

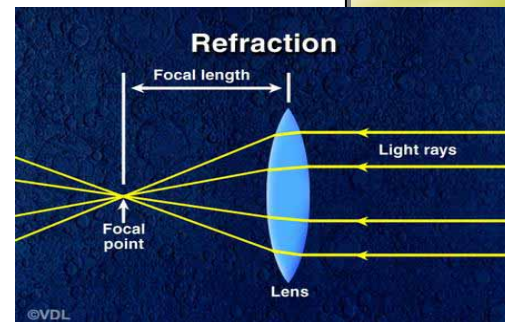
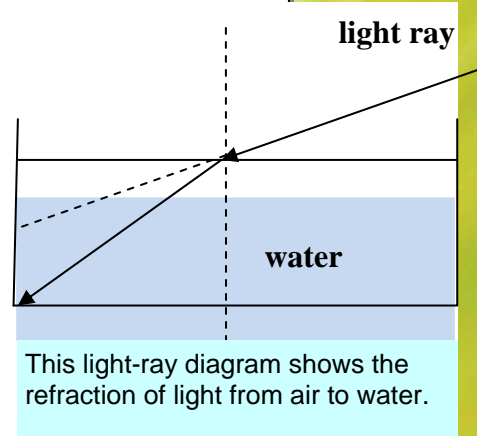
Light reflection and light refraction are often used to create optical illusions during a magic show. For example, mirrors can create the illusion that there are six apples when in fact light from just one apple is being reflected. Similarly, objects may appear to bend or break when light refracts through different materials. Similarly, reflection and refraction play roles in natural illusions, such as rainbows after a rain shower and mirages of standing water in a desert.

Principles of Refraction

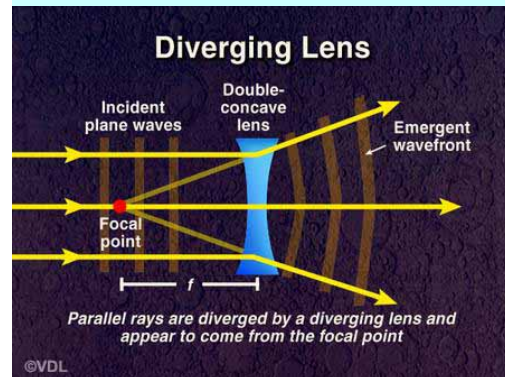
Most people are familiar with how light reflects from shiny surfaces. Fewer people understand what happens when light refracts as it travels through transparent materials. Light refraction occurs when light changes direction at the boundary between two different materials.

In the figure at right, a ray of light traveling in air approaches a tank of water. The black arrows indicate the direction of the light. As light passes from air to water, the light refracts, meaning that the direction of the light beam suddenly changes.

The vertical dotted line at the point the light enters the water is called the normal line. (The word “normal” can mean “perpendicular”; the normal line is perpendicular to the air-water boundary.) The angle between the incoming light ray (in air) and the normal line is called the angle of incidence. The angle between the outgoing light ray (in water) and the normal line is called the angle of refraction. The entire picture is called a light-ray diagram.



Converging lens (above) shows the intersection of light rays at the focal point. Diverging lens (below) shows how to find the focal point.



Note that refraction occurs only at the boundary between air and water. Otherwise, light travels in a straight line. Which way the ray's direction changes depends on a property of the materials called "index of refraction." In general, denser materials have higher indexes, while less dense materials have lower indexes. Moving from a low-index material such as air (with an index of refraction nearly 1) into a higher-index material such as water (index of refraction 1.33), a ray of light bends *toward* the normal line. If a ray starts in a high-index material and goes into a low-index material, it refracts *away* from the normal line.

Light refraction helps people understand how glass and plastic lenses can direct light. There are two basic types of lenses: converging lenses and diverging lenses. These lenses differ in what they do to incoming parallel light rays. A converging lens bends incoming parallel light rays together, while a diverging lens spreads them apart.

For the converging lens, the special point in space where these rays cross or intersect is called the focal point.

A diverging lens also has a focal point. However, since parallel light rays are spread apart by such a lens, the light rays never actually intersect each other. Here, the focal point is defined as a point where the outgoing rays appear to be coming from an observer looking at the lens. The focal point can be determined by tracing the outgoing rays backward (in figure at right, the pale yellow lines converging at the red dot).

