Section 11.1 Refraction of Light (Student textbook pages 449 to 456)

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

In this section, students will learn about the spectrum of light and explore refraction, learning about the index of refraction, the speed of light in a vacuum and other media, and incident and refracted rays.

Common Misconceptions

- Refraction is not light curving and changing speed *within* a medium. Light always travels in a straight line and at a constant speed within a medium. It is at the boundary between areas of different density (usually two different media) that refraction occurs.
- Refraction occurs within a medium wherever density changes, as in the case of the compression of air, which makes Schlieren photography possible (described in the section opener).
- Optical density is not the same as density, nor are they related. Neither is it related to the material's index of refraction. Optical density relates to medium transparency.
- The colours of the rainbow are not all primary colours. All colours are the result of combinations of the three primary colours: red, blue, and yellow (for pigments); or cyan, magenta, and yellow (for light).

Background Knowledge

Nothing has been measured travelling faster than the speed at which light travels (in a vacuum). This makes it useful as a standard of comparison.

Sunlight consists of a mixture of light with different wavelengths. A dispersion grating, however, will show that some colours are not present in sunlight. Some are absorbed by electrons in different elements, and some (such as brown) are actually formed by combinations of other wavelengths of light.

Primary colours are red, blue, and yellow (or cyan, magenta, yellow). Secondary colours are made by combining the primary colours (e.g., red and blue make violet). Indigo, which appears in a rainbow between blue and violet, is neither a primary nor a secondary colour. Its inclusion in the basic list of colours may have arisen moreover out of a desire to connect the list to the early sense of order in the universe as revealed by the commonality among the number of colours, planets (at the time), and days of the week.

A dispersive medium is one in which different wavelengths of light have slightly different indices of refraction. For example, crown glass is a dispersive medium since the index of refraction for violet light in this medium is higher than that of red light. This is responsible for a lens' failure to focus all colours at the same point. For this reason, manufacturers customarily base the refractive index of a lens on yellow sodium light; yellow light becomes the baseline for comparison.

Literacy Support

Using the Text

- During demonstrations and activities, have students identify the sections of text that explain what they are seeing.
- To help students connect to prior knowledge, create a K-W-L chart for this section on the chalkboard or hand out copies of **BLM G-48 K-W-L Chart**. Work with students to fill in the first two columns of their charts, showing what they already know about each topic and what they want to learn.

During Reading

- Students should read the textbook with the objective of answering questions they noted under What I Want to Know. Encourage them to revise notes as they gain understanding.

After Reading

- Students should fill in the last column of their K-W-L charts, identifying areas of personal growth.
- Have student pairs compare notes and help each other complete any gaps.

Using the Images

- ELL You may wish to show a video of a marching band to provide context for Figure 11.4 on page 450 of the student textbook.
- Begin by having students copy Figure 11.6 into their notes as a reference. They may add definitions, examples, and related equations as they complete the unit.
- Have students scan the text for tables of reference data such as Table 11.1, which provides indices of refraction for many substances. Have students copy these tables onto a reference sheet for use throughout the unit. As they read the section, encourage students to use sticky notes to link descriptions, definitions, or relevant equations to these tables.
- Figure 11.2 is a good example of refraction. Ensure students recognize that the beam is bending at the boundary between media, not during its path inside the water.
- Give students a prism and have them try to reproduce the spectrum shown in Figure 11.7. It can be challenging, even with a ray box, to create a narrow beam of white light. Have students examine the figure for clues that make this work: the incident ray should be nearly parallel to one side of the prism.
- Students may notice that the cartoon figure "Roy G BIV" in Figure 11.8 is in fact wearing the complete colour spectrum from head to toe.

Assessment FOR Learning		
Tool	**Evidence of Student Understanding**	**Supporting Learners**
Learning Check question 3	Rays are drawn showing light refracting closer to the normal in the more dense medium.	As a class, come up with a memory aid such as the higher the index of refraction, the bigger the angle is.
Practice Problems, page 455	The velocity of light in the given media is correctly calculated using the index of refraction.	Have students complete **BLM 11-2 Calculating the Speed of Light in Media.**
Section 11.1 Review questions, page 456	Terms are correctly used and identified.	Have students complete **BLM 11-1 Chapter 11 Key Terms** and/or create diagrams to define each term.
Section 11.1 Review questions, page 456	Angles of refraction are explained with reference to difference in velocity of light between two media.	Have students describe, in their own words, what the index of refraction is, what it means, and how it can be found.

Instructional Strategies

- DI Spatial learners could create a graphic organizer to keep track of learning about refraction. Students might use a spider map, or begin with a sample diagram (e.g., Figure 11.7 on page 452 of the student textbook) and link each feature to explanations on sticky notes.
- ELL Encourage English language learners to draw diagrams when answering Learning Check questions.
- ELL Have students start a vocabulary section in their notebooks with definitions and examples that will help them understand and use optic terms that have other meanings in everyday language (e.g., *index*, *normal*, *vacuum*, *medium*, and *media*). They may find it helpful to create a word map for each term, as described on page 448.

