Inquiry Investigation 11-A

Investigating Refraction, from Air to Water

In this investigation, you will compare the angle of incidence and the angle of refraction when a light ray travels from air into water.

Skill Check

Initiating and Planning

✓ Performing and Recording

✓ Analyzing and Interpreting

✓ Communicating

Safety Precautions

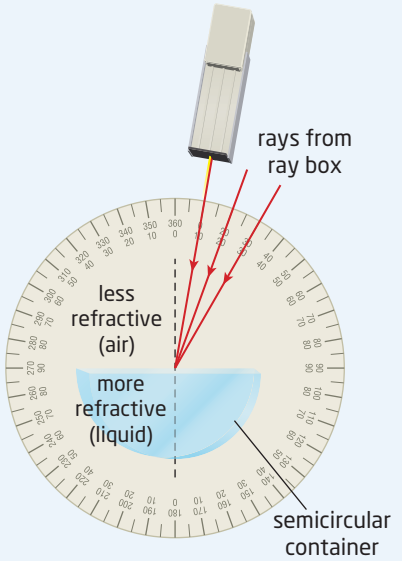
- Be careful not to spill any water.

Materials

- tap water
- clear, semicircular plastic container
- non-dairy creamer or chalk dust
- stir stick
- ray box
- polar graph paper

Math Skills

Go to **Math Skills Toolkit 3** to learn more about making graphs.



Shine the single beam toward the centre of the semicircular plastic container.

Question

What is the relationship between the angle of incidence and the angle of refraction when light passes from a medium where its speed is greater into a medium where its speed is lower?

Procedure

1. Design a table or a spreadsheet to record the angle of incidence ($\angle i$) and the angle of refraction ($\angle R$) for eight sets of data. Give your table a title.
2. Put tap water in the container. Dissolve a very small amount of non-dairy creamer in the water. This will make light rays visible in the water.
3. Position the container so that the centre of the flat edge is at the centre of a sheet of polar graph paper. A line joining the 0° to 180° markings should be a normal at the centre of the flat edge of the container.
4. Place a single slit in the ray box. Shine the light ray toward the centre of the container, as shown in the diagram on the left.
5. Shine the light ray along the normal, toward the flat edge of the container, so the angle of incidence is 0°. Record the angle of refraction.
6. Increase the angle of incidence in 10° steps, up to 70°. Record the angle of refraction for each angle of incidence.

Analyze and Interpret

1. Create a graph with the angle of incidence on the y-axis and the angle of refraction on the x-axis. Give your graph a suitable title. Plot your results, and draw a smooth curve of best fit.
2. Describe and explain the shape of your graph.

Conclude and Communicate

3. Summarize the answer to the investigation question.

Extend Your Inquiry and Research Skills

4. **Research** Research the principle of reversibility. Explain the principle in your own words.

Inquiry Investigation 11-B

Skill Check

Initiating and Planning

✓ Performing and Recording

✓ Analyzing and Interpreting

✓ Communicating

Safety Precautions

- Be careful not to spill any liquids.
- Ethyl alcohol is volatile. Keep the classroom well ventilated, and keep the container with ethyl alcohol covered.

Materials

- marker
- masking tape
- 4 semicircular plastic containers
- cover for one container
- water
- ethyl alcohol
- glycerol
- glass block
- ray box
- protractor

Analyzing the Index of Refraction

In this investigation, you will investigate the refraction of light as it passes through media with different refractive indices and determine whether there is a trend.

Question

How do the angles of refraction and incidence change in media with different indices of refraction?

Procedure

1. Make a table like the one below. Give your table a title.

Material	Angle of Incidence, $\angle i$	Angle of Refraction, $\angle R$	Index of Refraction, n
Air			
Water			
Ethyl alcohol			
Glycerol			
Glass block			

2. Label a semicircular container for each material in the table except for the glass block. Pour water, ethyl alcohol, and glycerol into the containers you labelled for them. Place a cover over the container containing ethyl alcohol.

3. Point a single ray from a ray box into each material listed in your table. Measure and record the angles of incidence and refraction.

4. Refer to **Table 11.1** on page 454. Find the indices of refraction for the materials you tested, and record them in your data table. For the glass block, use the index of refraction for crown glass.

