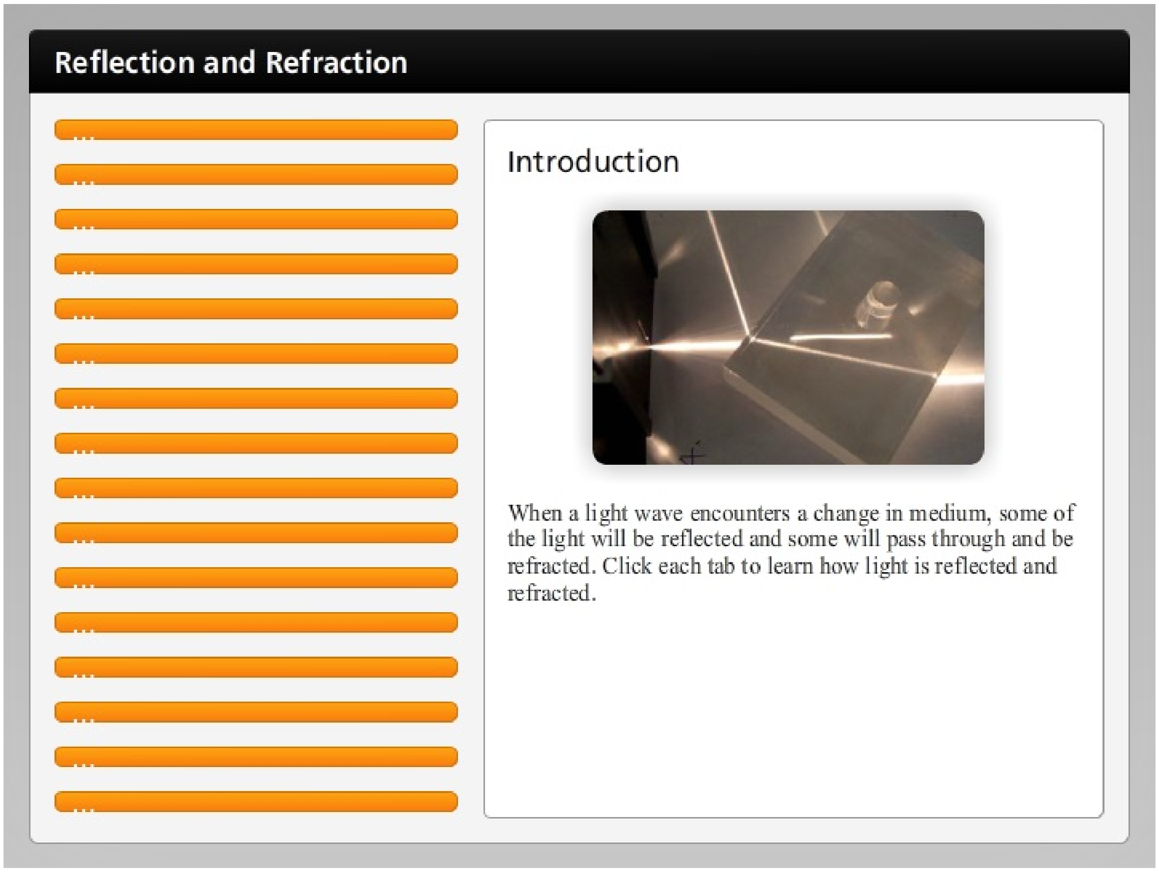
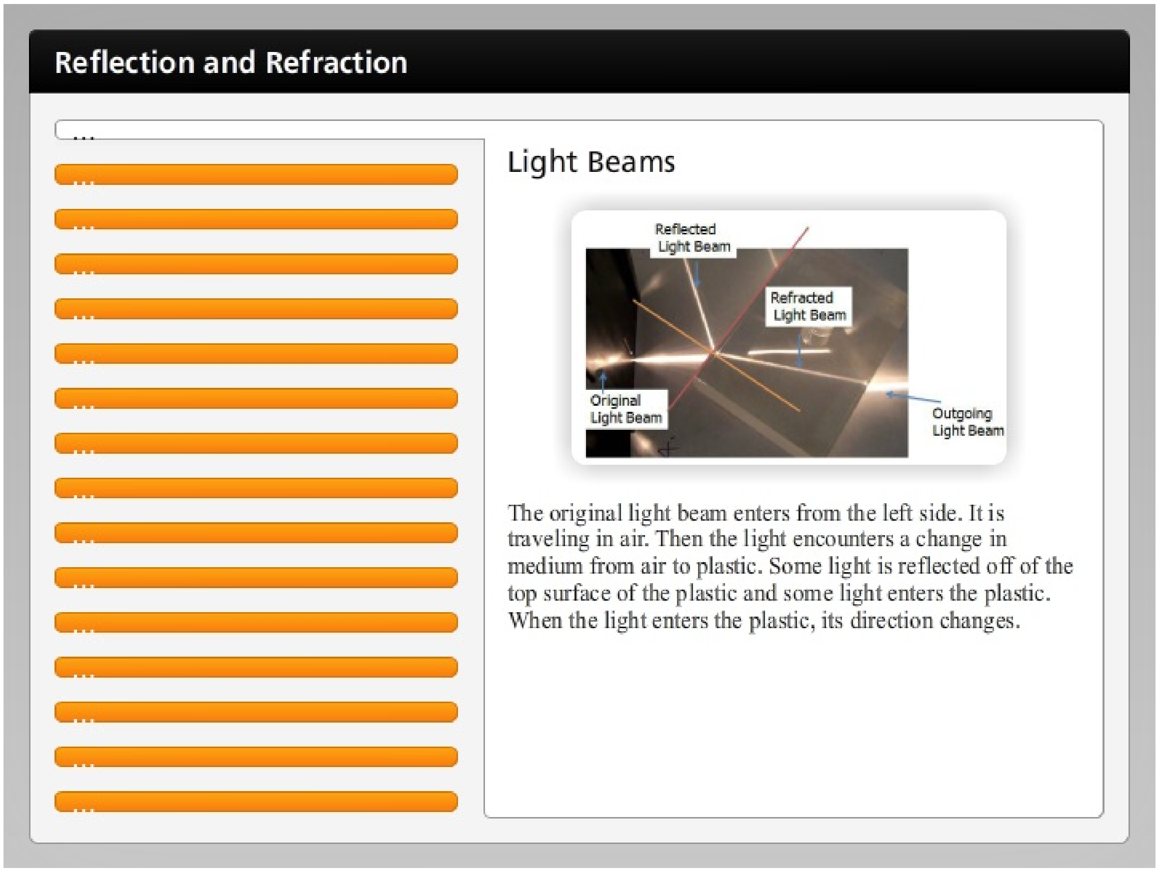
Module 10: Optics
Topic 3 Content: Reflection and Refraction

