TEACHER INSTRUCTIONS

Index of Refraction

Objective

To explore properties of light as it interacts with different materials including glass.

Background Information

Index of Refraction: When a beam of light crosses a boundary between two mediums, for example air to glass, the beam's speed and direction changes. The change of direction is referred to as refraction and depends on the relative speeds of light in the two mediums. By measuring the change in direction of a laser beam as it travels from the two mediums, you can calculate the index of refraction (*n*).

The index of refraction is defined as the ratio of the speed of light in a vacuum to its speed in a specific medium. Since the speed of light in air is very close to that of a vacuum, we approximate the speed of light in air as having an index of refraction of 1. The index of refraction of other materials can be calculated from the following equation:

Missing Equation

Where n is the index of refraction, c is the speed of light in a vacuum (3×10^8 m/s) and v is the velocity of light in a substance or material. The higher the index of refraction, the higher the optical density and slower is the speed of light. The table below lists the average index of refraction common materials.

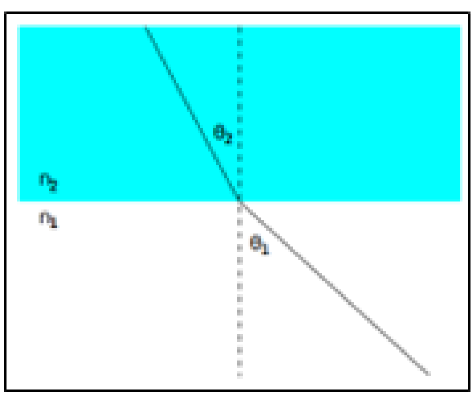


Figure 1. Refraction of a light ray crossing a boundary between mediums.

Table I. Index of Refraction.

Material	Index of Refraction (n)
Air	1.00
Ice	1.31
Water	1.33
Ethyl Alcohol	1.36
Oil (Vegetable)	1.47
Glass	1.52
Diamond	2.42

Light crossing a planar boundary between a medium with index of refraction n_1 and a medium with index of refraction n_2 changes direction at the boundary. The directions of travel of the light in the two mediums are related by Snell's law.

Missing Equation

Where n_1 is the index of refraction for the first medium and n_2 is the index of refraction for the second medium and the angles θ_1 and θ_2 are measured as shown in Figure 1 relative to a line normal (perpendicular) to the boundary.

Dispersion of White Light: White light (flashlight, sunshine, cell phone flashlight, etc.) appears white because it is a combination of all colors in the color spectrum, containing all the colors you see in a rainbow.

Each color you see is associated with a particular wavelength on the electromagnetic spectrum (Figure 2). Wavelength can be measured as the distance between two peaks in a wave. In the visible region, you can see from red, which has a wavelength of about 700 nm, all the way to violet, which has a wavelength about 400 nm.

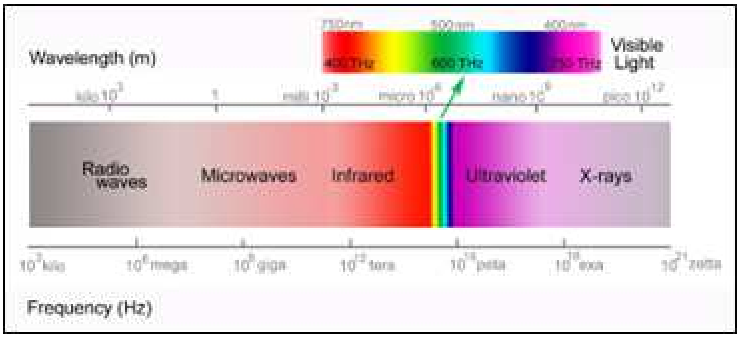


Figure 2. (Left) Electromagnetic Spectrum (Source: NIST.gov) (Right) Prism in sunlight.

When white light is separated into its different colors, it is called dispersion of light. A glass prism can be used to disperse white light (Figure 2). A prism is a solid polyhedron with all flat sides composed of two triangular bases and three rectangular surfaces that are inclined toward each other.

