Topic 4.5
What is refraction and how can it be used?

Specific Expectations

- **E2.1** use appropriate terminology related to light and optics, including, but not limited to: *angle of incidence, angle of reflection, angle of refraction, centre of curvature, focal length, luminescence, magnification, principal axis, radius of curvature*, and *vertex*
- **E2.3** use an inquiry process to investigate the refraction of light as it passes through a variety of media
- **E3.4** describe qualitatively how visible light is refracted at the interface between two different media

Skills

- plan an investigation
- conduct inquiries, using equipment safely and effectively
- analyze and interpret data
- communicate results using a variety of formats

Materials

Please see the teaching notes for each activity for a list of the materials required. Please see pages TR-50 to TR-52 for a summary of the materials required in this topic.

Overview

In this topic, students will investigate refraction: the bending of light when it crosses a boundary between two substances. Students will continue to build on their representational skills as they draw ray diagrams to record their observations. Students will be introduced to fibre optics, a common application of refraction, and will build a model of a fibre optic cable.

Common Misconceptions

- **Students commonly confuse refraction and reflection, and treat them as the same phenomenon.** Make specific reference to this misconception and encourage students to use care when choosing terms. Students could develop a mnemonic to help them remember which is which.

Background Knowledge

Refraction of light is commonly observed but poorly understood. This phenomenon occurs because of a change in velocity when light moves from one medium into another. At the boundary between two media, such as glass and water, light bends because its velocity is different in water and glass. We experience this phenomenon when we observe underwater objects, such as a fish in water, and realize that the fish's actual and apparent positions are different. This is also evident when you view a stick partially in and out of water. The part of the stick that is underwater appears to be bent at a strange angle. In this topic, students will investigate refraction and observe some applications of refraction.

A useful analogy in explaining the refraction of light would be to imagine a marching army as they march at an angle from pavement (a fast medium) into mud (a slower medium). The marchers on the side that marches into the mud first will slow down first. This will cause the whole army to turn slightly toward the normal.

Literacy Strategies

Before Reading

- This topic lends itself to construction of a word wall. Allow students to select and define key terms or assign key terms to students to define. Important key terms appear on page 334 and page 337. Encourage students to accompany their definitions with large demonstration drawings or ray diagrams.

During Reading

- Tell students explicitly what they should include in their notes. For example, date, title, point form or full sentences, main idea, supporting details, and so on.
- Encourage students to make connections with the text by writing notes in a two-column format. They can record information from the textbook in one column and examples from their life in the other column.

After Reading

- Use the Learning Check questions to guide a class discussion as a summary of this topic.
- Review the key concepts of this topic by completing a concept map. Students can also include concepts from other topics in this unit on the concept map.

Assessment FOR Learning		
Tool	**Evidence of Learning**	**Supporting Learners**
Learning Check, page 335	Students explain, using words and ray diagrams, that refraction is the bending of light at the intersection of two media, whereas reflection occurs as light bounces off surfaces.	• Model reflection and refraction in many different ways, using a variety of mirrors for reflection and substances such as glasses of water and glass prisms and lenses for refraction. Focus on the laws of reflection and the fact that refraction can involve bending toward or away from the normal depending on the media and the direction light is travelling. • Students can use **BLM G-49 Venn Diagram** to answer question 2. • Some students may benefit from assuming the role of a ray of light and acting out the differences between reflection and refraction.
Activity 4.18, page 341 Activity 4.19, page 342	Students make and interpret observations in the activities, and draw conclusions about refraction, including examples of total internal reflection.	• Provide several examples of refraction for students to examine. Discuss as a group what is happening to the light. • Discuss students' results in Activity 4.17 and draw diagrams together to explain what is happening before assigning Activity 4.18 and Activity 4.19. • Encourage students to make connections with partial reflection and refraction and the critical angle for glass, as part of a phenomena they experience daily when looking in or out of windows under different light conditions.

Topic 4.5 (Student textbook pages 332–343)

Using the Topic Opener

- Refraction occurs in many different circumstances as seen in the topic opener. Explain to students that refraction is the bending of light. Draw students' attention to each photograph, and discuss how light is bending in each case. Make explicit reference to everyday experiences and encourage students to discuss their own experiences with refraction with a classmate or as a class.
- Draw students' attention to the fact that the behaviour of light depends on the materials with which it interacts. This was true of reflection, and is equally true of refraction.
- Students will be required to draw ray diagrams in this topic. Ensure that they are prepared with sharp pencils, rulers, and erasers.