Introduction



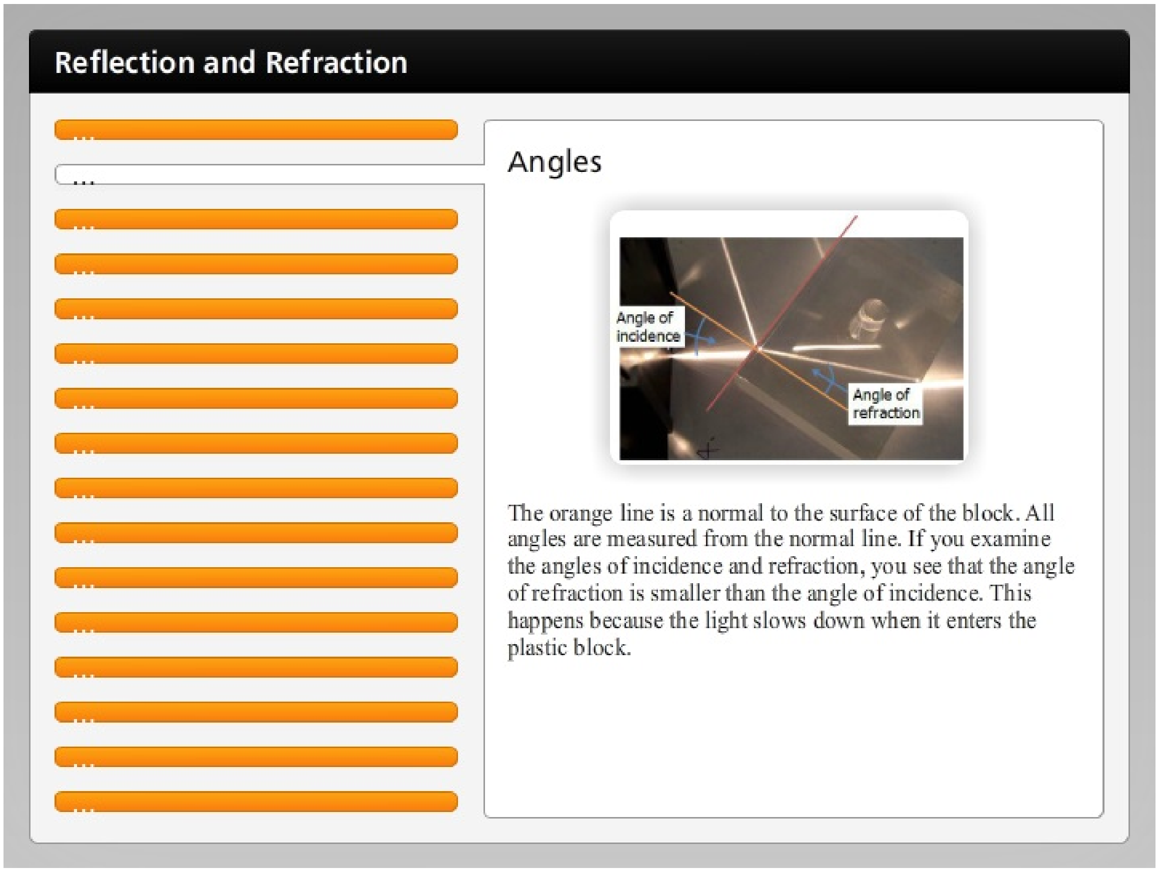
When a light wave encounters a change in medium, some of the light will be reflected and some will pass through and be refracted. Click each tab to learn how light is reflected and refracted.

Light Beams



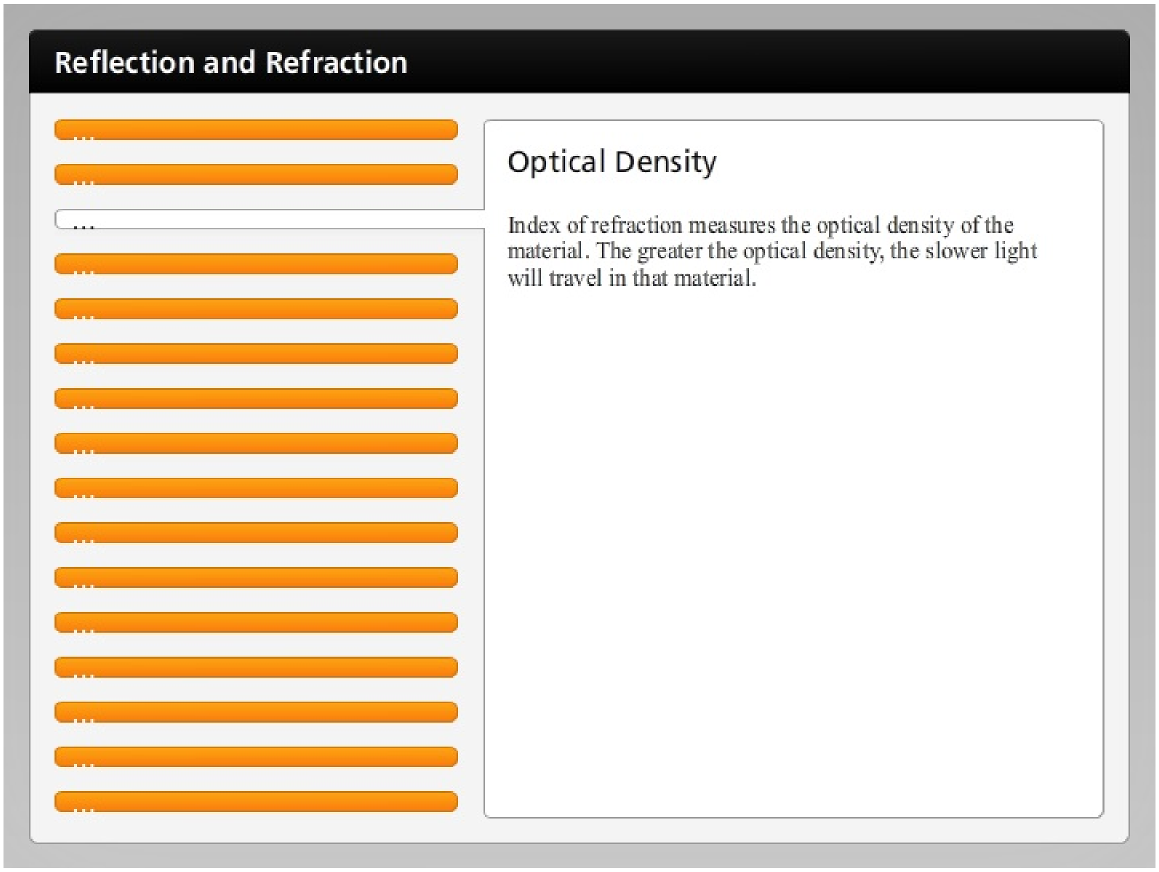
The original light beam enters from the left side. It is traveling in air. Then the light encounters a change in medium from air to plastic. Some light is reflected off of the top surface of the plastic and some light enters the plastic. When the light enters the plastic, its direction changes.

Angles



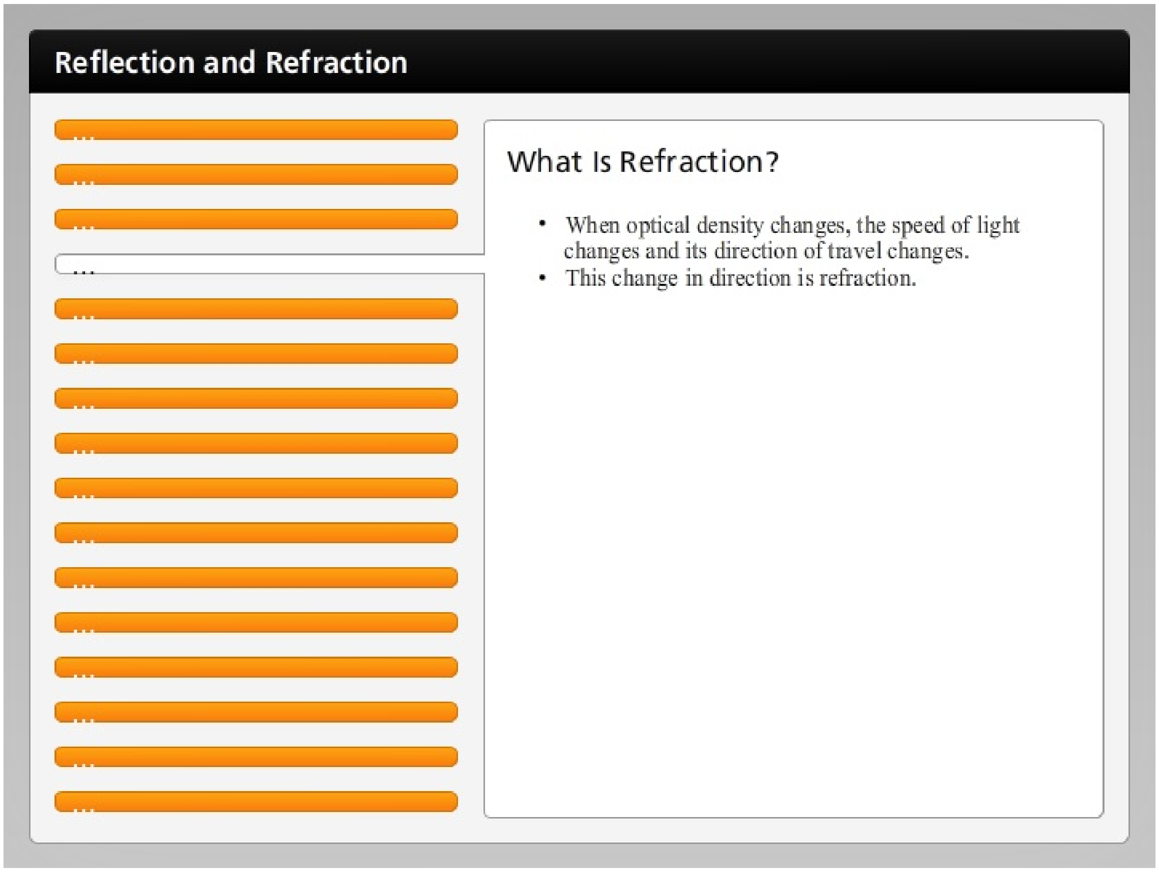
The orange line is a normal to the surface of the block. All angles are measured from the normal line. If you examine the angles of incidence and refraction, you see that the angle of refraction is smaller than the angle of incidence. This happens because the light slows down when it enters the plastic block.

