Light

Refraction and Lenses

Read to Learn

Refraction of Light

Light waves can change direction. Light always travels through empty space at the same speed—about 300,000 km/s. It travels more slowly when it moves through a medium such as air, glass, or water. This is because the atoms of the material interact with the light waves and slow them down.

As a light wave moves from one medium into another, its speed changes. If the wave enters the new medium at an angle, the wave will change direction. *The change in direction of a wave as it changes speed while moving from one medium to another is called* **refraction.** The index of refraction, shown in this table, is a property of each transparent material. The index of refraction indicates how much a medium can change the direction of light. A medium that has a high index of refraction is sometimes called slow because light moves more slowly through it. A medium that has a low index of refraction, such as air, is called fast.

Indexes of Refraction for Different Media

Medium	Index of Refraction
Vacuum	1.0000
Air	1.0003
Ice	1.31
Water	1.333
Oil	1.47
Ovenproof glass	1.47
Diamond	2.417

Moving Into a Slower Medium

Suppose you roll a toy car across a table straight at a piece of fabric. The front tires of the car slow down when they hit the fabric. The car continues to move in a straight line but more slowly. If you roll the car toward the fabric at an angle, one front tire will hit the fabric before the other. That side of the car will slow down, but the rest of the car will continue at the same speed until the other tire hits the fabric. This will cause the car to turn and change direction.

As shown in the figure below, a light wave behaves in a similar way when it moves into a slower medium. Recall that a normal is a line perpendicular to a surface. As light moves into a slower medium at an angle, it changes direction toward the normal.

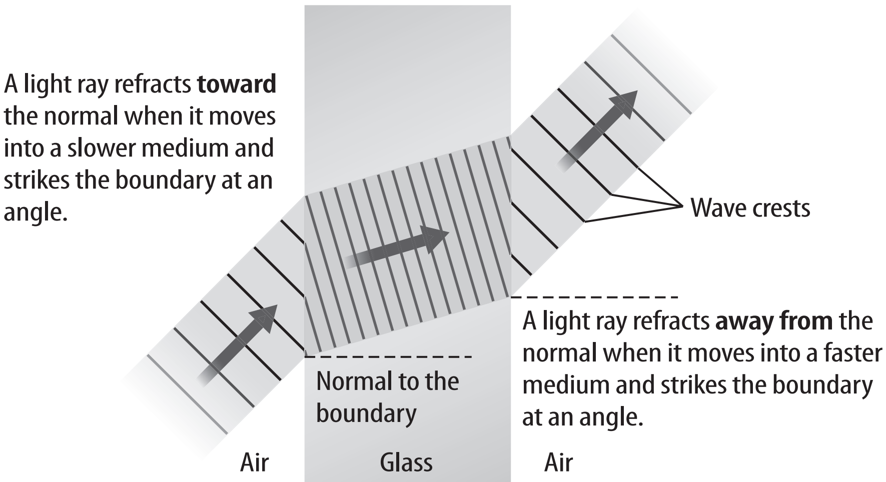
Moving Into a Faster Medium

What happens when light in the figure below moves back into the air? Suppose you ride your bike from a sidewalk into a muddy field and then back onto a sidewalk. You use the same energy to pedal the whole time, but you move more slowly in the mud. When you move back onto the sidewalk, you speed up.

Similarly, as light moves into a medium with a lower index of refraction, it speeds up. The wave is still at an angle, so the part that leaves the slower medium first speeds up sooner. This causes the wave to turn away from the normal, as shown on the right in the figure below.

You see the boundaries between surfaces such as air, glass, and water because of refraction. If transparent substances have the same index of refraction, you do not see the surfaces.

Refraction



Lenses

What do binoculars, eyeglasses, your eyes, and a camera have in common? Each contains a lens. *A* **lens** *is a transparent object with at least one curved side that causes light to change direction*. Recall that most of the light that strikes a transparent material passes through it. Light refracts as it passes through a lens. The greater the curve of the lens is, the more the light refracts. The direction of refraction depends on whether the lens is curved outward or inward.

