Section 11.3 Optical Phenomena in Nature

(Student textbook pages 468 to 475)

In this section, students apply their understanding of refraction to analyze the cause of refraction-based phenomena including rainbows, mirages, and apparent depth.

Common Misconceptions

- Mirages are sometimes described as elaborate fantasies in literature. Scientifically, a mirage is limited to the appearance of water, or of a reflected and distorted image of what is actually there. Our imagination is responsible for interpreting the reflected water and animals as mountains and trees (as shown in Figure 11.29D on page 474 of the student textbook).
- Literature and folklore often tell of following a rainbow to its source. While geometry may be able to extend a rainbow's arc to the ground, we cannot see a rainbow at ground level. The angle between the Sun, droplets, and observer does not support the optical effect there.

Background Knowledge

Students may wonder whether sundogs can be used to predict weather. Since sundogs indicate ice particles in the upper atmosphere, they can indicate a coming warm front, which often brings precipitation.

Although the idea behind apparent depth is simple enough, it has a profound implication in applications such as telescopes. Actually solving the equations for calculating the apparent depth of materials is beyond the scope of this curriculum. Indeed, it is a typical problem for first year university physics.

Literacy Support

Using the Text

- Have students use the SQ4R (Survey, Question, Read, Recite, Review, and Reflect) strategy for this section to activate prior knowledge, engage student interest, and assess their own learning.

Before Reading

- Survey the titles, headings, and subheadings used. Ask students to turn the headings into questions. For example, was the Sun behind you when you saw your last rainbow? Where do mirages commonly form?

During Reading

- To connect the text to prior learning, ask student to suggest answers to their own pre-reading questions. For example, "When I last saw a rainbow, the Sun was behind me like it is in the picture on p. 468."

After Reading

- Review this section of text to identify the main idea and important details. For example, notice the arrangement of colours is in a fixed order. Students can work together to reflect on the section content and continue to ask each other questions about important details.

Using the Images

- Have students look closely at the rainbow in Figure 11.23 (student textbook page 468). Light is scattered from the area between the rainbows, and tends to refract in the direction of the primary rainbow, so the ground and air is also brighter there. The reason that the trees in the bright area are somewhat blurrier is because of the extra scattered light. It is also why the trees between the rainbows seem clearer, because light from them has not been scattered by water droplets.

Specific Expectations

- **E1.2** analyse a technological device that uses the properties of light, and explain how it has enhanced society
- **E2.1** use appropriate terminology related to light and optics, including, but not limited to: *angle of incidence, angle of reflection, angle of refraction, focal point, luminescence, magnification, mirage,* and *virtual image*
- **E2.6** calculate, using the indices of refraction, the velocity of light as it passes through a variety of media, and explain the angles of refraction with reference to the variations in velocity
- **E3.4** explain the conditions required for partial reflection/refraction and for total internal reflection in lenses, and describe the reflection/refraction using labelled ray diagrams
- **E3.8** describe properties of light, and use them to explain naturally occurring optical phenomena

- When viewing Figure 11.24, point out that rainbows only form if there are many droplets of equal size. Otherwise, the light refracts to a different degree in each droplet and no rainbow is seen. This is why rainbows are not seen after every rainfall.

Assessment FOR Learning		
Tool	**Evidence of Student Understanding**	**Supporting Learners**
Learning Check questions, page 470	Students reference refraction when explaining phenomena.	Have students watch fish (or an ornament) in an aquarium, from the top, front, and sides. Have them compare these perspectives noting where the fish appear to be from each vantage point. Encourage them to reconcile the three different apparent positions, linking it to the effect of refraction.
Activity 11-4 Apparent Depth, page 471	Ray diagrams place the apparent depth within the block.	Show students how to make the pins line up, then trace the lines through to the point of intersection. Have students complete **BLM 11-11 Apparent Depth Data Analysis,** which scaffolds this process.
Section 11.3 Review question 3, page 475	Answers show students understand the angle at which light is reflected in droplets to create a rainbow.	Create a rainbow by shining a light into mist from a spray bottle. Have students circle the mist, noting when the rainbow is visible and when it is not.
Section 11.3 Review question 6, page 475	Explanations of shimmering show understanding of the effect temperature has on the density (refractive index) of a single media (air).	Have students draw ray diagrams in which several media appear in series, noting the number and nature of refractions that occur.

Instructional Strategies

- Have students carry out Activity 11-4 Apparent Depth and Activity 11-1 The Re-appearing Coin if they have not already done so.
- Demonstrate as many phenomena as possible to give students a "tangible" example of each: create a rainbow in mist, locate a fish's depth in a tank, observe the shimmering over a hot plate or flame, and show a mirage.
- Preview the figures with the class, then survey the class for personal experiences with optical phenomenon. What do they know about how these phenomena are created? What would they like to know?
- Present this section as a jigsaw. Split the class into four expert groups who each learn about a different optical phenomenon. Then, reorganize the class into groups of four, each with an expert in each phenomenon. Each expert then teaches the rest of their group. Students may find that **BLM 11-12 Optical Phenomena in Nature** helps them organize their note taking.