Optical Density



Index of refraction measures the optical density of the material. The greater the optical density, the slower light will travel in that material.

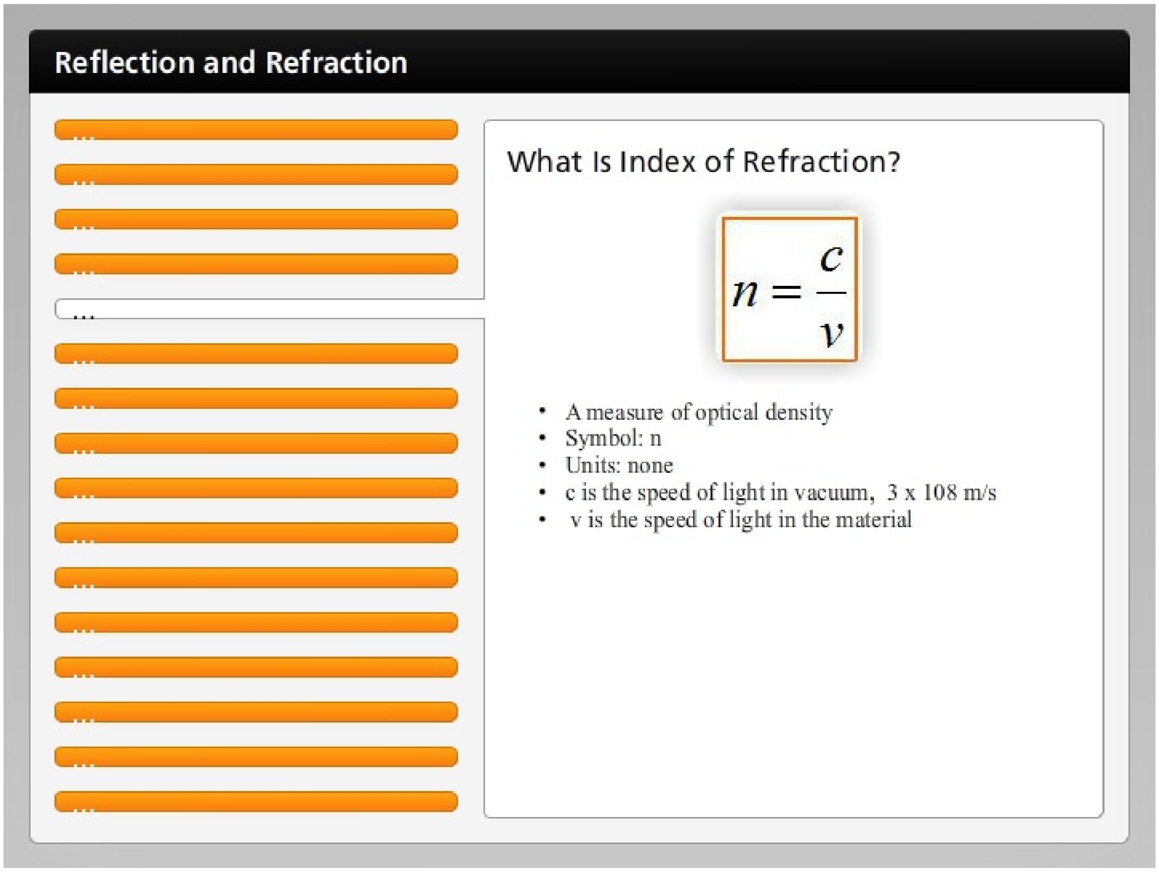
What Is Refraction?



- When optical density changes, the speed of light changes and its direction of travel changes.
- This change in direction is refraction.

Differences in optical density cause the speed of the light to change which makes the direction of the light change. We call this change in direction refraction.

What Is Index of Refraction?



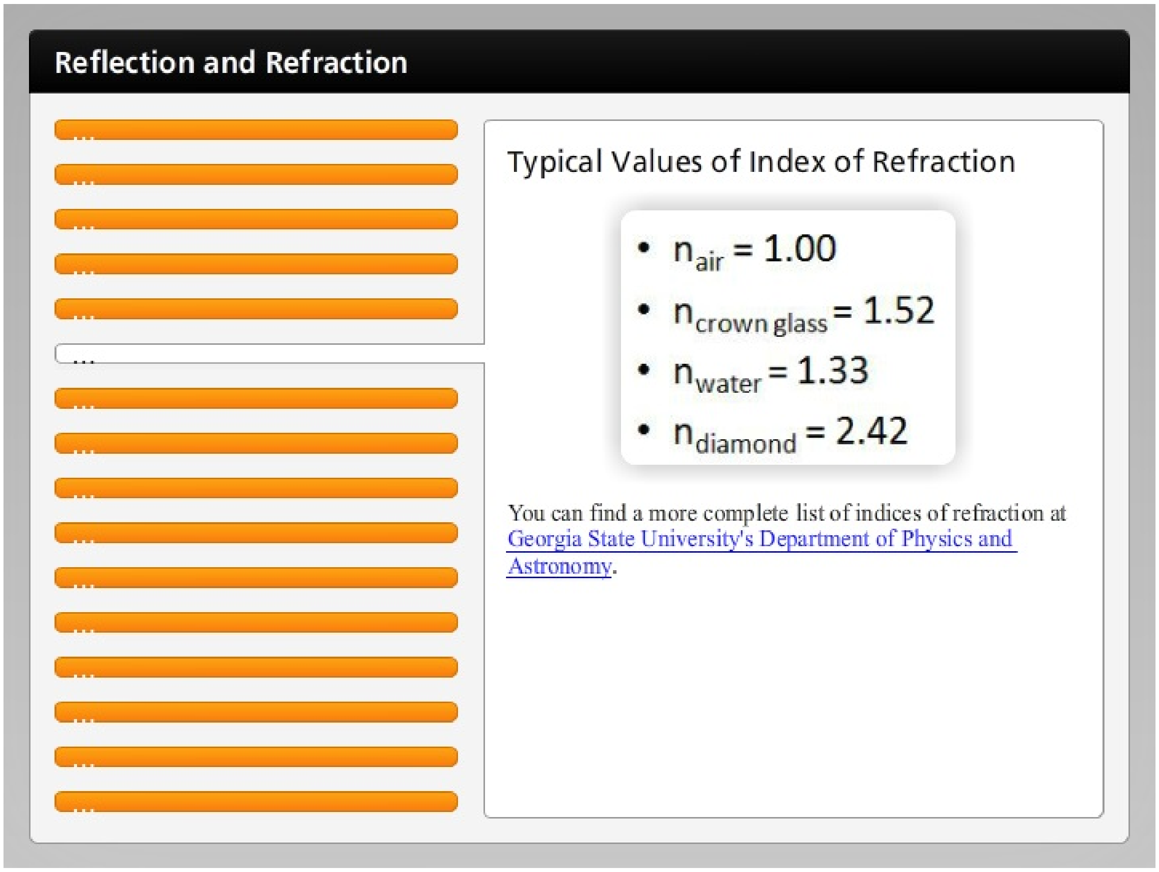
- A measure of optical density
- Symbol: n
- Units: none
- c is the speed of light in vacuum, 3 x 108 m/s
- v is the speed of light in the material

Index of refraction measures the optical density of the material, or medium. The greater the index of refraction, the slower the light will travel. The symbol we will use for index of refraction is lowercase n.

Index of refraction is a unit less number because it is found by dividing the speed of light in vacuum by the speed of light in that material. Since we are dividing speed by speed, the units will cancel out.

The speed of light in vacuum is given the symbol lowercase c. Its value is three times ten to the eight meters per second. The symbol lowercase v represents the speed of light in that material.

