance between the interface and the beam source is the "opposite." The angle would then simply be:

$$\theta = \arctan\left(\frac{opposite}{adjacent}\right) \qquad (3)$$

The index of refraction of the solution is obtained by substituting the corresponding values into equation (2).

What exactly does the index of refraction tell us? Visible light, laser, etc. are all electromagnetic waves, the speed of electromagnetic waves are different in matters than it is in vacuum. The speed of electromagnetic wave in matters is related to that of vacuum by the equation

$$v = \frac{c}{n} \tag{4}$$

Where c is the speed of light (3×10^8 m/s) and n is the index of refraction of a particular matter. The index of refraction of vacuum would be 1, since the speed of electromagnetic waves in a vacuum would equal to that of the speed of light. In this experiment it is assumed that air and vacuum are very similar. The concept behind equation (4) can be explained by Maxwell's equation, which is beyond the depth and range of this experiment.

Reflection is a much simpler concept since the reflected ray will always be at an angle equivalent to that of the incident light. Both reflected and refracted rays will be observed in this experiment. However, in the case of total internal reflection, refracted rays will not be observed. This happens when,

$$\sin\theta_1 \geq \frac{n_2}{n_1} \tag{5}$$

Materials and Equipment

Materials required for this lesson are (for each group of students):

- Beaker
- Straight pins
- Water
- Wire (24 cm. long to make a cradle for straight pin)
- Medicine-cups (to hold 1 part Joy)
- Water soluble pens
- Liquid detergent (Joy)
- Glycerin
- Square wire frame (use the same wire from cradle

Procedure

1. Before beginning the experiment, develop a hypothesis about the effect of water, and vinegar on electromagnetic light waves. Write your hypothesis below:

Initial Setup

2. Set up the tank and the beaker stand as shown in Figure 1.

3. Mark the position of the tank and the stand with chalk or tape. If the positions of the setup shifts during the experiment, always make sure it is adjusted back to its original position.

4. Fasten the laser pen to the clench, it is advised to wrap soft material (tissue paper) around the pen to get more stability.

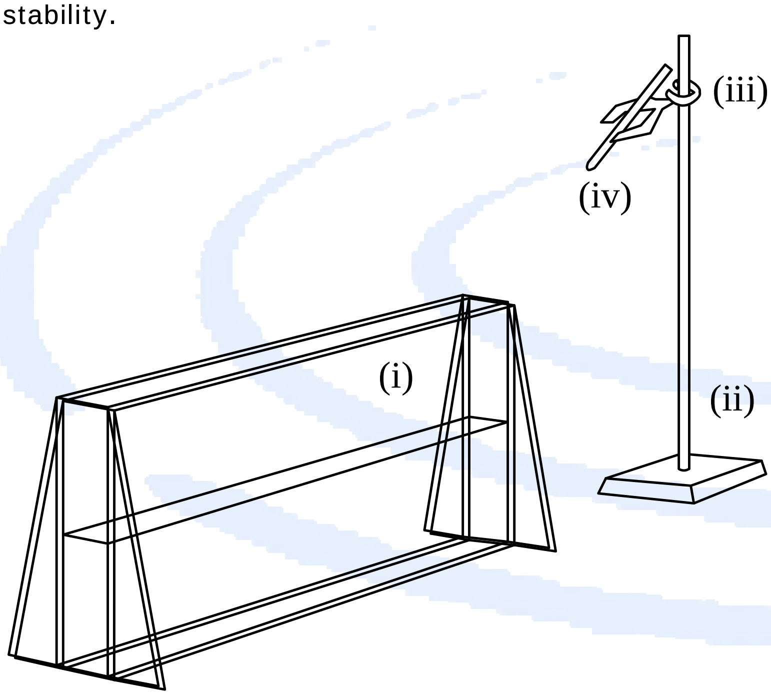


Figure 1. Initial Setup: (i) Plexiglas tank, (ii) beaker stand, (iii) test tube clench, (iv) laser pen.

The Good, the Bad, the Silly…

Writing a good hypothesis is harder than you think. For example:

When it gets cold, water turns to ice.

is an acceptable hypothesis, but not very helpful, since there are many temperature of "cold" when ice wouldn't form.

A better hypothesis would be:

When the temperature reaches 32 degrees Fahrenheit and remains at that temperature, water turns to ice.

The hypothesis:

When the temperature reaches 32 degrees Fahrenheit and remains at that temperature in a room with three windows that face North on a Sunday, water turns to ice.

While this last statement may be true, it contains a lot of unnecessary detail that makes it of little practical value, since there are lots of conditions that will cause ice to form that are excluded in this hypothesis.

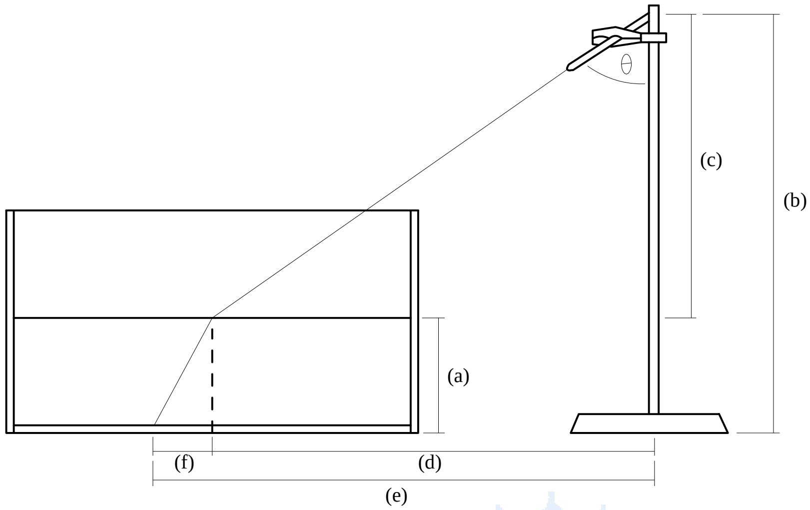


Figure 2. Distance and Angle Measurement Guide

Index of Refraction of Water

5. Fill the tank half-full of water.

6. Using Figure 2 as your guide, measure the values of (a) and (b) with a ruler and record them in Table 1 in the results section.