Convex Lenses *A lens that is thicker in the middle than at the edges is a* **convex lens.** The light rays that move through a convex lens come together, or converge. Because of this, a convex lens often is called a converging lens.

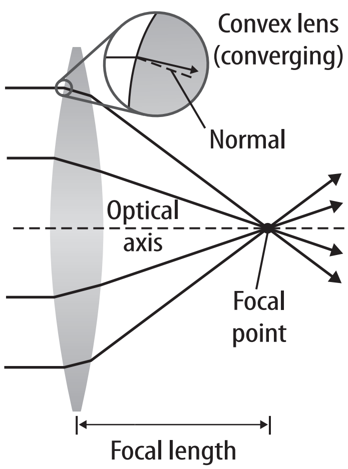
Concave Lenses *A lens that is thicker at the edges than in the middle is a* **concave lens.** The light rays spread apart, or diverge, as they move through a concave lens. A concave lens often is called a diverging lens.

Convex Lenses

Have you ever used a magnifying lens to look at a tiny insect? A magnifying lens makes things appear larger. If you look closely at the surface of a magnifying lens, you can see that it is a convex lens. Its center is thicker than its edges.

The figure at right shows how a convex lens refracts light. Notice that a normal to the curved surface slants toward the optical axis. Recall that light moving into a slower medium turns toward the normal. As a result, a convex lens refracts light inward and the light converges.

Convex Lens



Focal Point and Focal Length

Similar to a mirror, the point where rays parallel to the optical axis converge after passing through a lens is the focal point. The focal length of a lens is the distance along the optical axis between the lens and the focal point. Because you can look through a lens from either side, a focal point is on both sides of the lens. For a lens with the same curve on both sides, the lens's two focal points are the same distance from it.

Types of Images Like a concave mirror, the type of image a convex lens forms depends on the location of the object. A convex lens can form real and virtual images.

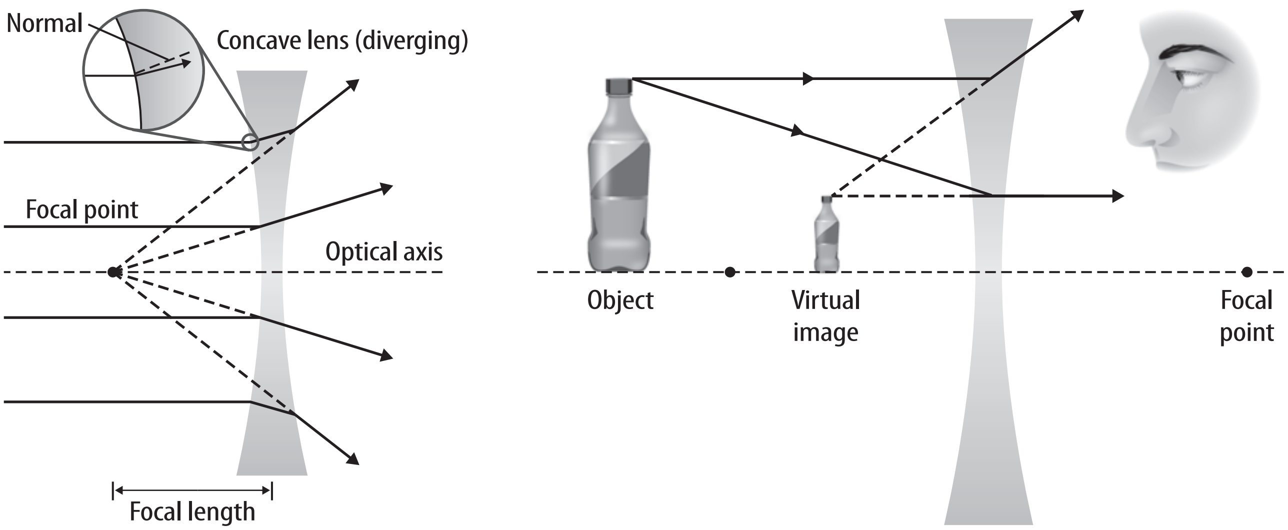
If you look through a magnifying lens at an object more than one focal length from the lens, the image you see is inverted and smaller. If you look at an object less than one focal length from the lens, the image is upright and larger. Your brain knows that light travels in straight lines. The image is virtual because your brain interprets the refracted rays as moving in straight lines.

