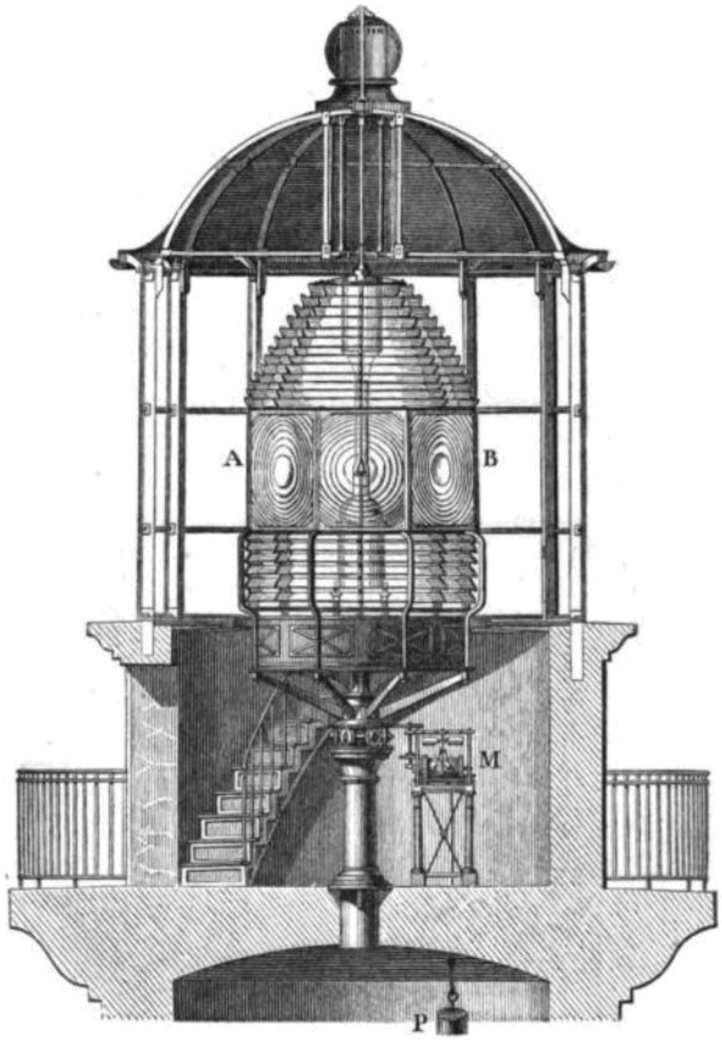
How Does a Fresnel Lens Work?



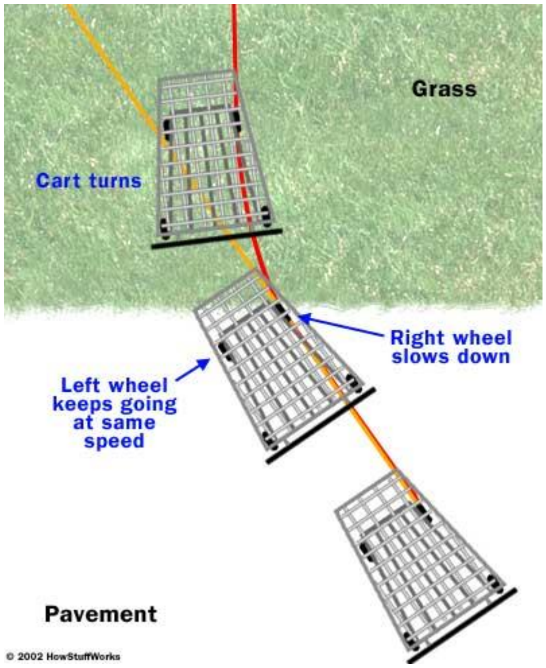
A small triangular prism, a pen light, and a mirror is what is needed for helping kids understand how a lighthouse lens works. Prior to the mid-nineteenth century, lighthouses relied on a silvered reflector placed behind a lamp. The reflector acted like a mirror and intensified the light and directed it outward. In 1823, the Fresnel lens improved illumination by concentrating and further intensifying light. Prisms were important in the process, which continued use of a reflector as well.