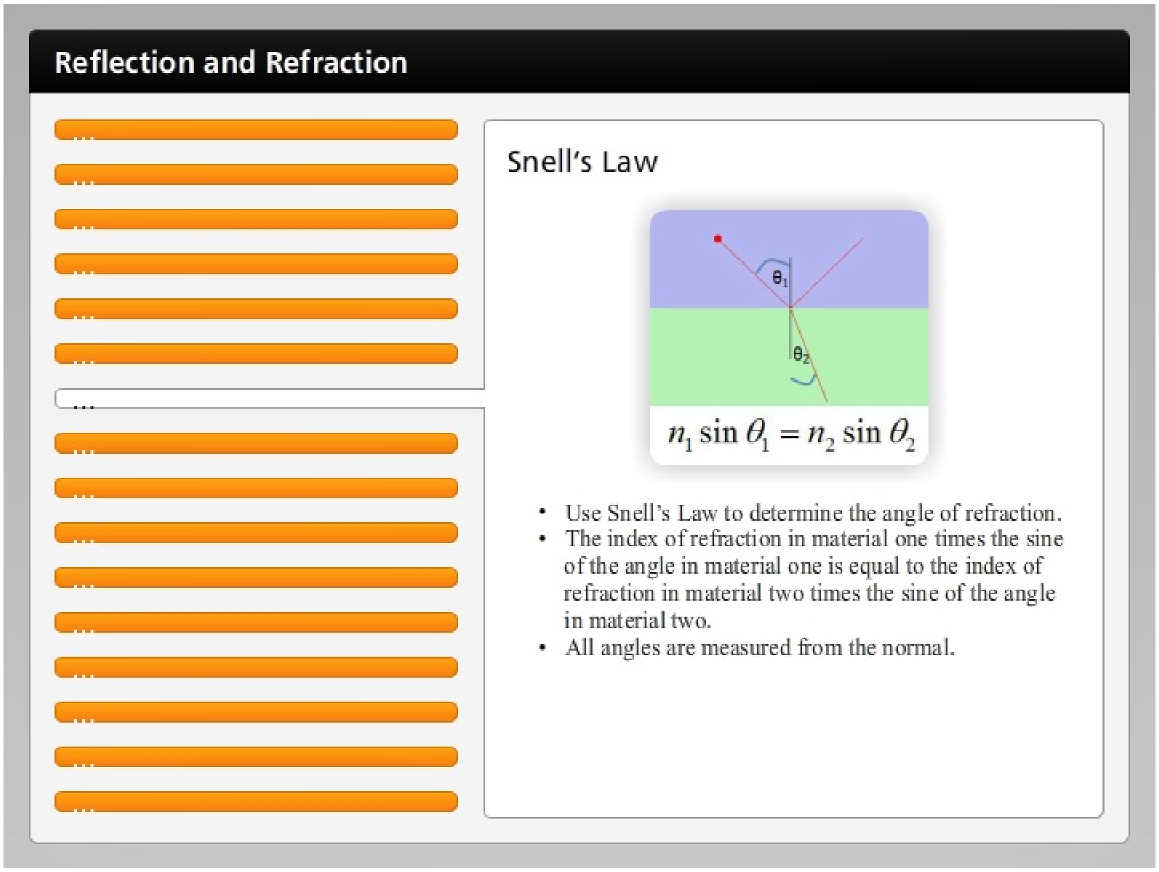
Typical Values of Index of Refraction



You can find a more complete list of indices of refraction at Georgia State University's Department of Physics and Astronomy.

Since the speed of light in air is very close to the speed of light in vacuum, the index of refraction of air is one point zero zero. The index of refraction of crown glass is one point five two. The index of refraction of water is one point three three. The index of refraction of diamond is two point four two.

Snell’s Law

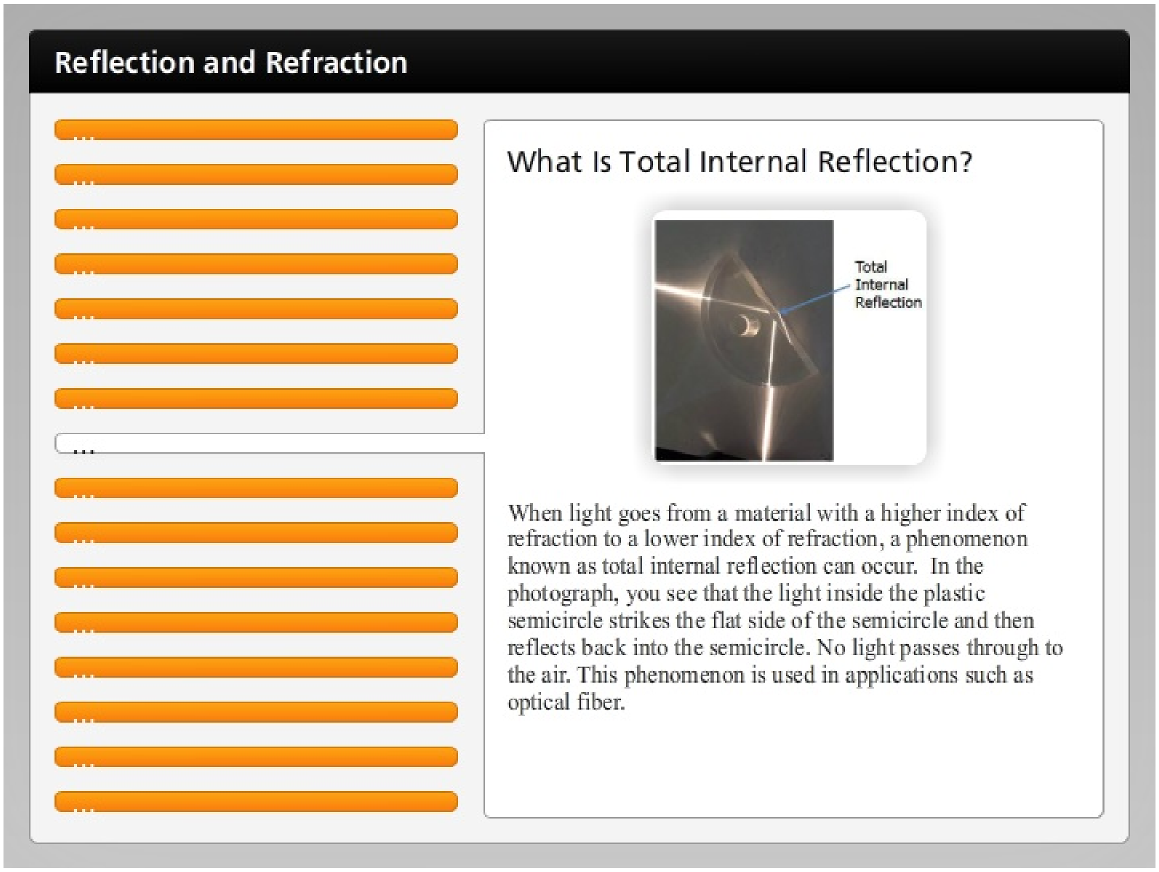


- Use Snell’s Law to determine the angle of refraction.
- The index of refraction in material one times the sine of the angle in material one is equal to the index of refraction in material two times the sine of the angle in material two.
- All angles are measured from the normal.

Snell’s Law is an equation that describes the relationship between the direction of light travel and the indices of refraction of the two materials.