Starting Point Activity (Student textbook page 333)

Pedagogical Purpose

Students will investigate the refraction of light in a tank of water at the air-water interface. Students will observe and explain a variety of optical phenomena.

Planning	
Materials	Per group: transparent tank (aquarium, plastic storage box, or large beaker) water pencil
Time	10 min in class 10 min preparation

Activity Notes and Troubleshooting

- Consider inviting a peer helper, preferably a senior physics student, to assist with management of this activity.
- If transparent tanks are not available, you could use large beakers. If you have many large beakers, students could conduct this activity in pairs.
- After the activity, discuss students' results. Focus students' attention on how the light bends at the interface of the media. Encourage students to share their explanations and ask questions or make suggestions to clarify. Have a tank of water set up for students to demonstrate with as they explain.

Additional Support

- DI Pair students who have strong spatial skills with students who require support.
- Students with visual challenges may find this activity difficult. Have a classmate with strong communication skills describe the process to them.
- DI Allow bodily-kinesthetic learners to move around the room to observe the light in the tank from different angles.
- ELL You may wish to pair English language learners with students who have strong English communication skills.

Starting Point Activity Answers

What Did You Find Out?

1. In all situations, light is distorted at the interface between water and air.
2. The amount of bending was different at different locations.
3. The surface of water looks like a mirror when viewed from below.
4. Explanations may vary. Light bends at the boundary between water and air.

Instructional Strategies for Topic 4.5

Student textbook pages 334–335

- Use a transparent tank from the Starting Point Activity to demonstrate refraction with a flashlight, ray box, or laser similar to Figure 4.35 on page 334 of the student textbook. Ask students to describe what is happening.
- Make liberal reference to the key terms, especially *incident ray, medium,* and *refracted ray*, to provide students with the means to describe the optical phenomena that they are investigating.
- DI Bodily-kinesthetic learners may benefit from acting out refraction, either by assuming the role of a light ray themselves or by pushing a small box such as a deck of cards from a smooth surface onto a rough surface.

Student textbook pages 336–339

- Remind students of what the air-water interface looked like from the bottom in the Starting Point Activity, or set up a tank and have them observe the interface. Draw their attention to its mirror-like properties. If light rays in the water hit the air-water interface, some are reflected back into the water. Recognizing this will help students understand total internal reflection and its applications.
- Students should complete Activity 4.19 before reading about fibre optics on page 338.

Activity 4.15 Interpret a Model to Describe Refraction

(Student textbook page 335)

Pedagogical Purpose

Students will examine and interpret a model used to describe refraction. In this analogy, the car represents a ray of light, the smooth pavement represents a fast medium for light (such as air), and the muddy surface represents a slow medium for light (such as water).

Planning	
Time	15 min in class

Skills Focus

- record information in ray diagrams

Activity Notes and Troubleshooting

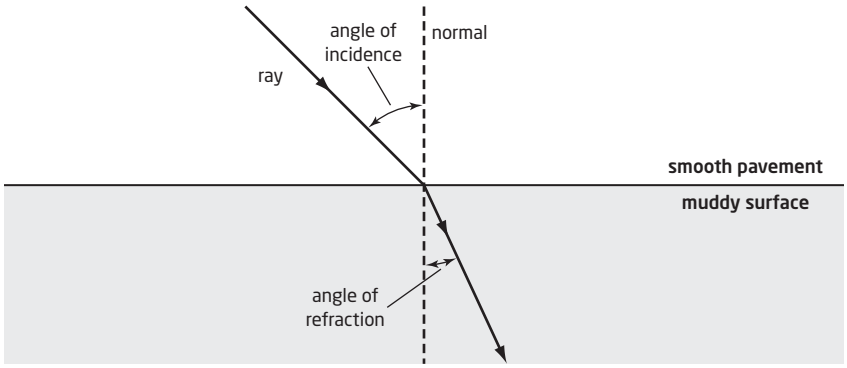
- Have students compare their diagrams and captions with a classmate's and make revisions as necessary.
- You could have a volunteer create their diagram and caption on chart paper to display in the classroom.