A prism refracts light and a mirror reflects lights. Demonstrate these principles to visitors. Shine the penlight through the prism and see light change direction. Shine the penlight into the mirror and see light change direction and intensify. If you‘re really handy, you can bounce the penlight beam off the mirror and through the prism to show both reflection and refraction of light. This is what happens in a Fresnel lens. Even a modern beacon uses the same concept; it’s just smaller, more compact, and requires little maintenance. Classical Fresnel lenses and modern optics operate on the same principles of physics. Light is gathered and concentrated, then cast seaward in the direction it needs to go.

First, read some background information on light:

Prisms often create tiny shimmers of rainbows inside a lighthouse lens when sunlight passes through them during the daytime. So beautiful! →

But also a chance to teach an easy physics lesson. The fundamental process at work in a rainbow is **refraction** -- the "bending" of light. Light bends -- or more accurately, changes directions -- when it travels from one medium to another. This happens because light travels at different speeds in different mediums. To understand why light bends, imagine you're pushing a shopping cart across a parking lot. The parking lot is one "medium" for the shopping cart. If you're exerting a constant force, the cart's speed depends on the **medium** it's traveling through -- in this case, the parking lot's paved surface. What happens when you push the shopping cart out of the parking lot, onto a grassy area? The grass is a different "medium" for the shopping cart. If you push the cart straight onto the grass, the cart will simply slow down. The grass medium offers more resistance, so it takes more energy to move the shopping cart. But when you push the cart onto the grass at an angle, something else happens. If the right wheel hits the grass first, the right wheel will slow down while the left wheel is still on the pavement. Because the left wheel is briefly moving more quickly than the right wheel, the shopping cart will turn to the right as it moves onto the grass. If you move at an angle from a grassy area to a paved area, one wheel will speed up before the other and the cart will turn.



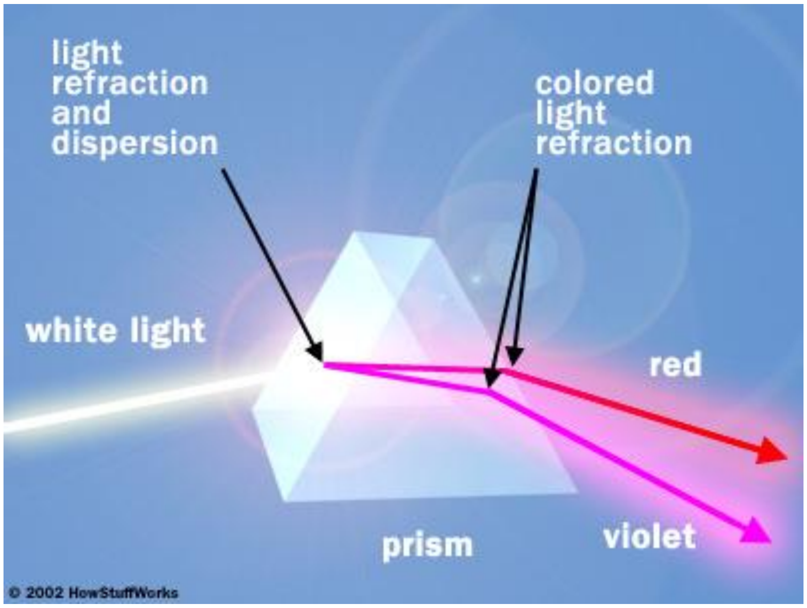
Diagrams Courtesy of “How Stuff Works”

Similarly, a beam of light turns when it enters a glass prism. This is a simplification, but think about it this way: One side of the light wave slows down before the other, so the beam turns at the boundary between the air and the glass (some of the light actually reflects off the prism surface, but most passes through). The light turns again when it exits the prism, because one side of it speeds up before the other.

