Keeper of the Los Angeles Harbor Lighthouse contemplating his 4th Order clam shell (also called a bivalve) lens. Circa 1930 photograph from U. S. Lighthouse Society archives.

LET THERE BE LIGHT

The History of Lighthouse Illuminants

By Connie Jo Kendall

Illuminants

In early times, an open flame produced by different materials provided the light in lighthouses. Bales of cotton soaked in oil worked for the Egyptians and the Pharos of Alexandria. Oakum and pitch was another early illuminant. Coal was recorded as an illuminant in the mid 900s, but was probably used prior to that date. Wood was introduced as an illuminant after 1500. After 1780 the preference for coal fires waned, but it wasn't until 1858 that the last coal fire was extinguished in a European lighthouse.

These early fires left a great deal to be desired. Often the signal was more smoke than light — especially during high winds and driving rain.

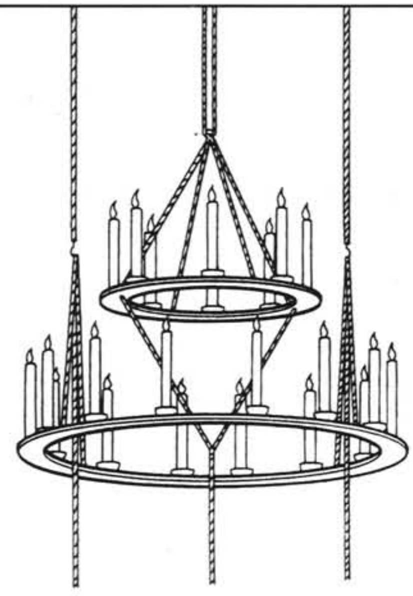
Candles were used in lighthouses from the early 1600s. The candles at the English lighthouse at Caistor, in 1628, weighed one-third pound each. In 1676, the candles at Harwich weighed one pound each. Sixty candles weighing one pound each were fitted to a chandelier in the first Eddystone Lighthouse and the resulting light was far superior to anything the mariner had seen before. This was the first tower with an enclosed lantern room. The third lighthouse to stand on Eddystone, constructed by the engineering genius Smeaton, was equipped with only 24 tallow candles.

The drawback of tallow or beeswax candles was the possibility keepers might use them for cooking or even eating if their larder ran low. Candle ends were a highly prized perk of lighthouse keeping — a years accumulation of candle ends had a high monetary value.

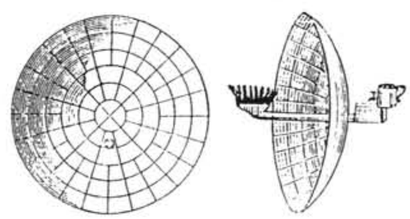
Lamp and Reflector Systems

In 1801 a flat brass plate was placed behind the coal fueled light at Harwich, England in an attempt to direct some of the light seaward. The soot from the fire, however, soon negated any reflection from the plate.

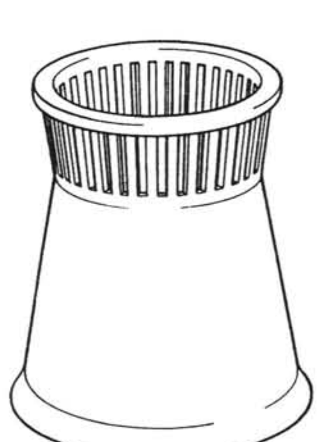
There is no record of who might have experimented with curved or parabolic reflectors. The earliest mention of this experimentation is made by Mr. William Hutchinson, a Liverpool publisher, in his book *Practical Seamanship*. He noted that in 1763, large, wooden, parabolic frames, lined with mirror glass, were placed behind the flame of the lighthouses at Bidstone and Hoylake at the entrance to the port of Mersey.



Smeaton's two tier, 24 candle, Eddystone chandelier.



An early lighthouse lamp backed by a reflector.



Coal brazier used throughout Europe. In the colder climates, like Scotland, as much as 400 pounds of coal was burned in a night. All drawings on this page from U. S. Lighthouse Society archives.

At the same time that reflector systems were coming into vogue, Aime Argand, a French scientist, developed the smokeless lamp in 1782. Prior to this, wicks were solid and either round or flat. Solid wicks, fueled by crude animal or vegetable oils (herring or other fish, rape or olive seeds) produced a great deal of smoke unless closely watched. The outer edges burned before the center, which smoldered. The inspector of the Boston Lighthouse in 1796 found the 16 solid wick lamp ineffective as "the lantern became in a short time full of smoak." This smoke was so suffocating that it was painful for any person to remain in it for any amount of time.