Activity 11-4 Apparent Depth (Student textbook page 471)

Pedagogical Purpose

This activity gives students experience with the phenomenon of refraction distorting distance. By tracing the rays, students translate their observations into familiar ray diagrams, confirming what they have seen in figures up to this point.

Planning		
Materials	Rectangular plastic block (clear) Thick piece of cardboard Ruler **BLM 11-11 Apparent Depth Data Analysis** The day before, gather materials and copy the BLM.	Blank paper 5 straight pins
Time	5 min	
Safety	Collect pins in a sharps container.	

Background

Points *C* and *D* allow students to extend the rays into the block, identifying the false image responsible for the illusion of apparent depth.

Activity Notes and Troubleshooting

- The plastic block should be clear and thick.
- Alternative materials:
  - stick pins in a bulletin board
  - magnets on a blackboard
  - coloured dots on a whiteboard
- Set up materials at the front of class as a model for students. Ensure students understand that they need to lower their eyes to the level of the cardboard for step 4.
- Before step 4, ask students to look straight through the block and mark the spot at which the *O* pin appears to be. After step 5, have them compare their results to this estimation.
- To increase experimental consistency and accuracy, have students trace the outline of the block on the paper so the block can be accurately replaced for step 7.
- Direct students to place the pins touching the block with *O* in the middle, and pins *A* and *B* a few centimetres in from the edges.
- For step 7, have students repeat the entire procedure of drawing ray diagrams (steps 3 to 6) using different colours to differentiate between the trials.
- To wrap up, have small groups of students compare answers and account for any differences (e.g., different set up or experimental error). Have students review their notes on Activity 11-1 in the chapter opener. What explanation or information can they now add?
- To extend, have students repeat the activity, with new locations for *A* and *B*. Or, have them use a thicker block or different material. Compare the results, identifying any pattern.
- Use **BLM A-35 Measuring and Reporting Rubric** to assess students' skill in observing and measuring.

Additional Support

- DI Bodily-kinesthetic learners will benefit from using larger objects such as people. Have them write out the activity, then act it out to explain it to the class.
- A student with visual disabilities could do this exercise using strings between each point in the incident and refracted rays. Use a different type of cord (e.g., fishing line and kite string) to differentiate between the rays.

Answers

1. Exact location will vary, but should be within the block.
2. Example: The light reflected from *O* refracts inside the block, making the rays converge sooner than they would have if the block was not there.
3. Answers should reflect the different refractive indices of plastic and water. The image created by water will appear farther away than that made by the plastic.

Learning Check Answers (Student textbook page 470)

1. Because the red light is directed downward more than the other colours, it is obscured by light from droplets lower in the sky.
2. a bright spot (often with rainbow colours) along a halo around the Sun
3. Aim below the fish, since refraction causes the fish to appear higher than it actually is.
4. Diagrams should show light reflecting twice internally before leaving the raindrops.

Section 11.3 Review Answers (Student textbook page 475)

Please also see **BLM 11-13 Section 11.3 Review (Alternative Format).**

1. When there are ice crystals high in the atmosphere, sundogs likely appear to the side and above the Sun, along the rim of a halo encircling the Sun.
2. Colours in a rainbow come from different droplets. Colours are seen in the opposite order from which they are refracted because lower droplets obscure colours lower in the order
3. Diagrams should show the Sun lower in the sky behind the person, the rainbow in front, and water droplets in the atmosphere.
4. Example: Light rays reflected from the fish to your eyes are refracted farther from the normal at the surface of the water, but your brain assumes a straight path, resulting in a misjudgement of the depth. See Figure 11.25 from page 470 of the student textbook. A fish should be in place of the underwater box.
5. Diagrams should show the fish "aiming" the insect lower than where it sees it. The actual path of the spit should be straight from the mouth to the insect.
6. Example: Knowing that light changes direction as it travels into media of different densities tells me that hot, moving air in which there are several changes in temperature (density) would cause many changes of direction in light rays as they travel to my eyes.
7. There has to be a layer of hotter air above a layer of cooler air.
8. See Figure 11.29C and D on page 474 of the student textbook.

Inquiry Investigation 11-A Investigating Refraction, from Air to Water (Student textbook page 476)

Pedagogical Purpose

This investigation provides students with direct experience of refraction, using their skills of data collection and analysis to confirm the governing principles.