In addition to bending light as a whole, a prism separates white light into its component colors. Different colors of light have different **frequencies**, which causes them to travel at different speeds when they move through matter.

A color that travels more slowly in glass will bend more sharply when it passes from air to glass, because the speed difference is more severe. A color that moves more quickly in glass won't slow down as much, so it will bend less sharply. In this way, the colors that make up white light are separated according to frequency when they pass through glass. If the glass bends the light twice, as in a prism, you can see the separated colors more easily. This is called **dispersion**.

Drops of rainwater can refract and disperse light in the same basic way as a prism. In the right conditions, this refraction forms rainbows. In the next section, we'll find out how this happens.



A prism separates white light into its component colors. For simplicity's sake, this diagram shows only red and violet, which are on opposite ends of the spectrum.

(From "How Stuff Works"-- http://science.howstuffworks.com/rainbow1.htm)

Color also affects the range, or the distance, a light can be seen. When white light passes through a red or green pane of glass, its range is reduced. This is why coastal beacons that must show their light far at sea are never green or red, but always white. Green and red lights work well in small harbors and rivers, however, since they need not show a long distance.

Refraction

Refraction is the bending of light through a substance. Different substances bend light at different angles. White light is made up of a full spectrum of colors. Each color has a different wavelength, and bends at a different angle. This is the same effect that produces rainbows in the atmosphere. The most common illustration of this is a glass prism.

The colors of the spectrum can be remembered easily with the acronym **ROYGBV** (pronounced: *roy-gee-biv*)

ROYGBV					
Red	**Orange**	**Yellow**	**Green**	**Blue**	**Violet**

A **prism** is a special piece of glass, crystal, or plastic that bends light. The light bends (*or refracts*) because it moves slower in the glass than it does in air. If different colors of light move at different speeds, each color bends a different amount. This splits the light into lots of different colors called a spectrum. This spectrum has the same colors as a rainbow does. Rainbows are also made by bending light. They happen when light is bent by tiny drops of rain floating in the air.

If you have ever looked at the lens of a magnifying glass, you know that it is thick in the middle and tapers to almost nothing at the edges. In other words, it is shaped like a lentil, which is where the word *lens* comes from. (In Latin, the word lentil is *lenticula*.)

An RV sometimes uses a lens to allow the driver to see out the back window. The thin piece of plastic that sticks to the rear window is called a **Fresnel lens**. It is flat on one side and ridged on the other. Fresnel lenses were first used in the 1820s as the lens that focuses the beam in lighthouse lamps. Plastic Fresnel lenses are used as magnifiers when a thin, light lens is needed. The quality of the image is not nearly as good as that from a continuous glass lens, but in lots of applications (like an RV), perfect image quality is not necessary.

The Inventor

The Fresnel lens is named for its inventor, French physicist **Augustin Jean Fresnel**. Fresnel studied light and optics in the 19th century.

The basic idea behind a Fresnel lens is simple. Imagine taking a plastic magnifying glass lens and slicing it into a hundred **concentric rings** (like the rings of a tree). Each ring is slightly thinner than the next and focuses the light toward the center. Now take each ring, modify it so that it's flat on one side, and make it the same thickness as the others. To retain the rings' ability to focus the light toward the center, the **angle** of each ring's angled face will be different. Now if you stack all the rings back together, you have a Fresnel lens. You can make the lens extremely large if you like. Large Fresnel lenses are often used as solar concentrators.

Fresnel Lenses for Lighthouses—

America's first lighthouse used a system of silvered reflectors to intensify the main light source, which was at first a whale-oil lamp. But, by the 1850's, the U.S. government authorized use of a new technology: the glorious, multiprismed lens invented in 1822 in France by Augustin Jean Fresnel (pronounced *Fray-nell*).

It was a marvel....a complex array of dazzling glass prisms and bull's-eye lens mounted in a gleaming brass framework. Each lens cost $12,000 at the time plus shipping costs from France.