Applications of Refraction

Light refraction explains many optical illusions. Three examples are the apparent shallowness of a swimming pool, the bending-straw effect, and water mirages.

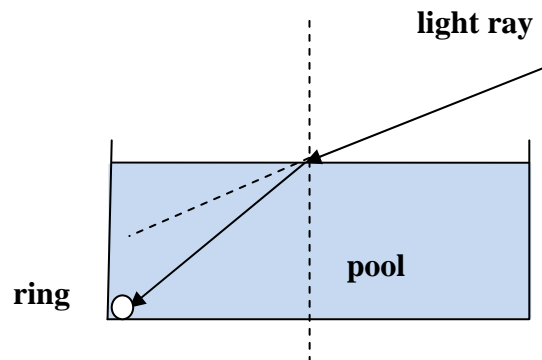
When a person peers into a swimming pool, the pool appears to be much shallower than the pool actually is. A gold ring at the bottom of a pool can help illustrate this



A straw appears to bend in water because of light refraction.

concept. If a flashlight with a narrow beam is shined into the pool at just the right direction, the light refracts at the surface and strikes the ring. Some of the light reflects from the ring and retraces the path of the light ray back to the observer.

It is natural to believe that light travels in a straight line from the ring to a person's eye. Therefore, the ring may seem to be in a more shallow location than it really is. The ring may appear to be at the end of the dotted line drawn in the water that extends the light ray. But the ring is actually below that spot. In this way, everything in a pool (including the bottom of the pool) appears closer to the surface than it actually is.



Looking for a gold ring in a swimming pool:
Is it above or below where it appears to be?

The bending-straw effect is another example of light refraction trickery. The tip of the straw in the water plays the role of the “apparent gold ring” in the above example. The end of the straw appears to be closer than it actually is. When an observer looks down at the straw as though about to drink from the straw, the part in the water appears to bend upward. Looking at the straw from the side of the glass, the straw appears to be broken.

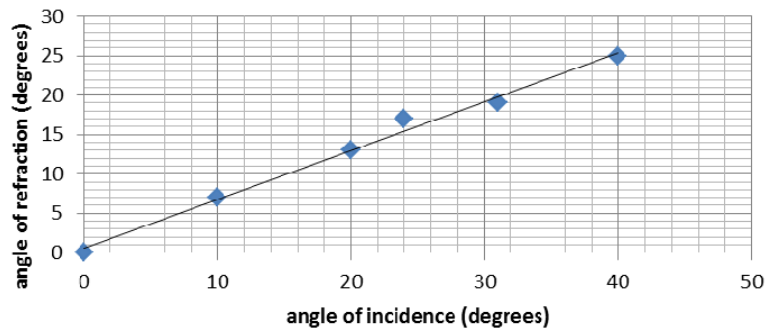
The water mirage—an apparent puddle seen at a distance on a highway on a hot day—is also the result of light refraction. Light refraction also causes mirages of water in a desert. What is seen in a mirage is not water but rather an image of the sky. Light travels from the sky to the hot road (or desert), and then gradually bends upward to the observer's eye. The light



Rainbows are created by water droplets serving as converging lenses.

gradually refracts because the light passes through different temperatures of air that have different indexes of refraction.

Rainbows are also created by light refraction. After a heavy rain, a mist of water droplets fills the air. Each droplet is like a fat converging lens. Light enters, refracts, reflects off the inside of the water droplet, and refracts again as the light leaves the droplet. Different colors of light refract at different angles. Droplets split incoming white light (a mixture of colors) with refraction, spreading the white light out into its component colors. The result is a stunning rainbow.

Student Lab Journal Entry**Light Refraction (Air to Oil)**

A student collected data on light refraction from air to oil, and recorded her results in a lab journal. A graph from her journal is shown above.

If no refraction occurred at the air-oil boundary, the data might have values of (0, 0), (20, 20), and (30, 30). Every angle of refraction would be the same as the angle of incidence.

The index of refraction of air is about 1; for oil it is about 1.5.

Therefore, incoming light will bend toward the normal line. For light traveling from air to oil, the angle of incidence will always be larger than the angle of refraction.

Conclusion

The effects of light refraction are visible every day as light travels through different materials on its way to the eyes. The "trickery" of refraction can deceive observers into seeing illusions, but science can be used to explain what is really happening.