Additional Support

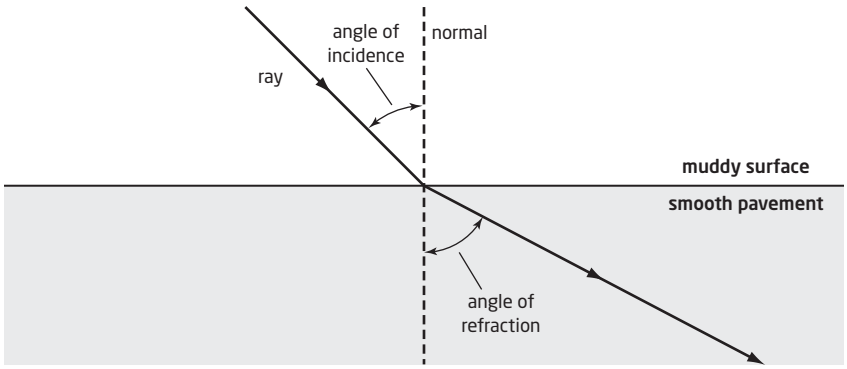
- DI Allow bodily-kinesthetic learners to move around the room to simulate the path of the light rays.
- ELL You may wish to pair English language learners with students who have strong English communication skills.
- Enrichment—Challenge students to draw a ray diagram showing what the car's path would look like travelling from smooth pavement to a muddy surface and back to smooth pavement.

Activity 4.15 Answers

1. A.



B.



2. When the speed of a light ray slows down, the light ray bends toward the normal. When the speed of a light ray increases, the light ray bends away from the normal.

Learning Check Answers (Student textbook page 335)

1. Refraction is the bending of light at the intersection of two media. Reflection occurs as light bounces off surfaces.

2. Venn diagram should include the following points.
Ray diagram for reflection: Angle of reflection is always equal to angle of incidence. Reflected rays are on same side of mirror as incident rays.
Ray diagram for refraction: Angle of refraction is not equal to angle of incidence It can be smaller or larger. Refracted rays are on opposite side of interface from incident rays.
Both: Include normal and incident rays. Show light interacting with a substance.

Learning Check Answers (Student textbook page 337)

1. a) Light refracts toward the normal.

b) Light reflects off the surface of water.

2. Total internal reflection is related to refraction and occurs when incident rays of light meet an interface between two media and exceed the critical angle. Before that occurs, light is refracted.

Activity 4.16 Modelling an Optical Fibre (Student textbook page 339)

Pedagogical Purpose

Students will investigate and model total internal reflection. In this model, light will follow the path of water draining from a clear plastic bottle.

Planning		
Materials	clear plastic bottle duct tape (about 5 cm) thumbtack masking tape (about 3 cm)	water bucket (or sink) flashlight (with an intense narrow beam)
Time	10 min in class 15 min preparation	

Skills Focus

- analyze and interpret qualitative data
- draw conclusions based on observations

Activity Notes and Troubleshooting

- Set up the materials as described and shown in the student textbook. Ensure all students can see the demonstration clearly from where they are sitting or standing.
- Be sure to test the apparatus before attempting this demonstration in class.
- The angle of the stream of water will change as the amount of water in the bottle decreases. The angle changes because the pressure changes, which is proportional to the height of water above the opening. At some stage the angle will exceed the critical angle and total internal reflection will occur.
- Read the activity with the class before the demonstration so that students know what they will be doing and what to watch for.
- Students can answer the What Did You Find Out? question as a think-pair-share activity.

Additional Support

- DI Pair students who have strong logical-mathematical skills with those who require support to interpret observations and draw conclusions.
- ELL You may wish to pair English language learners with students who have strong English communication skills.

Activity 4.16 Answers

What Did You Find Out?

1. In an optical fibre, light follows the path of the fibre by total internal reflection off the interface between the core and the cladding. In this activity, light follows the path of the water stream by total internal reflection off the interface between the water and the air.

Learning Check Answers (Student textbook page 339)

1. Answers may vary. A common example is looking at a stick or branch in water. The branch in the water will appear to be bent at a strange angle due to refraction of light at the air/water interface and light will also reflect off the surface of the water.
2. The angle of incident light must exceed the critical angle for that medium.
3. The fish is actually in a slightly different location because light reflecting off the fish is refracted at the water/air interface as it travels from the fish to your eyes.
4. Optical fibres carry more data and are smaller and lighter than copper cables.