The Fresnel lens was much more efficient at collecting and directing the light rays and produced a beam five times more powerful than the reflector system used previously. But, to take maximum advantage of the higher light intensity, the light had to be placed high enough to compensate for the curvature of the earth. When mounted at 100 feet above sea-level, a first-order Fresnel lens had a visible range of up to 18 miles at sea.

The new lenses were ranked in six sizes called orders. The weakest, ranked sixth, was used in lights on lakes and in harbors while the largest, first-order lenses were used in lighthouses on fogbound coasts. A first-order lens, made up of over 1000 prisms, stood up to 10 to 12 feet tall and measured 6 feet in girth and could weigh up to 3 tons. Many lighthouses have their original Fresnel lenses in place though many are now unused having been replaced by aero-marine beacons. Many of these beautiful lenses have been removed from the lighthouses and placed in museums and other display areas where the public can view and appreciate the workmanship that went into them. Others, unfortunately, have been vandalized when the lighthouses were abandoned and left unguarded.

The light source for the early lens was a lamp made up of up to 5 concentric wicks and fueled originally by sperm oil or lard oil, then by kerosene and finally replaced by the incandescent lamp. The Fresnel prisms could focus the rays of such a lamp into a beam of 80,000 candlepower. By the 1930's, most of the lamps had been replaced with incandescent electric bulbs, which brought beam intensity to as high as 4.5 million candlepower.

Figure 1

Some lights employ a fixed or stationary lens (Figure 1) projecting a steady, uninterrupted beam of light in all directions. Others show a set of flash-and-eclipse (dark) intervals called the "light characteristic" (Figure 2) with the repetition rate of the intervals called the period. When viewing a lighthouse, you can determine its period by timing the flash and eclipse which continuously repeat at 5 to 15 second intervals. Each light in an area has a unique characteristic and mariners distinguish one light from another by checking its period on a chart called a *Light List*.

Figure 2

To create the flash pattern, multiple lens panels were mounted around the circumference of the Fresnel lens assembly which was mounted on wheels on a circular track or floated in container of mercury, reducing rotational friction to a minimum, and rotated at a precise rate controlled by a clockwork mechanism. In this way, even a 6000-pound assembly could be rotated with the touch of a finger. The clockwork drive, powered by a weight which often traveled the interior height of the tower, was wound by hand using a crank in the lantern room. The weight required winding as often as every 4 hours, which meant the keeper had to make a trip to the lantern room several times each night. Large lighthouses had several keepers and a watchroom just below the lantern room where a keeper could sit on watch to be sure the light operated properly. The watch rotated every four hours between the keepers.

The characteristic of the light was determined by the number of lens panels, their placement around the Fresnel lens assembly, and the speed at which it was rotated.

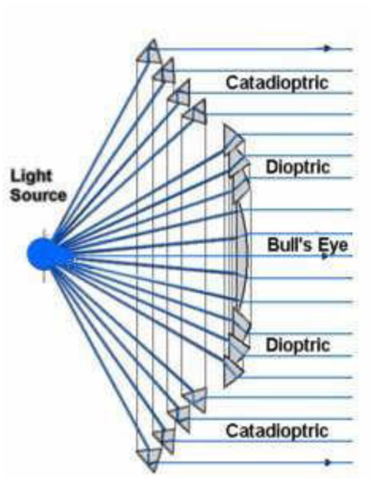


Figure 3

Figure 3 shows graphically how the Fresnel lens works. To bend and focus the rays to form a single, concentrated beam of high intensity light, the catadioptric prisms refract* and reflect; the dioptric prisms and center bull's eye lens refract. With just a 1000 watt bulb, a first-order Fresnel lens can generate a 680,000 candlepower beam visible up to 25 miles out to sea if set high enough.

Fresnel lenses, in many different forms, find many applications in today's modern world. They are used in the lens of traffic signals and to shape the light beam in overhead projectors, as well as in molded plastic versions which are sometimes placed on the rear windows of motor homes to broaden the driver's rearward field of view. Your car's headlights are Fresnel lenses too.