Teacher Toolkit - Total Internal Reflection

Objectives:

1. To describe how the relative intensity of a reflected ray and refracted ray at a boundary is dependent upon the angle of incidence.
2. To define total internal reflection and to state the conditions that are required in order for a light ray to undergo total internal reflection.
3. To define the critical angle, to derive an equation for the critical angle from Snell's law equation, and to use the equation to calculate the critical angle for the boundary between two media.

Readings:

The Physics Classroom Tutorial, Refraction and the Ray Model of Light Chapter, Lesson 3
http://www.physicsclassroom.com/class/refrn/Lesson-3/Boundary-Behavior-Revisited

Interactive Simulations:

1. Refraction Interactive http://www.physicsclassroom.com/Physics-Interactives/Refraction-and-Lenses/Refraction
   This simulation from The Physics Classroom allows a learner to explore the reflection and refraction of light at a boundary. Several substances can be chosen as the "Top" and "Bottom" substance. A laser can be dragged to any angle and a ray directed towards the boundary. A protractor allows for the easy measurement of the angles of incidence, reflection and refraction. The brightness of the three rays are indicated on the display. Learners can quickly observe that increasing the angle of incidence leads to an increase in the angle of refraction but also to a dimmer refracted ray and a brighter reflected ray. The Interactive comes with a ready-to-use activity that directs the learner towards the key observations to be found in the Interactive.
2. Bending Light, PhET https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html
   This Interactive tool allows the user to explore the reflection and refraction of light at a boundary. Users can choose from some pre-selected materials or choose a customized index of refraction value. Angles of incidence, reflection, and refraction can be measured with a built-in protractor. Light meters allow users to quantitatively measure the intensity of the reflected and refracted light relative to the incident light intensity. Other options are available that do not necessarily shine light upon the topic of total internal reflection.

Video and Animation:

1. What is Total Internal Reflection https://www.youtube.com/watch?v=NXGLBMTtk40
   This 10-minute video by Step-by-Step Science discusses the reflection and refraction of light at a boundary and uses several diagrams to demonstrate how an increase in the angle of incidence increases both the brightness of the reflected ray and the angle of refraction. The critical angle is defined and then derived from Snell's Law. A sample problem is performed to determine the critical angle for the water-air boundary.
2. Fiber Optic Cables https://www.youtube.com/watch?v=0MwMkBET_5I&feature=youtu.be
   Bill Hammack from the Department of Chemical and Biomolecular Engineering at the University of Illinois explains how optical fibers work and how engineers use them to send messages. The highlight of the 5-minute YouTube video is the demonstration of light piping through a liquid stream of propylene glycol. Reflection and refraction and total internal reflection are masterfully explained. Numerous engineering and communication applications are discussed.
3. Total Internal Reflection Demo: Optical Fibers https://www.youtube.com/watch?v=Lic3gCS_bKo
   Professor Boyd F. Edwards explains the importance of total internal reflection and its application to optical fibers. Dr. Edwards does several *light-piping* demonstrations and explains the physics behind each. The 3-minute video is from the Physics Demos YouTube channel.

Labs and Investigations: http://www.physicsclassroom.com/lab/refrn/RLlabs.html

1. The Physics Classroom, The Laboratory, R and R Lab
   Students use laser light and a Lucite hemi-cylindrical prism to investigate the effect of the angle of incidence upon the relative brightness of the reflected and transmitted ray.
2. The Physics Classroom, The Laboratory, A Critical Lab
   Students experimentally determine the critical angle for the air-water boundary and the air-Lucite boundary.

Demonstration Ideas:

1. Total Internal Reflection https://www.youtube.com/watch?v=NAaHPRsveJk
   This 1.5-minute video features a demonstration in which a beam of light is directed into a hemicylindrical block of glass. The light approaches along the curved side of the cylinder along the radial line so that there is no refraction upon entering the block. Refraction occurs at the flat edge of the block. The demonstration is performed on top of paper with angle markings. The angle of incidence at the glass-to-air boundary begins at 0° and is slowly increased. As angles get larger, the reflected light at the glass-to-air boundary becomes visible. As the angle continues to increase, the refracted light becomes dimmer and dimmer and the reflected light becomes brighter and brighter. At the critical angle, the refracted ray appears along the boundary and further increases in the angle of incidence shows that the refracted ray disappears.
2. Laser Viewing Tank https://www.youtube.com/watch?v=mtVbb_MWNDg
   Designed by California Physics Teacher Dean Baird, this versatile system allows students to see and control light beams. Scattering agent added to water in the plastic tank make laser beams visible. Students easily control observations involving simple refraction and total internal reflection. Watch as physics teacher Robert Douglas discuss this great teaching tool. Students love laser demos, keep the excitement coming with this demo!

Minds On Physics Internet Modules: http://www.physicsclassroom.com/mop

The Minds On Physics is a collection of interactive questioning modules that target conceptual understanding. Each question is accompanied by detailed help that addresses the various components of the question.

1. Refraction and Lenses, Ass't RL5 - Total Internal Reflection
2. Refraction and Lenses, Ass't RL6 - TIR and the Critical Angle

Concept Building Exercises: http://www.physicsclassroom.com/curriculum/refrn

1. The Curriculum Corner, Refraction and Lenses, Total Internal Reflection

Problem-Solving Exercises: http://www.physicsclassroom.com/calcpad/refrn/problems

1. The Calculator Pad, Refraction and Lenses, Problems #13-#18

Science Reasoning Activities: http://www.physicsclassroom.com/reasoning/refraction

1. Reflection and Transmission

Real Life Connections:

1. Passive Fiber Optics https://www.rp-photonics.com/passive_fiber_optics.html
   This multi-part tutorial provides a considerable wealth of detail on the guiding of a light beam through an optical fiber. It is an excellent source of information for teachers who wish to strengthen their understanding of fiber optics.
2. Rainbow Formation https://www.youtube.com/watch?v=7k85eD_tQZo
   The physics that underlies the formation of rainbows is extensively and systematically explained in this video by VSauce. In his usual intriguing manner, VSauce producer Michael Stevens describes several types of rainbows using a variety of images and explains the conditions under which they are formed. While there is a minimal amount of information about refraction and internal reflection, the video provides valuable information that answers a variety of our most curious students' questions.

Standards: **See HTML Version of Complete Toolkit for Details**

A. Next Generation Science Standards (NGSS) – Grades 9-12

Crosscutting Concepts

Patterns
Systems and System Models
Scale, Proportion, and Quantity

Science and Engineering Practices

Practice #1: Analyzing and Interpreting Data
Practice #2: Developing and Using Models
Practice #3: Planning and Carrying Out an Investigation
Practice #6: Constructing Explanations
Practice #7: Engaging in Argument from Evidence