Concave Lenses

Because a concave lens is thicker on the edges than in the middle, the light rays that pass through a concave lens diverge, or spread apart. The left side of the figure below shows why. Notice that a normal to the curved surface slants away from the optical axis. Because light entering a slower medium changes direction toward the normal, the lens refracts light outward. The light diverges.

The right side of the figure below shows the type of image a concave lens forms. The figure shows only two rays coming from the tip of an object, but the number of rays is really infinite. Suppose you stand at the right side of the lens and look at the object. The refracted rays reach your eyes, but your brain assumes the light traveled the path shown by the straight dashed lines. You see a virtual image that is smaller than the object.

Concave Lenses



Refraction and Wavelength

You have read that the curved surfaces of lenses affect the refraction of light rays. The wavelength of light also affects the amount of refraction. Have you seen sparkling cut-glass ornaments hanging in a window? When sunlight strikes the glass, rainbows appear on the wall. These "sun catchers" work because different wavelengths of light refract different amounts.

You know that white light is made up of different colors. Each color of light has a different wavelength and frequency. The speed of a wave in a material is related to its wavelength. Waves with longer wavelengths travel at greater speeds in a material than waves with shorter wavelengths. Therefore, when entering a material, light with longer wavelengths travels faster and refracts less than light with shorter wavelengths. As a result, violet refracts the most because its wavelength is the smallest. Red has the longest wavelength and refracts the least.

Prisms

As white light passes through a piece of glass called a prism, each wavelength of light refracts when it enters and again when it leaves. Because each color refracts at a slightly different angle, the colors separate. They spread out into the familiar spectrum called a rainbow.

Rainbows

Why do rainbows appear in the sky only during or after a rain? Rainbows form when water droplets in the air refract light, like a prism. Each wavelength of light refracts as it enters the droplet, reflects back into the droplet, and refracts again when it leaves the droplet. The wavelengths of light near the blue end of the spectrum refract more than wavelengths near the red end of the spectrum. This effect produces the separate colors you see in a rainbow.

Detecting Light

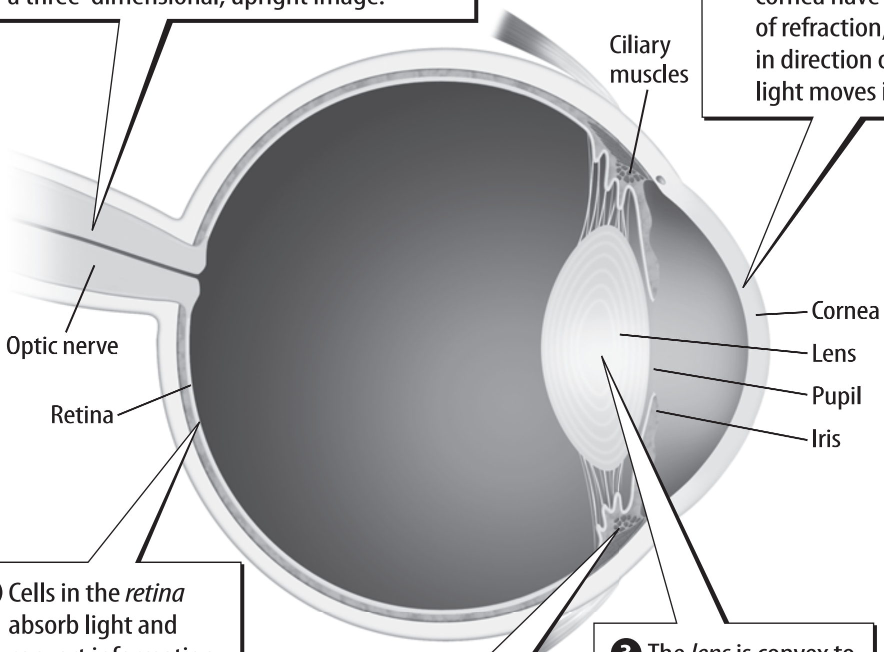
Objects emit or reflect light into your eyes. You have read that the material that makes up an object reacts to various wavelengths of light in different ways. The material absorbs some wavelengths of light. Other wavelengths reflect to your eyes, providing information about shapes and colors. Your brain interpret this light energy so that you recognize the images as people, places, and objects.