When light is directed through one of the rectangular faces, it enters the prism and exits through the other rectangular prism. Different colors of light (different wavelengths) travel through materials at different speeds, therefore the refractive index is different for every color.

Now when a single beam of white light enters through the prism, the different colors it is composed of will bend at different angles. This separation of white light into its component colors results in the observation of a rainbow. Many natural phenomena are explained by the dispersion and scattering of light, including rainbows in the sky after it rains, colors seen in soap bubbles, the color of the sun, the color of the sky at different times, and the color of smoke in winter.

Demo Description

During this demo, students will test dispersion of white light through a prism and learn about the index of refraction by shining monochromatic light through different materials such as glass, water, oil, and candy glass.

Students will investigate the refraction of light traveling from air into glass using a semicircular acrylic glass. Students will also investigate the refraction of light traveling from air into a hollow plastic rectangular container filled with water and then oil.

The plastic walls of the container do not change the direction of travel of the light, because the air-plastic and plastic water boundaries are parallel to each other. The refraction shown is due solely to the difference between the indices of refraction of air and water or oil.

Keywords

- Wavelength – measured as the distance between two peaks in a wave
- Electromagnetic spectrum – shows the range of all types of electromagnetic radiation
- Dispersion – when white light is separated into its different colors
- Monochromatic light – light of a single-wavelength
- Index of Refraction (n) – the ratio of the speed of light in a vacuum to that in a second medium of greater density
- Snell's Law – a relationship between the path taken by a light ray in crossing a boundary between two contacting mediums and the refractive index of each

Materials List

Items Provided in the Kit:

- Acrylic Prism
- Acrylic Semicircle
- Hollow Plastic Container
- Protractor

Items Provided by Teacher/School:

- Cardboard
- Laser Pointer
- Water
- Vegetable Oil

Safety Precautions

Laser pointers are safe when properly used as a visual or instructional aid. If shone directly into the eye, a laser pointer can cause serious injuries to the eye. Direct students to never shine laser directly into their or anyone else's eyes.

Instructions for Creating a Rainbow using a Prism

1. Take your prism outside and observe the sunlight through it (Figure 2).

2. Create a setup like the one in Figure 3(A). Place the prism in the upright position. You can use sunlight, a flashlight, or even your cell phone light as the source of white light. You will want to create a thin slit using cardboard to make a narrow beam of white light. Make sure the room is dark in order to better see the rainbow.

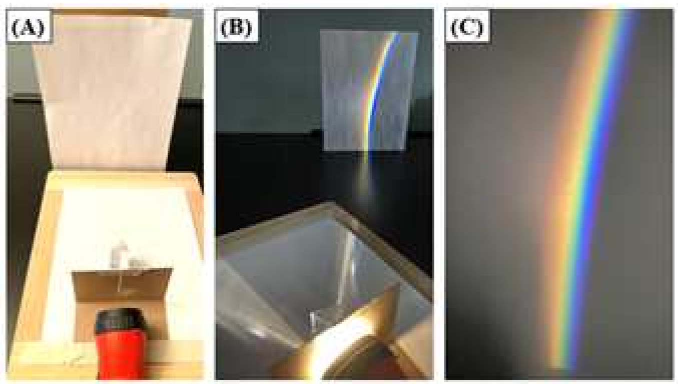


Figure 3. (A) Light & prism set up. (B) Light & prism set up in use. (C) Close up of rainbow created.

3. Rotate the prism until you see the rainbow form. What colors do you see, in what order? Can you make the spectrum broader and colors more distinct?

Instructions for Determining Index of Refraction

1. Using a piece of paper and using a straight edge, draw a line across the center, and then draw another line perpendicular to that line.

2. Place your semicircular glass along one of the lines you drew, centered on the point at which they cross. Trace the shape of the glass in case the container moves from the lines.