7. Perform calculations to find (c), record the value in Table 1.

8. Adjust the angle of the laser pen to avoid the bean striking the edges of the tank, also make sure that you can observe a red dot at the bottom of the tank.

9. Tighten the clench so that the laser pen is secure.

10. Measure the angle between the laser pen and the stand, record them in Table 1.

11. Perform calculations to find (d), record the value in Table 1.

12. Measure the distance from the center of the stand to the red laser point (e), then perform calculations to find (f), record in Table 1.

Index of Refraction of Vinegar

13. Repeat steps 5-12 above. It is strongly encouraged to maintain the same laser pen angle and liquid height.

14. Record the corresponding values into Table 2 in the results section. Do not remove the vinegar from the tank for it will be used again in the next section.

Index of Refraction of Unknown

What if an unknown liquid layer is above water and vinegar? Assuming that separating the layers would be a long and tedious task, is it still possible to deduce the index of refraction of this liquid?

Note: The unknown liquid can be hazardous. Please use gloves and DO NOT pour down the drain.

15. Slowly and carefully add 5-10 cm of water on top of the vinegar layer from the previous section.

16. With the same manner, add 5-10 cm of the unknown on top of the water layer.

17. Make sure everything is in place according to the Initial Setup procedures.

18. When all the liquid interface are at equilibrium, measure the depth of each layer and record in Table 3 in the results section.

19. Adjust the angle of the laser pen to avoid the beam striking the edges of the tank, also make sure that you can observe a red dot at the bottom of the tank. Measure the angle and record in Table 3.

20. Measure the distance from the center of the stand to the red laser point, record in Table 3.

Total Internal Reflection

21. Lower the clench with the laser pen to a position close to the bottom of the tank.

22. With CAUTION, tilt the pen upward so the laser hits the water surface from below.

23. Adjust the laser pen to a position that you can observe the refracted beam on the other side of the tank above the water surface.

24. Slowly, adjust the pen again until you can not see the refracted beam and a bright spot on the other side of the tank below the water surface will appear. Secure the pen, measure the acute angle between the pen and the stand.

25. Record the values in Table 4.

Results

Table 1

	Measurements (cm)
(a) Depth of water	cm
(b) Height of stand (from base to laser pen)	cm
(c) = (b)-(a)	cm
Angle θ	degree
(d) = (c) tan θ	cm
(e) Distance from stand to red point	cm
(f)	cm
Angle of refraction of air	degree
Angle of refraction of water	degree
Index of refraction of air	degree
Index of refraction of water	

Table 2

	Measurements (cm)
(a) Depth of water	cm
(b) Height of stand (from base to laser pen)	cm
(c) = (b)-(a)	cm
Angle θ	degree
(d) = (c) tan θ	cm
(e) Distance from stand to red point	cm
(f)	cm
Angle of refraction of air	degree
Angle of refraction of vinegar	degree
Index of refraction of air	degree
Index of refraction of vinegar	

Table 3

	Measurements
Depth of vinegar	cm
Depth of water	cm
Depth of unknown	cm
Angle θ	degree
Distance from stand to red point	cm

Table 4	Measurements
Angle θ	degree

Analysis

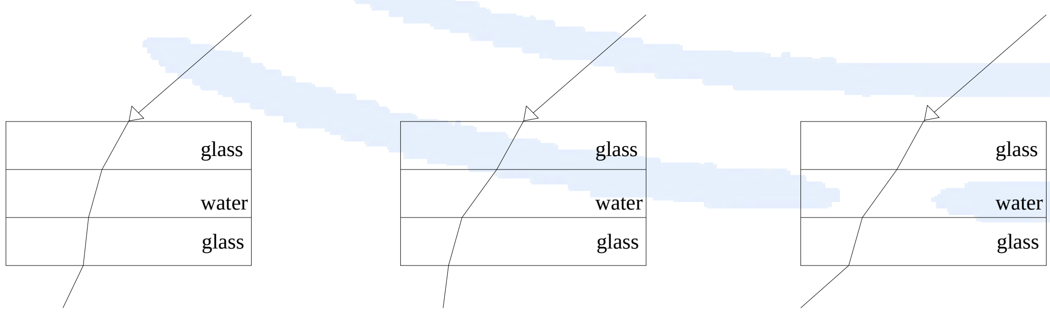
1. Find the index of refraction for water and vinegar respectively from the experimental results. Show your work.

2. Sketch two diagrams clearly showing the interface, the incident and refracted beams, and the angles of refraction for water, vinegar, and air.

3. In the last section of the lab, you were to determine the index of refraction of an unknown liquid. What is the critical angle for water?

4. Would the critical angle for the unknown solution be greater, equal, or less than that of water?

5. Which of the following diagrams correctly represents the refracted beam as a result of the incident light? n = 1.5 for glass. (circle all that apply)



6. An optical fiber is surrounded by another dielectric. In the first case, the dielectric has an index of refraction of 1.45, and in the second case, it has an index of refraction of 1.00. Compare the critical angles for total internal reflection in the fiber in these two cases.