Activity 4.17 The Reappearing Coin (Student textbook page 340)

Pedagogical Purpose

Students will experience a real life example of refraction of light travelling from water to air.

Planning	
Materials	Per pair: cup or another container with opaque sides coin water container (to pour water from)
Time	5 min in class 5 min preparation time

Skills Focus

- analyze and interpret qualitative data
- draw conclusions based on observations

Activity Notes and Troubleshooting

- Consider inviting a peer helper, preferably a senior physics student, to assist with management of this activity.
- Test the containers you choose before students do the activity. Ensure that the coin cannot be seen over the edge of the container when the container is empty, but can be seen when the container contains water.

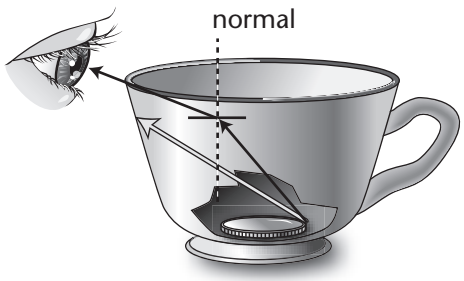
Additional Support

- Students with visual challenges may find this activity difficult. Have a classmate with excellent communication skills describe the process to them.
- DI Allow bodily-kinesthetic learners to move around the room to view the coin from different angles and distances.

Activity 4.17 Answers

What Did You Find Out?

1., 2.



Activity 4.18 Refraction of Light (Student textbook page 341)

Pedagogical Purpose

Students will investigate refraction and partial reflection of light travelling from air to glass or plastic to determine the direction light bends or reflects when encountering a medium with greater optical density. They will see that the speed of light is slower through glass or plastic than it is through air.

Planning		
Materials	Per group: blank sheet of paper ray box with a single slit	rectangular block of glass or transparent plastic pencil ruler
Time	15 min in class 10 min preparation	
Safety	Remind students about the safe use of electrical equipment.	

Skills Focus

- work cooperatively
- record observations in ray diagrams
- analyze and interpret qualitative data
- draw conclusions based on observations

Activity Notes and Troubleshooting

- Consider inviting a peer helper, preferably a senior physics student, to assist with management of this activity.
- Test the glass or transparent plastic blocks or prisms before the activity to ensure none are cracked.

Additional Support

- DI Pair students who have strong spatial or logical-mathematical skills with those who require support.
- Students with visual challenges may find this activity difficult. Have a classmate with strong communication skills describe the process to them.
- DI Allow bodily-kinesthetic learners to move around the room as they follow and predict light paths.

Activity 4.18 Answers

What Did You Find Out?

1. Some light reflected off the surface of the block at an angle equal to the angle of incidence and some light passed into the block and refracted toward the normal.
2. The light ray bent at the surface of the block. The direction of the light ray remained unchanged as it passed through the block.
3. The direction of the light ray that emerged from the block was the same as the direction of the incident ray. The light ray refracted toward the normal as it passed into the block and away from the normal as it passed out of the block.
4. Some light reflected in the air at the first surface of the block. Students may also have seen a small amount of reflection in the block at the second surface.

Activity 4.19 Reflection and Refraction of Light (Glass to Air)

(Student textbook page 342)

Pedagogical Purpose

Students will investigate refraction and partial reflection of light travelling from glass to air to determine the direction light bends or reflects when encountering a medium with lower optical density. They will see that the speed of light is faster through air than through glass.

Planning		
Materials	Per group: blank sheet of paper ray box with a single slit pencil	ruler protractor glass semicircular prisms **BLM G-9 Data Tables** (optional)
Time	25 min in class 10 min preparation	
Safety	Caution students about the safe use of electrical equipment.	

Skills Focus

- work cooperatively
- record ray diagrams in an appropriate format
- analyze and interpret qualitative data
- draw conclusions based on observations
- plan investigations

Activity Notes and Troubleshooting

- Consider inviting a peer helper, preferably a senior physics student, to assist with management of this activity, particularly with helping students design their procedures for Inquire Further question.
- Test the glass semicircular prisms before the activity to ensure none are cracked.
- Model step 1 to step 5 for students, or set up the materials as described for students to refer to as they follow the written instructions.
- Students can work in small groups. Make each group responsible for ensuring that all group members can explain the group's results.
- Students can use **BLM G-9 Data Tables** to record their observations.

