Section 11.2 Partial Refraction and Total Internal Reflection

(Student textbook pages 458 to 467)

In this section, students will investigate how, and by how much, light refracts (changes direction) when it enters a new medium. They will also investigate the conditions that prevent light from exiting a transparent medium (total internal reflection), and some of the implications and applications.

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
- **E3.7** identify the factors, in qualitative and quantitative terms, that affect the refraction of light as it passes from one medium to another

Common Misconceptions

- The angle of incidence is measured from the normal (perpendicular), not the surface of the medium. This means that light from the setting Sun, for example, is at a large angle of incidence to the water. This is opposite to how we talk about the Sun being high in the sky, for example.
- Light *does* escape the medium in which total internal reflection occurs. Just not on the same general path at which it entered the medium. The light is totally redirected, sometimes reversed, as it bounces off the opposite edge of the medium.
- Sometimes reflection and refraction are considered exclusive phenomenon. Actually, both nearly always occur at the same time, to different degrees.
- Internal light reflection is not an illusion and does not occur because the medium is no longer transparent. Total internal refraction occurs because of the angle of the light and the difference between the refractive indices of the two media.
- Calculators may give an error message when students solve for the angle of total internal reflection. This is a mathematical way of stating that there is no angle of refraction. This is true in this case because the light ray cannot exit the medium with the higher index of refraction, resulting in total internal reflection.

Background Knowledge

Because each medium has a unique index of refraction, this value can be used to identify materials. This helps differentiate between real and fake diamonds, for example. Cubic zirconia may look very much like diamond, but it does not glisten quite the same way, because the media have a different index of refraction. To tell them apart, a jeweller need only shine a laser at one facet of a cut gemstone and see where the ray of light emerges. The light will emerge at a different place for every gemstone, because they each have a different index of refraction.

Figure 11.11 illustrates that at the junction between two media with different indices of refraction, some light will be reflected and some will pass into the new media. In general, the greater the difference between the refractive indices of the media, the more reflection (and less transmission) there will be. Also, the greater the angle and the closer the light gets to the critical angle, the more the light that will be reflected. The critical angle depends on the media involved, and is defined as the angle at which the refracted angle equals 90°. In water, the critical angle is 49°.

Tropical water looks bluer because the Sun is more directly overhead there than at Canadian latitudes. More sunlight enters the water, which scatters blue light more than other colours, so more blue light exits the water to reach our eyes.

Literacy Support

Using the Text

- Encourage students to view the text as a whole, relating the narrative to the photos of the optical phenomena as well as to the ray diagrams that break down what is happening.

Before Reading

- Have students prepare for learning by reading the Section 11.2 Review questions on page 467, noting what facts they should watch for as they read.
- Ask students to define *critical* (the point at which change happens). In the sense of critical angle, students will be looking for an angle where light is shone to produce a noticeable change in effect. It will be up to students to determine what this effect will be.

During Reading

- Have students write questions based on the headings, then trade with a partner to test comprehension. They should coach each other on any questions they had trouble with.
- Have students monitor comprehension by recording their thoughts as they read, then pair with another student to summarize content and answer outstanding questions.

After Reading

- Ask students to summarize their learning by preparing a 3-2-1 list: three things they have learned, two things they are not sure of, and one thing they would like to focus on more deeply. Ask students to share their list with a partner and work together to dig more deeply into the concepts that they are not sure about or to discuss the one thing that they want to learn more about.

Using the Images

- Some students may find it difficult to relate ray diagrams to diffuse natural light. You may wish to point out that real-world surfaces are not completely smooth like a ray diagram. Have students feel a painted wall, relating the bumpy surface to the number and variety of refractions and reflections that occur at the surface. This results in much more diffuse light than the single ray shown in diagrams.
- To help students make sense of Fig 11.13, use a chair and actual rearview mirror to set up the situation in the classroom. Have students take the mirror apart to explore its shape, then draw their own ray diagrams. Note, they should show the driver's eye below the mirror as is standard in North American vehicles.
- To help students recognize the different scenarios presented in Figure 11.17, it may help to rotate A so that all prisms are orientated the same way and the angle of the *ray* changes.
- Figure 11.13 shows the application of partial reflection in rearview mirrors. A good homework question is to have students sit in a car in daylight and at night to try the mirror and report back on the differences. (Remember that this will be new to most students!) You can bundle this question with question 5 of the section review for maximum benefit.

Assessment FOR Learning

Tool	Evidence of Student Understanding	Supporting Learners
Learning Check questions, page 461	Answers show an understanding that both reflection and refraction occur at the boundary between media.	Have students look through a window, identifying both their own reflection and the (transmitted/refracted) view outside the window. Alternatively, show pictures in which the flare of a camera flash is visible on the window (reflection) as well as the scene behind the window.
Activity 11-2 Investigating Properties of Light, page 459	Incident and reflected rays are at equal angles. Incident and emergent rays are refracted to equal degrees.	Have students complete **BLM 11-7 Ray Diagrams in Several Prisms,** which scaffolds this practice.
Activity 11-3 The Fountain of Light, page 463	The critical angle is measured at 49°.	Have the student physically move a pair of rulers or pens, representing the angle of incidence and refraction, and they should see that, when refraction increases past 90°, total internal reflection results.