The Human Eye

Eyes respond quickly to changing conditions. As the figure below shows, the iris changes the size of the pupil which controls the amount of light that enters an eye. The cornea acts as a convex lens and focuses light when it enters the eye. The shape of the cornea cannot change. The shape of the eye's lens, however, can change. Changes to the shape of the lens can alter its focal point. This enables a person to see objects clearly either far away or near.

The parts of an eye work together to focus light and to send signals about what you see to the brain. Follow the steps in the figure to learn what each part of the eye does.

How the Eye Works



1. The *cornea* protects the eye. Light refracts as it enters and as it leaves the cornea. Because air and the cornea have very different indexes of refraction, the greatest change in direction of light rays occurs as light moves into the cornea.

2. The *iris* is the colored part of your eye. The *pupil* is an opening in the center of the iris that can change size from 2 mm to 8 mm to let different amounts of light into the eye.

3. The *lens* is convex to help focus incoming light to form an upside-down image on the retina.

4. The *ciliary muscles* change the shape of the lens, making it flatter or rounder so that you can focus clearly on objects at any distance.

5. Cells in the *retina* absorb light and convert information about the amount of light and color into electric signals.

6. Electric signals from the retina travel to the brain through the *optic nerve*. The brain combines signals from both eyes to produce a three-dimensional, upright image.

Seeing Color

You might have noticed that it is harder to see colors in dim light. Why does this happen? Different cells on the retina of an eye make it possible for a person to see both colors and shades of gray. *A* **rod** *is one of many cells in the retina of the eye that respond to low light*. The human retina has about 120 million rods. Rods enable you to see near the sides of your eyes rather than along the direct line of vision. This type of eyesight is called peripheral [puh RIH fuh rul] vision.

A **cone** *is one of many cells in the retina of the eye that respond to colors*. The human retina contains 6 to 7 million cones that require more light to produce signals. These cones respond to red, green, and blue wavelengths of light. Recall that these primary colors of light can combine and form all the other colors. When light strikes a cone, the cell produces an electric signal that depends on the light's intensity and its wavelength. Your brain combines signals from all rods and cones and forms the colors, the shapes, and the brightness of the objects you see.

Correcting Vision

In a person with normal eyesight, the cornea and the lens focus light directly on the retina. This forms a sharp, clear image. Some eyes, however, have an irregular shape. Manufactured lenses can correct these problems.

If an eyeball is too long, light focuses in front of the retina. A person with this kind of vision problem is nearsighted. He or she sees near objects clearly, but distant objects far away are blurred. Eyeglasses that have concave lenses correct this problem.

In other instances, the eye can be too short. Light focuses behind the retina. A person with this kind of vision problem is farsighted. He or she can clearly see objects far away, but objects that are near are blurred. Eyeglasses that have convex lenses correct this problem.

Refraction and lenses make it possible for you to see. Light refracts as it moves from one medium into another. Different colors refract at different angles. A lens causes light to change direction. For example, the cornea and lens of the eye focus light onto the retina. Many people need eyeglasses or contact lenses to help focus this light.