Additional Support

- DI Pair students who have strong logical-mathematical skills with those who require support.
- If some students require assistance in setting up their data table, work with them to design a table together. Have students refer to Science Skill Toolkit 8, Creating Data Tables on page 390.

Activity 4.19 Answers

What Did You Find Out?

1. Light refracts away from the normal when travelling from glass to air, therefore the angle of refraction will always be greater than the angle of incidence when light passes from glass into air.
2. The angle of reflection (if any) is always equal to the angle of incidence.
3. The critical angle for glass is approximately 40°. To determine this, students would look for evidence of partial reflection and refraction. Beyond the critical angle, all light is reflected internally.
4. If the angle of incidence is greater than the critical angle, all light will be reflected internally. No light will be refracted.
5. As the angle of incidence increases, the brightness of the refracted rays decreases while the brightness of the reflected rays increases.

Inquire Further

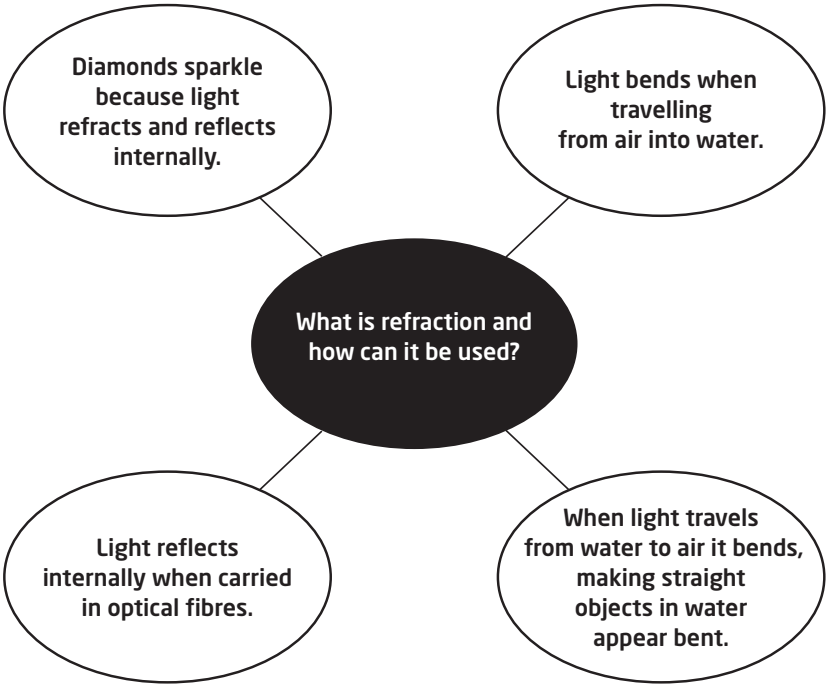
6. Answers may vary. Students should use the flat side of the semicircular glass prism and shine light at varying incident angles, measuring the angle of reflected and refracted light.

Topic 4.5 Review (Student textbook page 343)

Please see also **BLM 4-19 Topic 4.5 Review (Alternative Format)**.

Answers

1. Answers may vary. For example:



2. a) Away from the normal.

b) Toward the normal.

3. The speed of light is greater in quartz than in ruby, because light is refracting away from the normal as it passes from the ruby to the quartz.

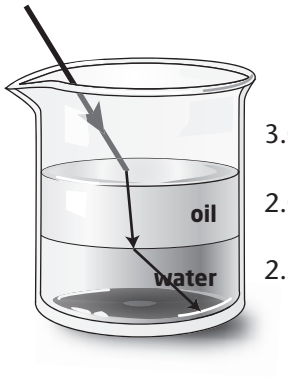
4. Total internal reflection occurs when rays of incident light exceed a critical angle for the medium in which they are travelling. As a result they do not refract at the interface between media. Instead, they are completely reflected.

5. With a ray box, shine light at equal incident rays and compare angles of refracted rays. If the angles of the refracted rays are the same, then the blocks are the same substance. If the angles of refracted rays are different, then the blocks are different substances.

6. Sketches should be similar to part B in Figure 4.41 on page 338.

7. a) The light ray will bend toward the normal as it passes from the air into the oil. Then it will refract away from the normal is it passes from the oil into the water.

b)



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2.0×10^8 m/s

2.25×10^8 m/s