Instructional Strategies

- To introduce the ideas, provide students with a triangular prism, a rectangular prism, and a light source. Tell them to point the light at each prism until they get the light to come out the other side of the prism at the same angle but in a new place (refraction) and in a completely new direction (total internal reflection).
- Bring in a toy lamp that uses fibre optic strands to create lights at the ends of "hairs." Bend the strands to show students that the light is "trapped" in each strand. Place a drop of water anywhere along a strand to "free" the light, letting it exit the strand at that point. Explain that the light can refract out into the water drop because the index of refraction of the water is much higher than that of air.
- For notes on using the Making a Difference on page 463 of the student textbook, see page TR-4-4 of this Teacher's Resource. This STSE relates total internal reflection to the use of fibre optic cables that make up the Internet. You may wish to pair this feature with reading on Optical Fibres on page 465 of the student textbook.

Activity 11-2 Investigating Properties of Light (Student textbook page 459)

Pedagogical Purpose

Drawing and analyzing the path of an actual ray of light as it passes from air to glass and back to air helps internalize the principles of refraction.

Planning		
Materials	Glass block Sheet of paper Ray box (single slit) **BLM 11-7 Ray Diagrams in Several Prisms** (optional) The day before, gather the materials and make copies of the BLM or assign as homework the task of preparing a data table.	Pencil Ruler Protractor
Time	5 min	

Activity Notes and Troubleshooting

- A laser pointer could be used if ray boxes are not available.
- Demonstrate how to use the ray box and protractor.
- Make the classroom as dark as possible to help students see the ray.
- Have students prepare a data table before allowing them to carry out the activity independently or in pairs.
- Emphasize step 5, explaining that the transmitted ray is drawn by connecting the dots that touch the block's outline.
- Students may find that **BLM 11-7 Ray Diagrams in Several Prisms** helps them get started.
- Instead of, or in addition to the glass block, this activity could be carried out with any clear material that does not disperse the light (create a rainbow). For example, acrylic or ice.
- Wrap up the activity by having students compare results. Each will have used a different incident angle, but should all find that the emergent ray is at the same angle. Account for any discrepancies, or have students with outlying data repeat the activity.
- Use **BLM A-35 Measuring and Reporting Rubric** to assess students' skill in collecting data.

Additional Support

- DI ELL This is an excellent activity for many learning styles, especially bodily-kinesthetic, visual, and English language learners.
- To reinforce that the incident and emergent rays are parallel (question 2a), have students trace the emergent ray, then lift the block to see that the ray is parallel to the line they drew.

Answers

1. **a.** The angle of reflection and angle of incidence are equal.
   b. All light is reflected by the mirror, but the block transmits (refracts) light as well as reflecting some.
2. **a.** The incident and emergent rays are parallel (occur at the same angle to the normal).
   b. The emergent ray is a little weaker, since some light was reflected, and it is "displaced" or offset from the incident ray.

Activity 11-3 The Fountain of Light (Student textbook page 463)

Pedagogical Purpose

This activity illustrates total internal reflection, showing how it works in flexible media such as water (here) or optical fibres.

Planning		
Materials	Clear plastic bottle (without label) Duct tape (about 5 cm) Thumbtack 3 cm masking tape	Water Bucket (or sink) Flashlight Scissors
Time	10 min	
Safety	Clean up any spills promptly as they may create slippery floors.	

Background

This is a classic demonstration used to illustrate total internal refraction. At the turn of the last century, it was sometimes called "Colladon's fountain of fire."

Activity Notes and Troubleshooting

- A laser pointer may be substituted for the flashlight. This reduces the amount of scattered light around the stream and may make the reflected beam more visible.
- If done as a demonstration, you may wish to use a laser pointer in place of the flashlight. This may reveal several reflections inside the stream of water as it falls.
- Remind students that the angle in step 5 is measured from the normal, at right angles to the (bending) surface of the water stream.

Additional Support

- DI ELL This is an excellent activity for many learning styles, especially bodily–kinesthetic, visual, and English language learners.
- To help student measure at step 5, have them take a photograph of the light beam in the water (turn the flash off). Chalk dust in the air will make the emergent light ray more visible. Alternatively, first have students trace the natural path of light onto a paper, then compare the point at which this traced path and the water fountain diverge.
- To challenge, have students compare observations from holes of different sizes.
- Use **BLM A-39 Co-operative Group Work Rubric** to assess students' group work.

Answers

1. Answers will deviate a little due to experimental error.
2. The greater internal refraction occurred closer to the bottle because that is where the angle was the greatest.

Learning Check Answers (Student textbook page 461)

1. It is reflected.
2. Reflection shows the scene behind the driver, while changing the angle of the mirror reflects most of the light away from the driver and provides a dimmer, refracted image at night.
3. Underwater, only the light directly above reaches the observer, the rest is refracted or reflected by the water away from the observer.
4. Example: Looking through a drinking glass, I can see a distorted (refracted) image of the room and my own reflection.

Section 11.2 Review Answers (Student textbook page 467)

Please also see **BLM 11-10 Section 11.2 Review (Alternative Format).**

1. Example: When light shines into a media at an angle more than the critical angle (49° in water) it refracts 90° to the normal at the boundary of the medium, resulting in total internal reflection. See Figure 11.16B and C from page 462 of the student textbook.
2. when the angle of incidence is very small
3. The angle of incidence must be greater than the critical angle, eliminating refraction.
4. Each individual fibre is made of a glass core surrounded by an optical cladding that has a lower index of refraction than the core.
5. A is set for night time use, and B is set for daytime use since A directs most light away from the driver, projecting a refracted image.
6. No, because the light does not travel at an angle greater than the critical angle (40° for glass).
7. Example: Optical fibres have made smaller and faster information technology possible. Camera applications have had the greatest impact, making less invasive medical operations possible.
8. The very large index of refraction and many facets mean that light entering a diamond is reflected off many surfaces, sending light in many directions (sparkle).