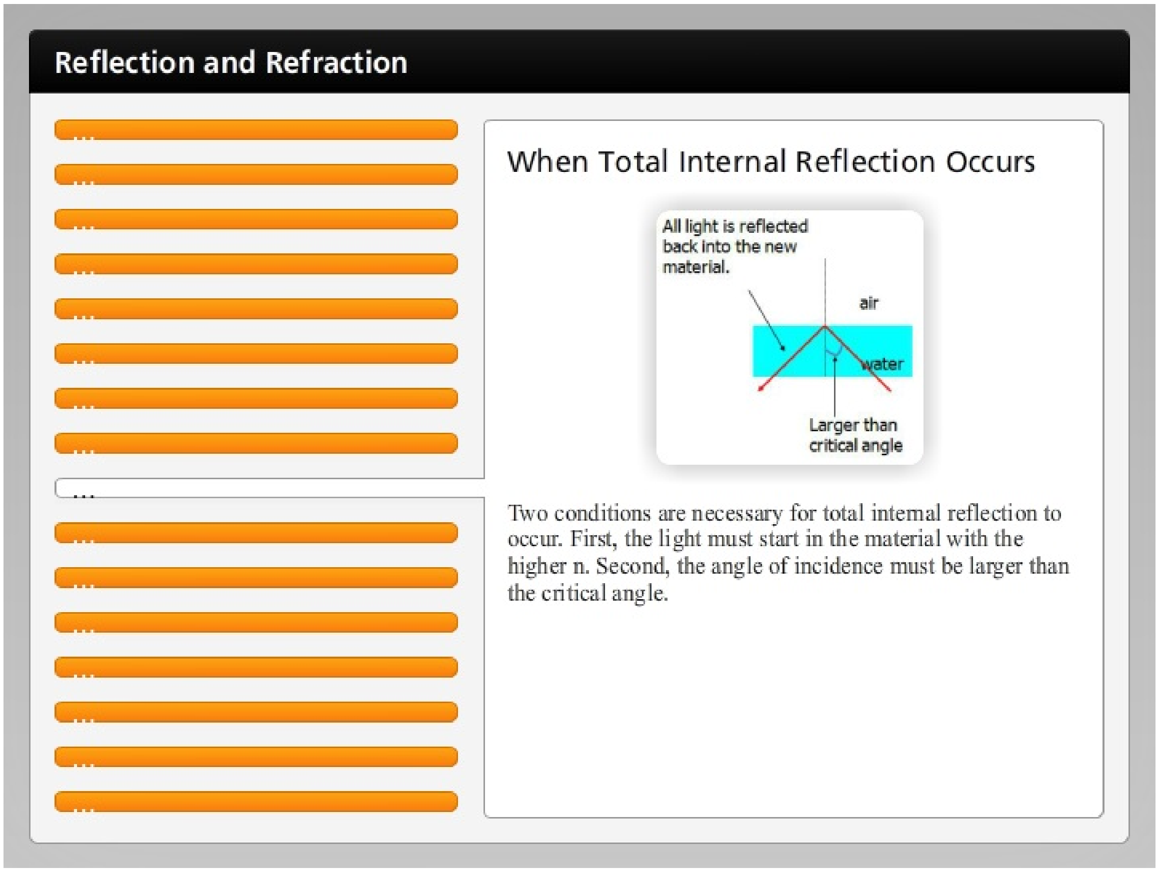
Snell’s Law says that the index of refraction in material one times the sine of the angle in material one is equal to the index of refraction in material two times the sine of the angle in material two. Both of the angles must be measured from the normal as shown in the diagram. We will practice using this equation in the practice session.

What Is Total Internal Reflection?



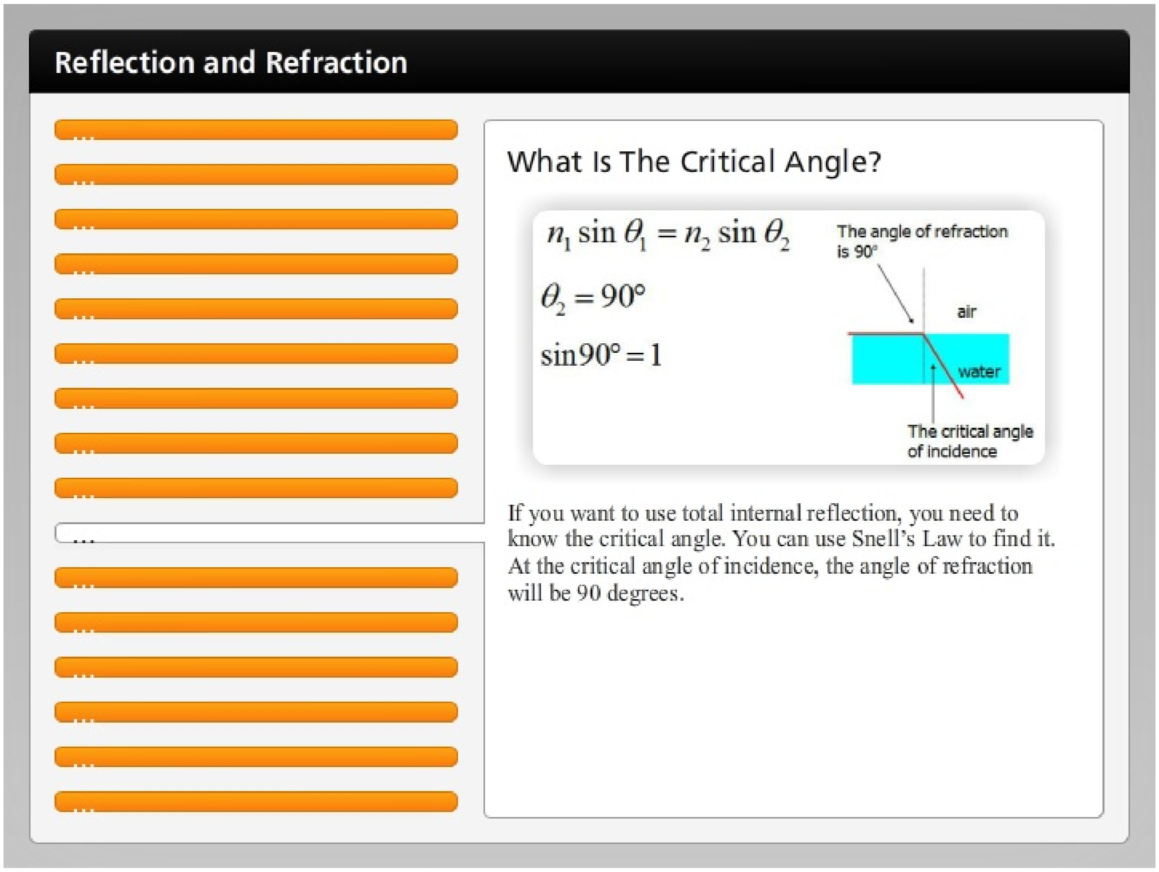
When light goes from a material with a higher index of refraction to a lower index of refraction, a phenomenon known as total internal reflection can occur. In the photograph, you see that the light inside the plastic semicircle strikes the flat side of the semicircle and then reflects back into the semicircle. No light passes through to the air. This phenomenon is used in applications such as optical fiber.

When Total Internal Reflection Occurs



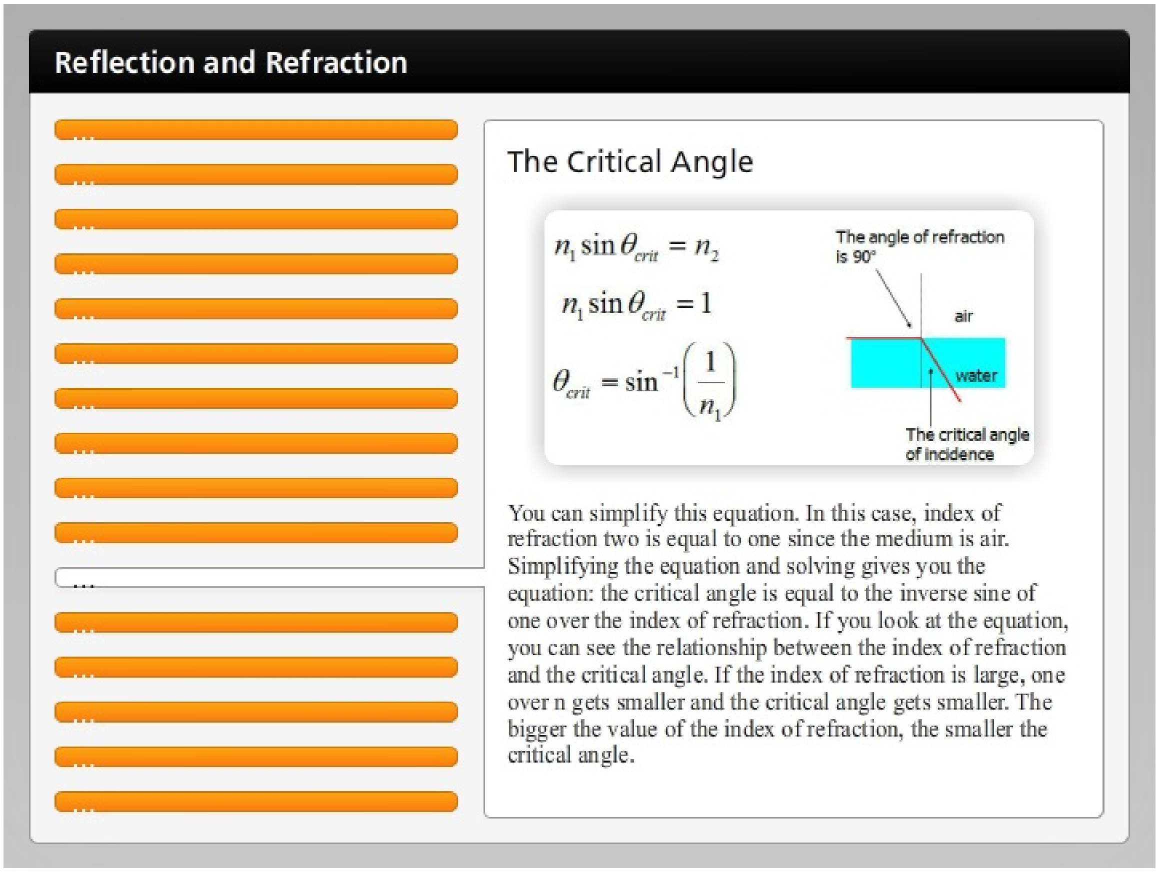
Two conditions are necessary for total internal reflection to occur. First, the light must start in the material with the higher n. Second, the angle of incidence must be larger than the critical angle.