Analyze and Interpret

1. How do the angles of refraction and incidence change in media with different indices of refraction?

Conclude and Communicate

2. Summarize your findings in a statement explaining the trend you observed.

Extend Your Inquiry and Research Skills

3. Research Research refractometers. Explain what a refractometer is and how refractometers are useful to society.

Real World Investigation 11-C

Skill Check

Initiating and Planning

✓ Performing and Recording

✓ Analyzing and Interpreting

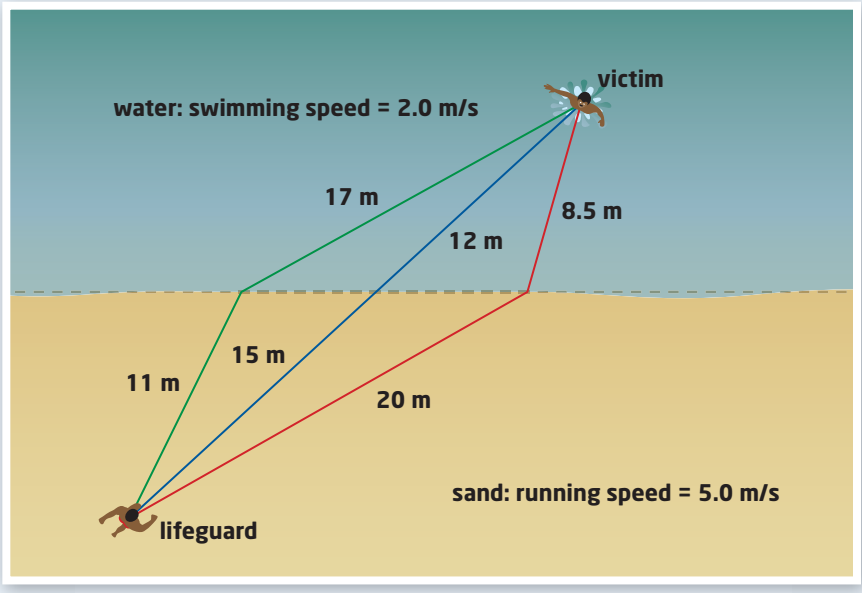
✓ Communicating

Materials

- calculator

Saving Time

A lifeguard hears cries of distress from someone in the water. To reach the drowning victim as soon as possible, the lifeguard must take one of the three paths shown in the diagram below. Each of the three paths has two parts. First, the lifeguard runs on the sand at 5 m/s. Then the lifeguard swims in the water at 2 m/s. How is the time taken to reach the victim related to the time spent running and the time spent swimming?



There are three different paths that the lifeguard could take.

Question

How does this analogy illustrate Fermat's principle?

Prediction

Predict which path the lifeguard should take to reach the victim in the shortest amount of time. Explain your prediction.

Organize the Data

1. The formula for speed is

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

Rearrange this formula to show how you can calculate the time taken.

2. Copy the following table into your notebook. Give your table a title. Enter the distance data from the diagram.

Path	Sand			Water			Time to Reach Victim (s)
	Distance (m)	Time Running (s)	Speed (m/s)	Distance (m)	Time Swimming (s)	Speed (m/s)	
Green							
Red							
Blue							

3. Calculate the time taken to run and swim along each of the three paths. Show your work, and enter your results in your table.

Analyze and Interpret

4. Which path takes the least time for the lifeguard to rescue the swimmer?

Conclude and Communicate

5. Explain how this analogy illustrates Fermat's principle.

6. Evaluate the analogy.

Extend Your Inquiry and Research Skills

7. **Inquiry** How much time would be lost if the lifeguard chose the blue path, which is a straight line to the victim?

8. **Research** Research the French mathematician Pierre de Fermat (1601–1665), who developed this principle.

A lifeguard has to reach the victim as soon as possible.

Inquiry Investigation 11-D

Investigating Total Internal Reflection in Water

In this investigation, you will investigate the relationship between the angle of incidence and the angle of refraction when a light ray travels from water into air.

Skill Check

Initiating and Planning

✓ **Performing and Recording**

✓ **Analyzing and Interpreting**

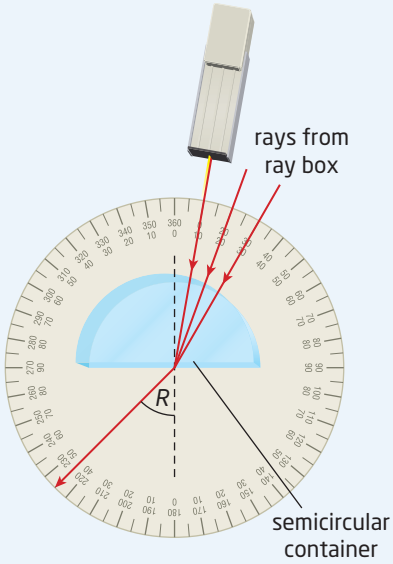
✓ **Communicating**

Safety Precautions

- Be careful not to spill any water.

Materials

- tap water
- clear, semicircular plastic container
- non-dairy creamer or chalk dust
- stir stick
- ray box
- polar graph paper



The curved side of the semicircular plastic container must face toward the light source.

Procedure

1. Design a table or a spreadsheet to record the angle of incidence ($\angle i$), the angle of reflection ($\angle r$), and the angle of refraction ($\angle R$) for several sets of data. Give your table a title.
2. Put tap water in the plastic container. Dissolve a very small amount of non-dairy creamer in the water.
3. Position the container on the polar graph paper, as shown in the diagram on the left. The flat edge of the container must be on the horizontal 90°–90° line, with its centre on the 0°–0° line.
4. Use the ray box to shine a single light ray toward the centre of the straight edge, directly along the normal. Record the angles of incidence, reflection, and refraction.
5. With the light ray directed toward the centre of the straight edge, increase the angle of incidence by increments of 5°. Record the angle of reflection and the angle of refraction. Note the brightness of the reflected and refracted rays relative to each other.
6. When the angle of incidence results in a refracted ray that is close to the flat edge of the container, increase the angle of incidence by increments of 1°. Record the critical angle and your observations when the angle of incidence is greater than the critical angle.

Analyze and Interpret

1. Does the incident ray bend when it enters the curved side of the plastic container? Explain your observation.
2. What is the critical angle for light travelling from water into air? What is the angle of refraction at the critical angle?

Conclude and Communicate

3. What happens when the angle of incidence is greater than the critical angle?

Extend Your Inquiry and Research Skills

4. **Inquiry** Design a periscope that uses prisms and total internal reflection.