Refracton occurs when light passes between two media with different indexes of refraction (the ratio of the speed of light in vacuum to the speed in a given material).

\[ n = \frac{c}{v} \]

If the light is incident on the new material at an angle other than perpendicular, it will be bent. This bending is known as refraction.

The change in the direction of light ray depends on the refractive index (i.e., physical property) of each medium. If the speed of light is slower in the second material than in the first, the light ray will be bent toward the direction normal to the surface (towards the perpendicular). The opposite reaction occurs when the light ray enters a material with an index of refraction which is lower (higher speed of light). The direction of the refracted ray must also depend on the angle of incidence; the direction that the light ray impinges upon the interface of the materials.

A relationship between the indexes of refraction and the angles of incidence/refraction was obtained by Willebrord Snell in 1621. This analytic solution is now known as Snell’s law:

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

Note that \( n \) is the refractive index of the two materials (1 and 2) and \( \theta \) is the incident and refracted angles. According to the formula, we can infer that as the incident angle gets larger, the refracted angle gets larger as well.

As stated before, when light travels from one material to another with a lower index of refraction, the beam will be bent away from the normal (away from perpendicular). As the angle of incidence increases, this effect will become more pronounced. At a particular incident angle, called the critical angle, the refracted ray will travel along the boundary of the two materials. In other words, the angle of refraction will be \( 90^\circ \) to the normal and \( \sin \theta_1 = 1.00 \). If the incident angle continues to increase, Snell's law would tell us that \( \sin \theta_2 > 1.00 \), but this can never happen. Thus, there cannot be a refracted ray. In this case, the light ray will be reflected at the same angle from the normal as the angle of incidence and will not exit the first material. This phenomenon is called total internal reflection.

Total internal reflection has been applied to numerous technologies across several industries, including telecommunications, medicine, binocular design, and jewelry making. One of the biggest industries that take advantage of this effect is telecommunications. Fiber optic cables are used to transmit vast amounts of data at very high speeds. The cables themselves are made out of extremely pure glass (silica) or plastic with refractive index of about 1.50. In air, the critical angle would be \( \theta_c = 41.8^\circ \). However, most cables come encased in another clear material, cladding, with a low index of refraction, which ensures nearly 100% of the light is reflected.

When light enters a fiber optic cable, the light is completely reflected inside the cable and travels through it. Fiber optics provides several advantages over conventional conducting cables. These cables can be used over greater distances (lower losses) and with higher bandwidths (data rates). They are also immune to electromagnetic interference and interference from each other.

The fastest single core transfer rate for one of these cables was 101 Tbit/sec (370 channels at 273 Gbit/sec). The fastest multicore transfer rate was 1.05 petabits/sec. Most commercially available cables have up to 80 fibers bundled together with a typical transfer rate of 10-40 Gbit/sec.

**EXPERIMENT**

In this experiment, the laser light is captured inside a falling column of water. The light travels through the water and, at some point, meets the boundary between the water and the air. If we note that water has refractive index of 1.33 and the air has an index of approximately 1, then we know that the critical angle for the light to undergo total internal reflection is 48.8° from normal. As long as the water pressure in the spout is great enough, the light will be contained within the column. Of course, some of the light rays are scattered and escape from the water, which is why we can see them. The rays left inside will follow the path of the water until they completely dissipate.