What Is The Critical Angle?



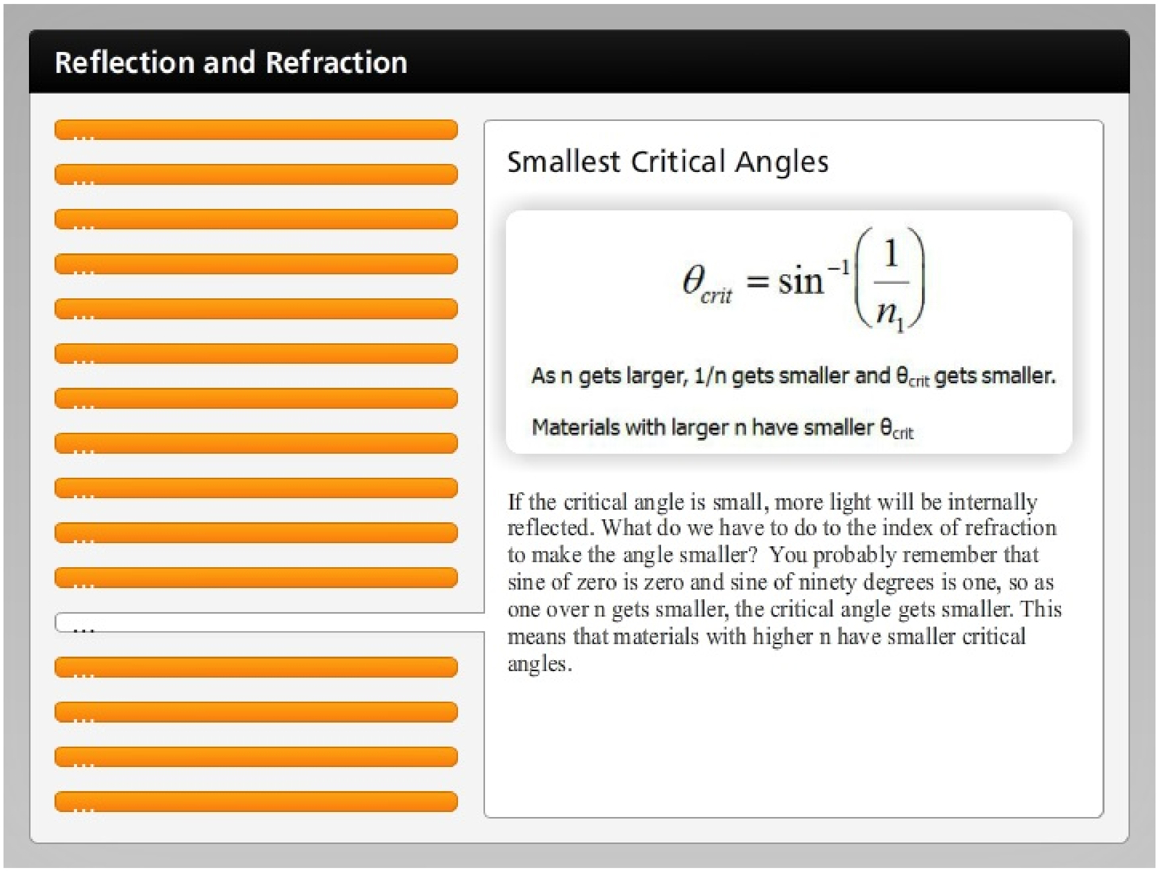
If you want to use total internal reflection, you need to know the critical angle. You can use Snell's Law to find it. At the critical angle of incidence, the angle of refraction will be 90 degrees.

The Critical Angle



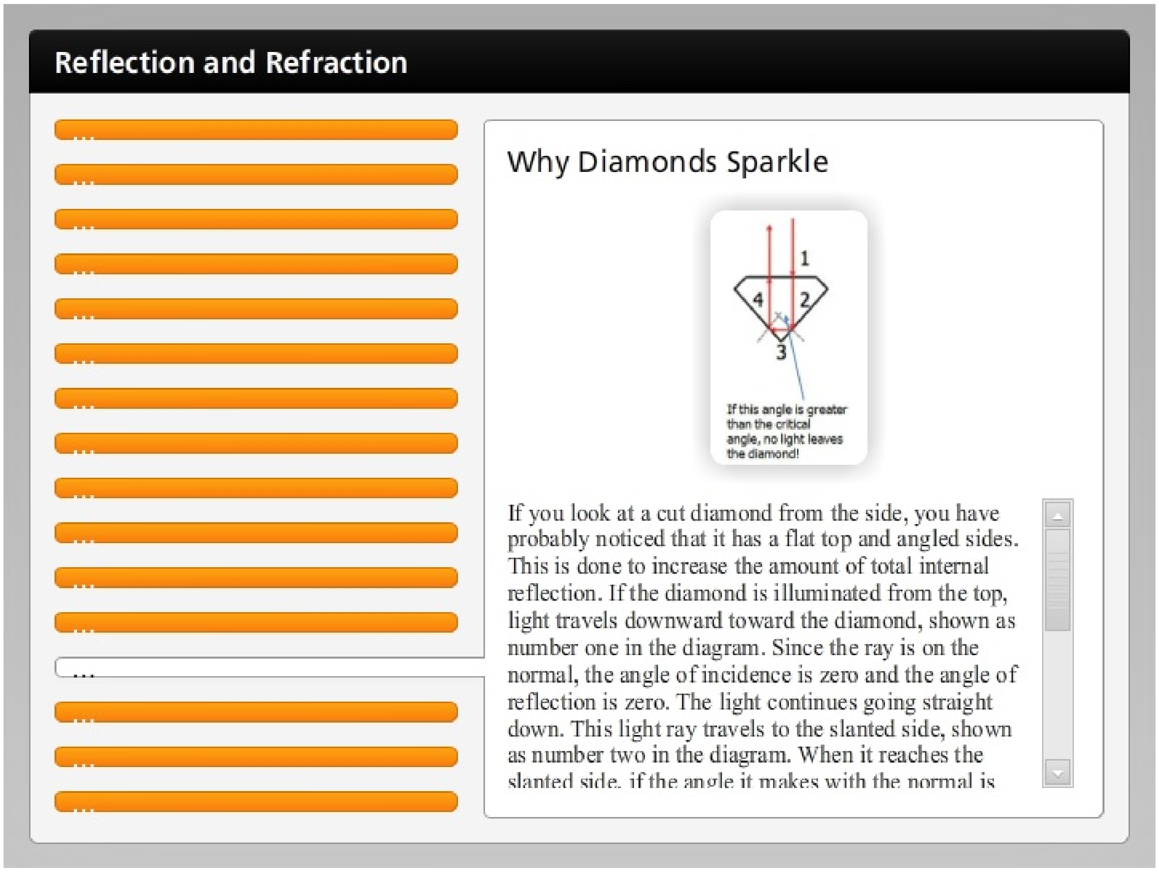
You can simplify this equation. In this case, index of refraction two is equal to one since the medium is air. Simplifying the equation and solving gives you the equation: the critical angle is equal to the inverse sine of one over the index of refraction. If you look at the equation, you can see the relationship between the index of refraction and the critical angle. If the index of refraction is large, one over n gets smaller and the critical angle gets smaller. The bigger the value of the index of refraction, the smaller the critical angle.