3. Using your protractor, create marks indicating angles 0° to 90° shown in Figure 4. (*You can also use the printed angle circle provided in this handout. You will still need your protractor for intermediate angle measurements.*)

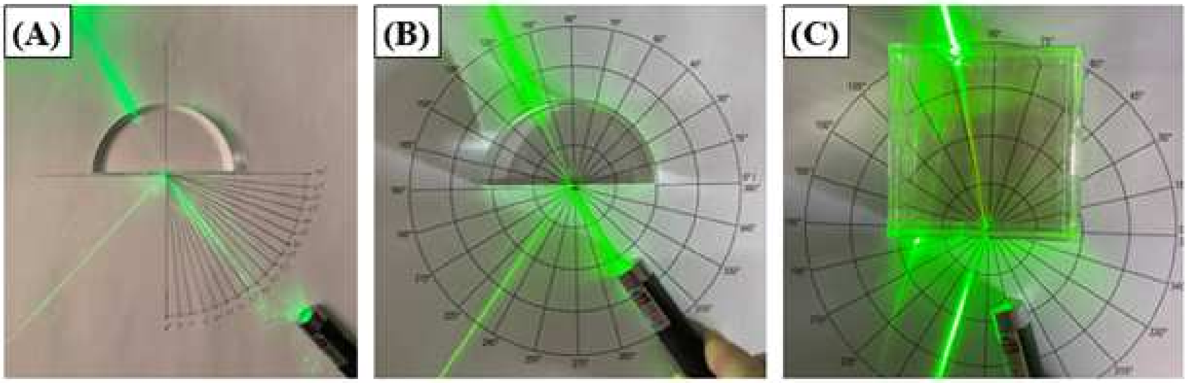


Figure 4. Refraction of a laser pointer light ray through the semicircle (A) on a handmade index circle and (B) printed one. (C) Refraction of a laser pointer light ray through the hollow rectangle filled with water.

4. Place your laser pointer at the center of the flat side of the glass. This will define the incident ray, which makes an angle (Incident angle θ_1) with the normal to the flat surface of the container. Mark the spot where the ray emerges from the other side of the glass. This will be refracted angle θ_2. Use your protractor to measure this angle (Figure 5).

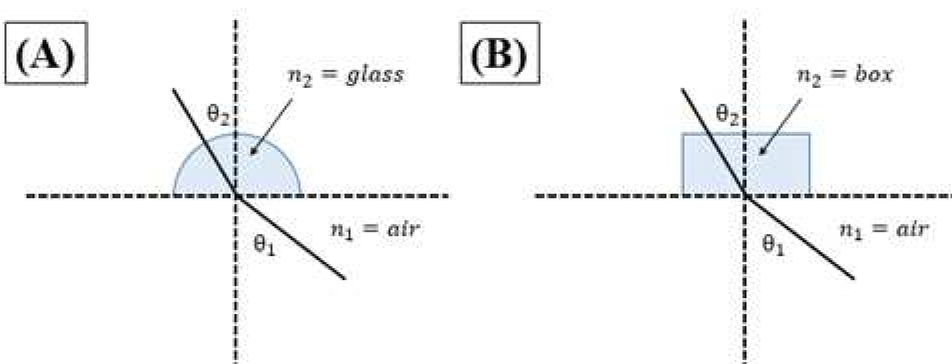


Figure 5. Measuring incident and refracted angles for the (A) semicircle and (B) hollow container.

5. Repeat this procedure for more angles of incidence.

6. Use Snell's Law to calculate n_2. The index of refraction of air is 1.00, this will be your n_1 value. The best way to do this is to fill in Table II and plot a graph of sin θ_1 vs. sin θ_2. Using the linear fit, display the equation. Your value for n_2 will be the slope of this line.

7. Repeat steps (#1-6) using the hollow plastic rectangle using various substances including water and oil in order to obtain the index of refraction for each substance.

8. If you have create a block of glass candy you can perform steps (#1-6) to obtain the index of refraction for the candy glass.

Table II. Angle Measurements for Snell's Law.

Trial	**Incident Angle (θ_1)**	**Refracted Angle (θ_2)**	**n_1 sin (θ_1)**	**sin (θ_2)**
1	0			
2	5			
3	10			
4	15			
5	20			
6	25			
7	30			
8	35			
9	40			
10	45			
11	50			
12	55			
13	60			
14	65			
15	70			
16	75			

Additional Demonstrations and Experiments

For younger students, instead of doing the Snell's Law angle measurements and calculations, teachers can simply have students observe light refracting through several mediums. Pictures can be taken and compared to get an idea of relative index.