- Concrete examples may help students understand the abstract concepts involved in the exciting and slightly magical application of refraction for Schlieren photography. Survey the class for bike riders. Ask them what happens when they are riding a bike on pavement and suddenly hit sand or gravel. (Answer: The bike slows immediately and the front wheel turns.) An analogy may also be drawn to hitting dense chunks of fudge when scooping ice cream. The scoop immediately slows down and is thrown off course. Explain that a similar thing happens to light when it crosses the boundary between air of different densities: the light (bike or scoop) slows down and is thrown off course. The same happens when one wheel of a car slips into the gravel shoulder, causing the tire (and car) to "refract" towards the normal (perpendicular to the boundary). The wheel on the soft shoulder encounters more resistance and moves more slowly than the wheels on the road.
- Students may become frustrated trying to identify indigo in the spectrum. It will be interesting and reassuring to learn that the human eye is weakest at picking up frequencies of light near indigo. Some otherwise well-sighted people cannot distinguish indigo from blue and violet.
- If you follow an inquiry-based model of learning in your classroom, begin this section by having students carry out Real World Investigation 11-C Saving Time. Then have students read this section in the textbook, identifying links between the principles of light refraction and the lifeguard's solution as they read. See page TR-4-46 of this Teacher's Resource for teaching notes on this lab.
- If there is snow or mud on the ground, take students outside to model diffraction. Have them hold hands in a line, taking a step in rhythm, noting that as the line crosses into the deep snow (or mud) steps are harder to take and the line bends.
- Students may ask how light knows which direction to turn to take the fastest route across a medium. At this level, students often want to ascribe motives to actions, seeing the physical world in human terms. Fermat's principle, as illustrated in Figure 11.5, can be derived from the basic concepts of light, motion, and a straight line being the shortest distance between two points. However this requires university level calculus.
- Schlieren photography is an example of a career in photonics (the science of light). To pursue a career in this field, a degree in physics from a university is usually required, or one might choose a program such as Photonics Engineering Technician or Technologist at Niagara College or the Bachelor of Applied Technology in Photonics at Algonquin College. Go to **www.scienceontario.ca** for more information and links.
- As a class, create a Venn diagram to summarize the similarities and differences between reflection and refraction. You may wish to distribute **BLM G-47 Venn Diagram**, which scaffolds this process.
- Before exploring indices of refraction, reactivate students' understanding of ratios by using some sample problems from a math textbook. Then, as a class, work through the calculation for the index of refraction in water on page 452. Students should then complete the sample problem on page 455 individually, trading with a partner to check each other's solution. **BLM 11-2 Calculating the Speed of Light in Media** scaffolds this process.
- Have students carry out Inquiry Investigation 11-A Investigating Refraction, from Air to Water. See page TR-4-43 of this Teacher's Resource for teaching notes on this lab.
- Use **BLM A-39 Co-operative Group Work Rubric** to assess students' group work in this section.

Learning Check Answers (Student textbook page 451)

1. the speed at which it travels
2. the change in direction and speed of light as it crosses the boundary from one medium to another
3. See Figure 11.2 on page 450 of the student textbook.
4. Example: Pulling a wagon from the sidewalk into sand. Diagram should show that pulling becomes more difficult in the sand and that this makes the wagon slow and change direction when it hits the sand.

Section 11.1 Review Answers (Student textbook page 456)

Please also see **BLM 11-6 Section 11.1 Review (Alternative Format).**

1. Medium 1 is water and medium 2 is air since the ray is bent away from the normal in medium 2, it must be the less dense medium (air).
2. The index of refraction represents the ratio of the speed of light in a vacuum to the speed of light in a given medium.
3. 2.04×10^8 m/s
4. Temperature and pressure greatly affect the density of a gas, which determines its index of refraction. Thus, the index given is valid for the gas only under the stated conditions.
5. **a.** A prism disperses white light into its component colours because each colour of light travels at a slightly different speed, and is thus refracted to a different degree within the prism.

   b. Yellow light, because the angle of refraction is smaller for yellow light than for violet light, it must be travelling faster.
6. Since the index of refraction (n) is a ratio of the speed of light in a vacuum (c) over the speed of light in another medium (v), and nothing moves faster than the speed of light in a vacuum ($c > v$), then the value of n must always be greater than 1.
7. The angle of incidence must be zero (perpendicular to the boundary). The diagram should show light crossing the boundary between the two media at right angles, in which case there is no opportunity to deviate closer to or away from the normal.
8. Example: Shine a laser pointer into each sample. The block, which refracts the light more toward the normal, has the larger index of refraction (the flint glass). The diagram should show light shining into the glass blocks, redirecting closer to normal (perpendicular) in the flint sample than in the glass sample.