Planning	
Materials	Tap water Clear, semicircular plastic container Non-dairy creamer or chalk dust Stir stick Ray box Polar graph paper **BLM 11-3 Investigating Refraction Data Analysis** (optional) Day before, gather materials and make copies of BLM.
Time	60 min
Safety	Spilled water can cause slippery floors. Clean up any spills promptly. Remind students never to eat in the science classroom.

Background

When light passes from a medium where its speed is greater, as in air, to a medium where its speed is less, as in water, the angle of refraction will always be less than the angle of incidence.

Activity Notes and Troubleshooting

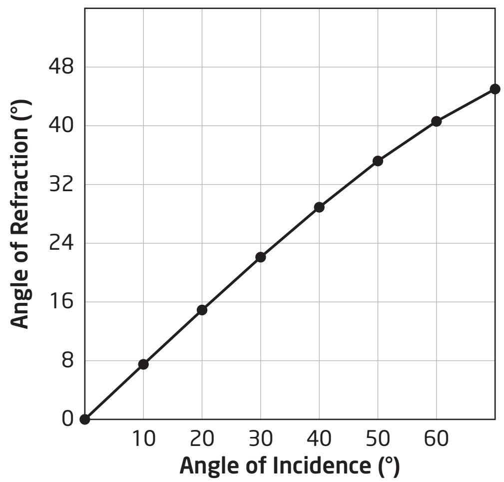
- A single creamer is enough to sufficiently cloud two litres of water.
- Two litres of water is sufficient to see this effect.
- Model the set-up on your desk for students, showing how it fits the description in step 3.
- Show students how to use polar graph paper.
- Show students how to use a ray box to produce a single ray of light.
- Have students prepare observation charts before they begin.
- Use **BLM A-41 Conduct an Investigation Rubric** to assess students' performance.

Additional Support

- DI This is an excellent investigation for logical-mathematical and bodily-kinesthetic learners.
- Allow students to use spreadsheet software to create a table or spreadsheet of their measurements and to graph results.
- Distribute copies of **BLM 11-3 Investigating Refraction Data Analysis** for students to record their observations and analyze results.
- Draw a labelled ray diagram on the board, as a memory aid for the terms *angle of incidence*, *angle of refraction*, and *normal*.

Answers

1.



2. Between an angle of incidence of 0° and 50°, the graph was nearly straight, but the slope increased dramatically as the angle of incidence approached 70° because of increased light dispersion.
3. As light passes from a medium where its speed is greater (air) into a medium where its speed is lower (water), the angle of refraction is always smaller in comparison to the angle of incidence, meaning that the refracted ray is closer to the normal.
4. Example: When light passes from air to water, the ray refracts toward the normal. Along the reverse path, light refracts away from the normal.

Inquiry Investigation 11-B Analyzing the Index of Refraction

(Student textbook page 477)

Pedagogical Purpose

This investigation has students calculate indices of refraction from first-hand experimental results, showing them that the values are derived, not assigned.

Planning	
Materials	Marker Masking tape 4 semicircular plastic containers Cover for one container Glass block 50 mL ethyl alcohol 50 mL glycerol 50 mL water Ray box Protractor **BLM 11-4 Analyzing the Index of Refraction** (optional) The day before, gather materials and make copies of the BLM.
Time	10 min to prepare 60 min in class
Safety	Ethyl alcohol is volatile. Keep the classroom well ventilated and keep the container covered. Clean up any spills promptly, as slippery floors may cause falls.

Background

This activity draws directly on the content of section 11.1.

Activity Notes and Troubleshooting

- Try to have all samples at room temperature to improve the accuracy of results.
- You may wish to prepare a class set of sample liquids in semicircular plastic containers beforehand.
- Set up five stations around the classroom and have students rotate through each set-up.
- Ensure there are no bubbles in the sample, which would skew results.
- To wrap up, collate students' results, identifying a pattern and possible sources of error for any outliers.
- Use **BLM A-18 Data Table Checklist** to assess students' observations.

Additional Support

- Display a labelled ray diagram to remind students which ray is incident and which is refracted.
- Distribute **BLM 11-4 Analyzing the Index of Refraction,** which scaffolds this process.
- Perform a sample calculation together, as a class.
- To challenge, have students calculate the index of refraction of ice and boiling water. How do these compare to the index of refraction for room temperature water? Have them draw a ray diagram to show how light would behave as it passed from boiling water, to room temperature water, to ice.

Answers

1. The angle of incidence does not change, but as the index of refraction increases, the angle of refraction increases.
2. As the index of refraction increases, the angle of refraction increases.
3. A refractometer measures a liquid's index of refraction. They can be used to detect the concentration of sugar, salt, or other substances dissolved in a liquid. For example, in veterinary medicine, a refractometer can be used to measure the amount of protein in a sample of blood or urine, which helps quantify the animal's health.