Additionally, students can measure several angles and input values directly into Snell's Law equation.

A virtual version of the index of refraction experiment can be found here:
https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html

Cleanup and Replacement Parts

Cleanup of the hollow plastic container can be performed with standard dish soap and water.

TEACHER DISCUSSION QUESTIONS

Questions to ask Before the Demonstration

1. Ask students to list where they have seen rainbows before and if they can describe what they saw.

Discussion: Rainbows in the sky, bubbles, through smoke, etc.

2. Ask students what they think the difference between white light and laser light is.

Discussion: The difference between laser light and a white light source (such as a light bulb or your cell phone light) is that laser light is monochromatic. Monochromatic means that all of the light produced by the laser is of a single wavelength, while the white light is made of many wavelengths in the visible spectrum (See Figure 2).

3. Ask students what they think will happen to light as it is shown through different mediums. Does the composition matter? How?

Discussion: The higher the index of refraction, the higher the optical density and slower is the speed of light.

Questions to ask During the Demonstration

1. What colors do you observe when white light is shown through the prism? In what order do they appear?

Discussion: Students should see a rainbow of colors from red to violet.

2. Do you see a more distinct rainbow appear when the white light is shined though the cardboard slit compared to when it is shined directly on the prism?

Discussion: Students should see a more distinct rainbow when the cardboard is used to create a narrow beam of light.

3. What do you observe as the laser light is directed through each medium?

Discussion: Students should see the light refract through each medium. If they look close enough they should see it refract at slightly different angles depending on the medium.

Questions to ask After the Demonstration

1. Ask students if they can explain what a rainbow is and how it's formed.

Discussion: The formation of a rainbow is related to the dispersion of white light. Water droplets can act as "mini prisms" and the outcome can be similar to that of light through a prism. Water droplets are spherical and have a different index of refraction from the surrounding air of which they are suspended in. When sunlight (white light) hits the water droplets it refracts and spreads into its constituent colors through dispersion.

2. Ask students what colors make up a rainbow and why they appear in order they do.

Discussion: The rainbow pattern is made up of seven colors in a specific order. The color red is at the bottom and the color violet is at the top. The wavelength of red light is higher so it deviates the least, while the wavelength of violet is lower and deviates the most.

3. Can rainbows appear on other planets? Why or why not?

Discussion: You need sunlight and raindrops to create a rainbow like we see on Earth after a storm. There is no other planet that we currently know of that has liquid water on its surface or in sufficient quantities in the atmosphere to make rain. However, dispersion of light can happen in other way as discussed in the introduction.

4. Is the speed of light faster in glass or water?

Discussion: Light is slowed down in transparent media such as air, water, and glass. The higher the index of refraction (n) value, the more optically dense a material is and the slower that light will travel in that material.

4. (*For younger students*) Ask students to compare the refraction observed in each medium then compare with that in Table I. Do they follow a trend? Can you predict the index of refraction for other materials?

Discussion: Students should see a trend in that direction in Table I.

5. (*For older students*) Are your graphs of sin 1 vs. sin 2 compatible with a linear model? Is it compatible with Snell's Law?

6. (*For older students*) What are your best values for the index of refraction of glass, water, and oil? How does it compare with the accepted values?

STUDENT QUESTION HANDOUT

Index of Refraction

1. Make a list of examples of where you have observed rainbows.

2. What colors do you observe when white light is shown through the prism? In what order do they appear?

3. Do you see a more distinct rainbow appear when the white light is shined though the cardboard slit compared to when it is shined directly on the prism?

4. Can rainbows appear on other planets? Why or why not?

5. What do you observe as the laser light is directed through each medium?

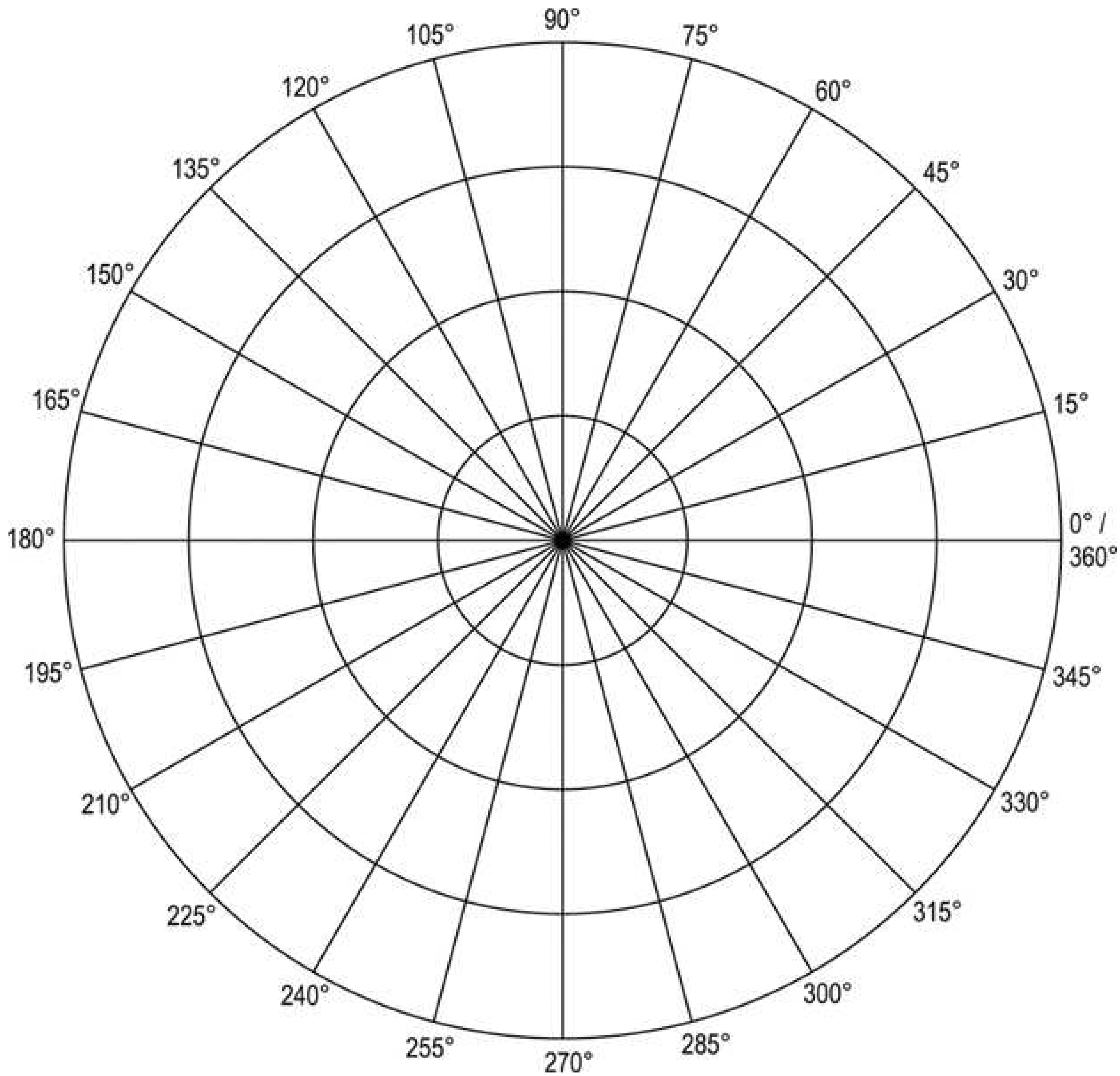
6. Is the speed of light faster in glass or water?

7. Compare the refraction observed in each medium then compare with that in Table I. Do they follow a trend? Can you predict the index of refraction for other materials?

8. (*For older students*) Are your graphs of sin 1 vs. sin 2 compatible with a linear model? Is it compatible with Snell's Law?

9. (*For older students*) What are your best values for the index of refraction of glass, water, and oil? How does it compare with the accepted values?

10. What are some applications and ways in which we can use index of refraction?


90°
75°
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