Smallest Critical Angles



If the critical angle is small, more light will be internally reflected. What do we have to do to the index of refraction to make the angle smaller? You probably remember that sine of zero is zero and sine of ninety degrees is one, so as one over n gets smaller, the critical angle gets smaller. This means that materials with higher n have smaller critical angles.

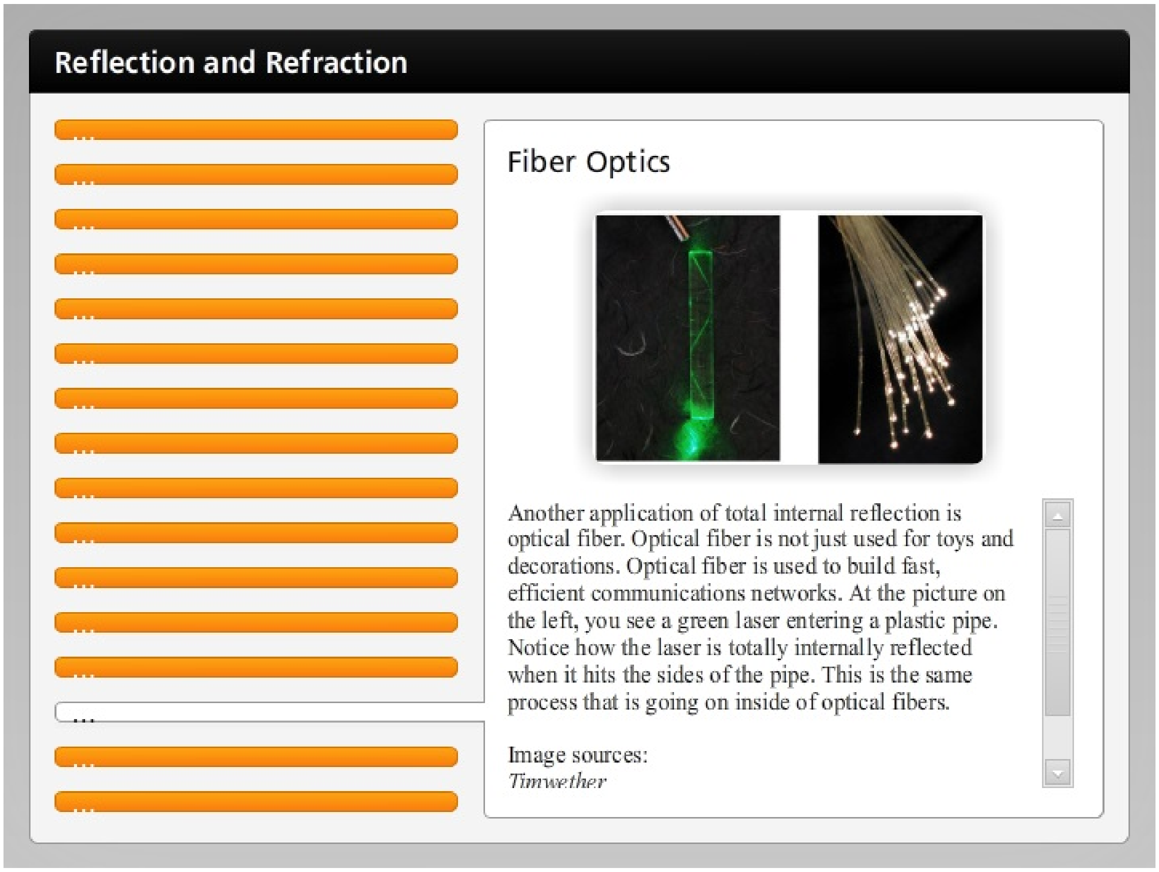
Why Diamonds Sparkle



If you look at a cut diamond from the side, you have probably noticed that it has a flat top and angled sides. This is done to increase the amount of total internal reflection. If the diamond is illuminated from the top, light travels downward toward the diamond, shown as number one in the diagram. Since the ray is on the normal, the angle of incidence is zero and the angle of reflection is zero. The light continues going straight down. This light ray travels to the slanted side, shown as number two in the diagram. When it reaches the slanted side, if the angle it makes with the normal is greater than the critical angle, all of the light will be internally reflection. This is shown as number three in the diagram.

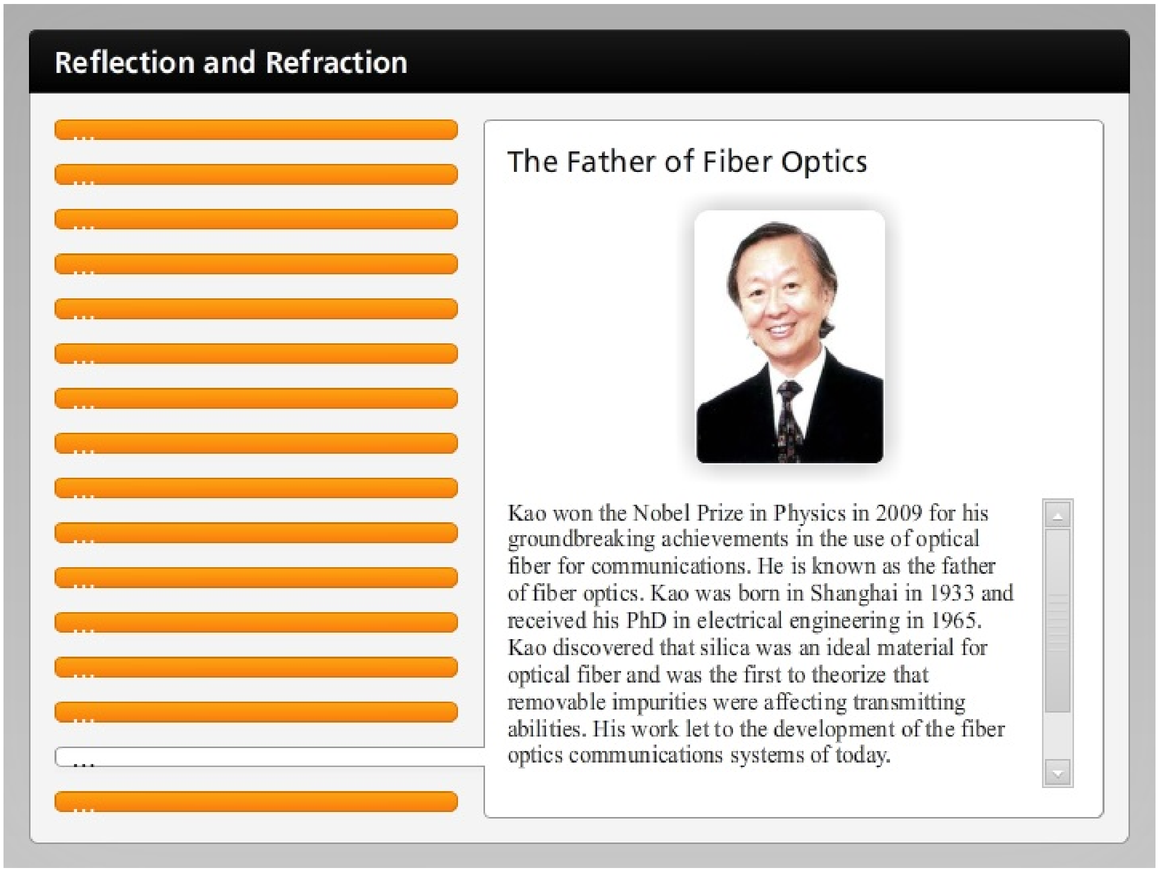
When the light reaches the other slanted side, if the angle it makes with the normal is greater than the critical angle, all the light will be internally reflected. This is shown as number four in the diagram. That ray then goes back through the top of the diamond, so you see a sparkly diamond! The larger the index of refraction of the stone, the smaller the critical angle will be and the less steep the slanted sides will have to be cut.

Fiber Optics



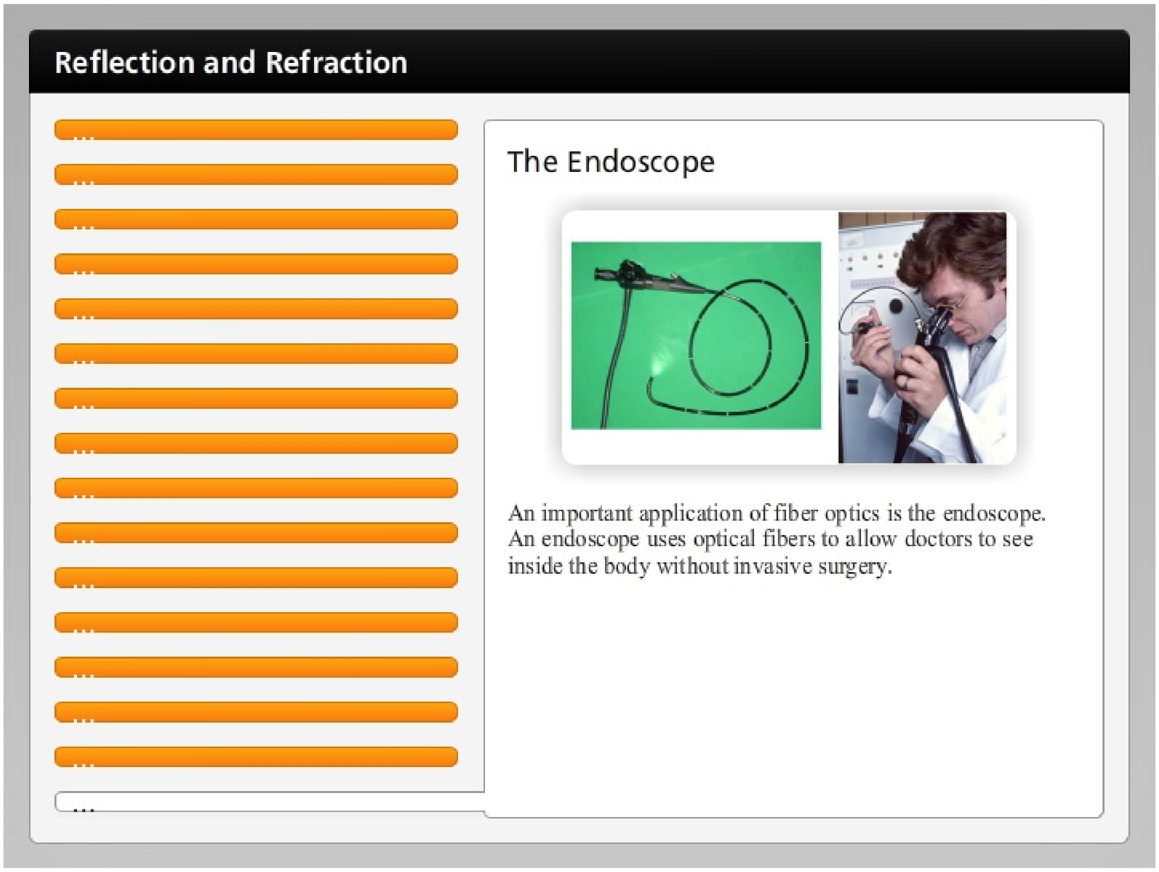
Another application of total internal reflection is optical fiber. Optical fiber is not just used for toys and decorations. Optical fiber is used to build fast, efficient communications networks. At the picture on the left, you see a green laser entering a plastic pipe. Notice how the laser is totally internally reflected when it hits the sides of the pipe. This is the same process that is going on inside of optical fibers.

The Father of Fiber Optics



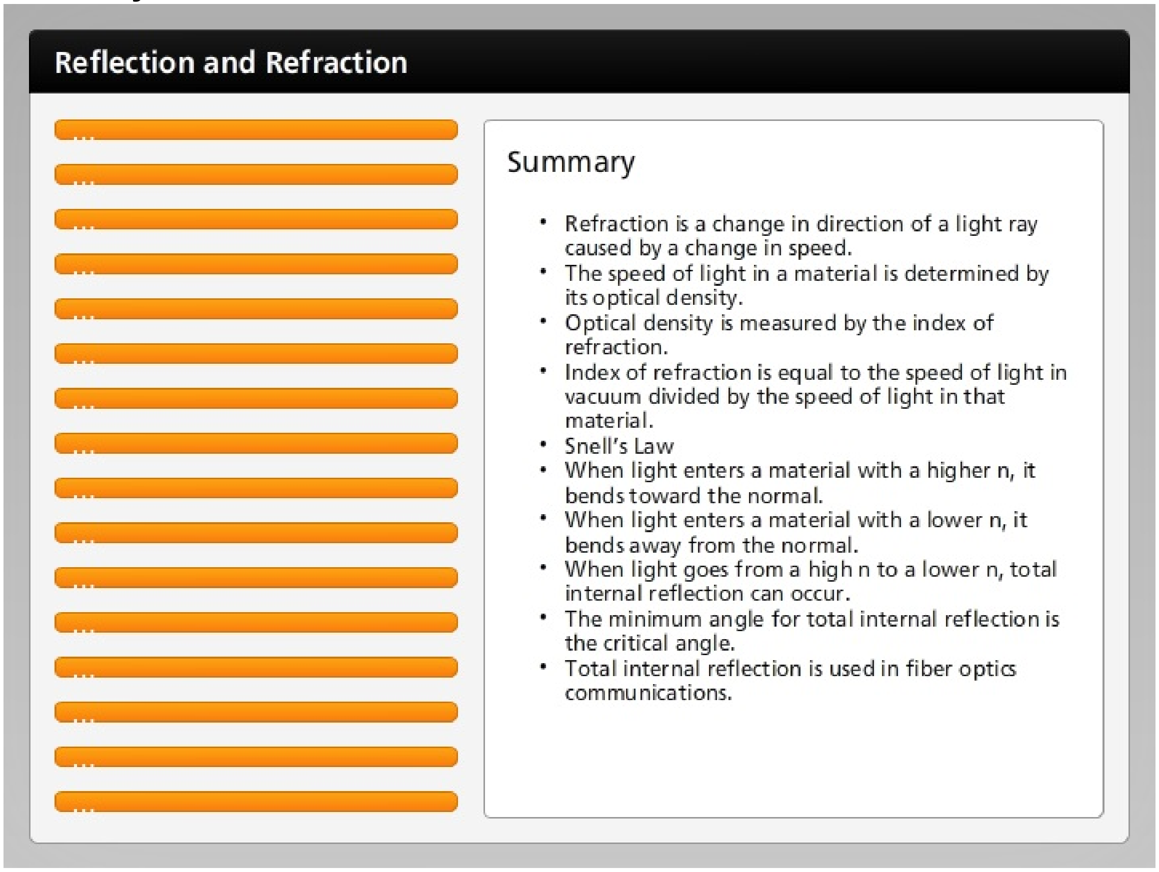
Kao won the Nobel Prize in Physics in 2009 for his groundbreaking achievements in the use of optical fiber for communications. He is known as the father of fiber optics. Kao was born in Shanghai in 1933 and received his PhD in electrical engineering in 1965. Kao discovered that silica was an ideal material for optical fiber and was the first to theorize that removable impurities were affecting transmitting abilities. His work let to the development of the fiber optics communications systems of today.

The Endoscope



An important application of fiber optics is the endoscope. An endoscope uses optical fibers to allow doctors to see inside the body without invasive surgery.

Summary



- Refraction is a change in direction of a light ray caused by a change in speed.
- The speed of light in a material is determined by its optical density.
- Optical density is measured by the index of refraction.
- Index of refraction is equal to the speed of light in vacuum divided by the speed of light in that material.
- Snell's Law
- When light enters a material with a higher n, it bends toward the normal.
- When light enters a material with a lower n, it bends away from the normal.
- When light goes from a high n to a lower n, total internal reflection can occur.
- The minimum angle for total internal reflection is the critical angle.
- Total internal reflection is used in fiber optics communications.

In summary, in this lesson we learned that: Refraction is a change in direction of a light ray caused by a change in speed. The speed of light in a material is determined by its optical density. Optical density is measured by the index of refraction. Index of refraction is equal to the speed of light in vacuum divided by the speed of light in that material.

Snell's Law describes the relationships between the indices of refraction and the angles of incidence and refraction. When light enters a material with a higher n, it bends toward the normal. When light enters a material with a lower n, it bends away from the normal. When light goes from a high n to a lower n, total internal reflection can occur. The minimum angle for total internal reflection is the critical angle, that can be calculated using Snell's Law. Total internal reflection is used in fiber optics communications.