Real World Investigation 11-C Saving Time

(Student textbook pages 478 to 479)

Pedagogical Purpose

This investigation has students examine an analogy to gain an understanding of principles affecting (invisible) light rays.

Planning		
Materials	Calculator The day before, make copies of the BLM.	**BLM 11-5 Saving Time Data Analysis**
Time	60 min	

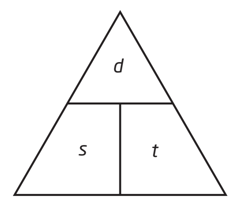
Background

Fermat's principle is sometimes called "the principle of least time" and is the basis for Snell's law, which describes, in mathematical terms, the relationship between the angles of incidence and refraction.

The actual calculations that show this to be true are typically taught in university physics or calculus. The principle behind it is related to the four-dimensional geometry of space-time.

Activity Notes and Troubleshooting

- To introduce the activity, show a video from the National Lifeguard Service competition. Ask students to note at which point on the beach the lifeguards enter the water. Ask why they wouldn't follow a straight line; the shortest distance between two points.
- As a class, carry out sample calculations of *distance* = *speed* × *time* such as "How long would it take a car driving at 100 km/h to travel 100 km? 200 km?"
- To help students manipulate the equation, arrange the variables in a triangle, with a T divider in the centre. Explain that each iteration of the equation can be found by covering the unknown with a thumb, then writing the equation that can be seen. The horizontal line represents division and the vertical line represents multiplication.



- Use **BLM A-29 Problem Solving Rubric** to assess students' work.

Additional Support

- DI Have bodily-kinesthetic learners try this themselves, using mud or deep snow in place of water. Alternatively, have them use a toy car in place of the lifeguard.
- Allow students to use a spreadsheet to make calculations.
- **BLM G-24 Problem Solving Using GRASP** may help students get started.

Answers

4. red

5. The sand represents a medium in which light travels fast and the water represents one in which it travels more slowly.

6. Example: This is a useful investigation because most people have experienced running through both sand and water.

7. 0.75 s

8. Though no question is asked, students may find Fermat's wide range of interests and accomplishments interesting. For example, an accomplished mathematician, he served in the French parliament.

Inquiry Investigation 11-D Investigating Total Internal Reflection in Water (Student textbook page 480)

Pedagogical Purpose

This investigation provides students with direct experience of total internal reflection, using their skills of data collection and analysis to confirm its governing principles.

Planning		
Materials	500 mL tap water Clear, semicircular, plastic container Non-dairy creamer or chalk dust **BLM 11-8 Investigating TIR in Water** The day before, gather materials and make copies of the BLM.	Stir stick Ray box Polar graph paper **BLM 11-9 Build a Periscope** (optional)
Time	60 min	
Safety	Clean up any spills promptly as they may create slippery floors. Remind students never to eat in the science classroom.	

Background

Total internal reflection occurs when an incident ray of light strikes a medium boundary at an angle larger than the critical angle, with respect to the normal to the surface. The critical angle in water is 49°.

Activity Notes and Troubleshooting

- To draw students in, show them applications of prisms and total internal reflection such as redirecting camera lenses to provide two-way video calls on a camera phone or to shoot around corners with a conventional camera. Or even simply in an SLR camera to redirect the image from the lens to the viewfinder.
- A single creamer is enough to sufficiently cloud two litres of water. Ensure there are no bubbles in the sample, which would skew results.
- Half a litre of water is sufficient to see this effect.
- Model the set-up on your desk for students, showing how it fits the description in step 3. Note that the set-up is similar but opposite to that in Investigation 11-A.
- Remind students that the incident ray in this case is *inside* the water. This investigation measures the refraction of light as it enters air (exits the water). Or, until it eventually does not exit the water.
- Show students how to use polar graph paper and how to produce a single ray of light from a ray box.
- Have students prepare observation charts before they begin, with space for about 15 observations.
- To support or extend students' answers to question 5, supply **BLM 11-9 Build a Periscope**.
- To wrap up, collate students' results and compare them to results for Investigation 11-A.
- Use **BLM A-1 Making Observations and Inferences Checklist** to assess students' work.

Additional Support

- ELL Explain the term *periscope* or take students to a playground that has one built into the play structure.
- Allow students to use spreadsheet software to make calculations.
- Display a labelled ray diagram to remind students which ray is incident and which is refracted in this investigation.
- Distribute copies of **BLM 11-8 Investigating TIR in Water** for students to record their observations and analyze results.

Answers

1. No, because the ray strikes the boundary along the normal (90° to the surface).
2. 49°, 90°
3. total internal reflection
4. Example: