Refraction Applications: Total Internal Reflection

Diamonds

Diamonds are one of the most valuable natural materials on Earth because of their hardness and sparkle. The hardness of a diamond is due to the vast network of carbon-carbon bonds that make up its structure. The sparkle of a diamond is due to both the cut of the diamond faces combined with its unique index of refraction. Diamond has a very high refractive index \((n = 2.42)\) compared to regular glass \((n = 1.50)\). This means that light will travel slower in diamond than glass. As light rays travel from air into diamond (or diamond into air), it will be bent or refracted more than in glass (as shown in the diagram below). When a light ray enters glass, it is bent towards the normal. When traveling back to the air, the ray is bent away from the normal. The critical angle for glass is \(42^\circ\). This means that if the angle of incidence is more than \(42^\circ\), all light will be reflected back into the glass. In glass, the ray of light will eventually pass out of the glass before it goes back to the eye of the observer.
In diamond, the critical angle is only 24°. This means that a light ray that enters the diamond from above will only exit the diamond if the angle of incidence is less than 24°. Instead of exiting the diamond, the light undergoes total internal reflection inside the diamond until eventually exiting the diamond on the same side it entered. This bouncing of light is the cause of the sparkle in diamond. This effect is also observed in expensive leaded crystal as well.

Why are diamonds so shiny?

What does the term total internal reflection mean?

**Fibre Optic Cables**

Fibre optic technology uses light to transmit information using a glass or plastic cable. Once inside, the light cannot escape due to total internal reflection and is continually reflected back inside the cable (as shown in the diagram below). Fibre optics are used in communications for phone lines and the internet. High speed internet service would be impossible without the high data transmission speeds due to fibre optics. Fibre optics are also used in medicine to allow very tiny devices called endoscopes to see within the human body.
Triangular Prism

Many optical devices such as binocular sand cameras use triangular prisms to reflect light using total internal reflection. Mirrors also reflect light but also absorb some light and the reflective surface will deteriorate over time. In contrast, a prism will reflect almost 100% of the light if the incident angle is past the critical angle. This is also used in submarine periscopes to view the surface while submerged (see diagram).

Rainbows

When we see a rainbow we are also witnessing the effects of atmospheric refraction. In this case, the effect relies on the presence of water vapour in the air so that sunlight is bent in the water droplets to create total internal reflections, which then disperses the white light into the complete visible colour spectrum.
Total Internal Reflection Questions:

1. What two conditions must be met for total internal reflection to occur?

2. What speed is light travelling at in the following mediums? (Assume the light is travelling back into air)
   a) water (n = 1.33)
   b) glass (n = 1.55)
   b) leaded crystal (n = 1.72)