Argand tried a simple experiment having a magical effect on lighthouse illumination and, eventually, lighting people's homes. He placed a metal tube inside another, slightly larger, metal tube. There was just enough space between the two tubes to slide in a wick and extend it slightly above the top. The wick could be adjusted up or down by means of a small screw. When the wick was fueled and lighted it produced a bright, steady flame with most of the carbon (produced by the wick) being burned. The column of air on the outside of the larger tube and inside of the smaller tube (up the middle), provided an air current on both sides of the wick.

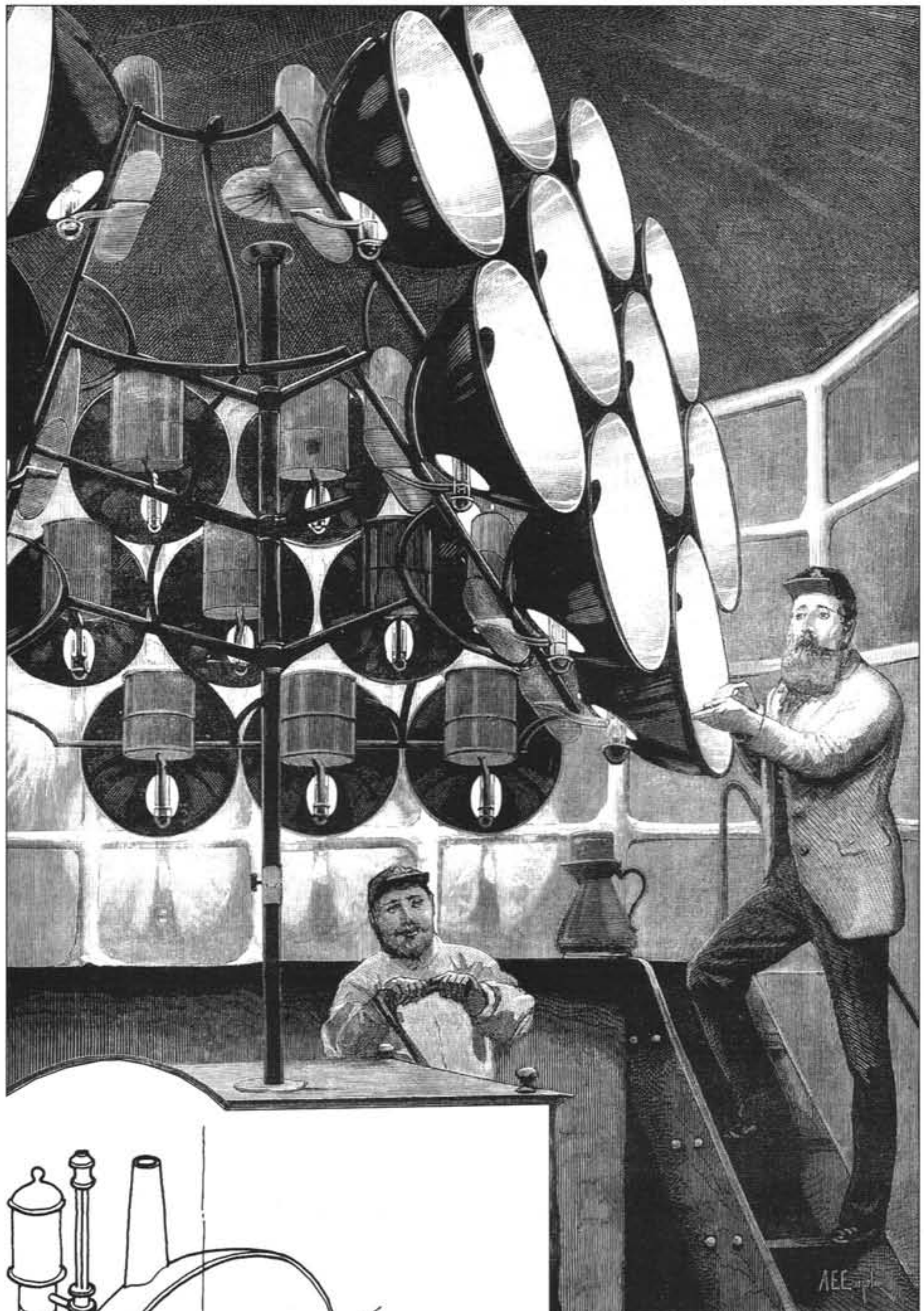
The lamp was further improved by an accident. Argand's brother was in Argand's studio one day and accidently broke a glass flask. For amusement, he lowered what remained of the body and neck of the flask over one of Argand's new lamps and the flame immediately rose and burned more brightly. This accident lead to the hipped neck glass chimney we associate with oil table lamps.

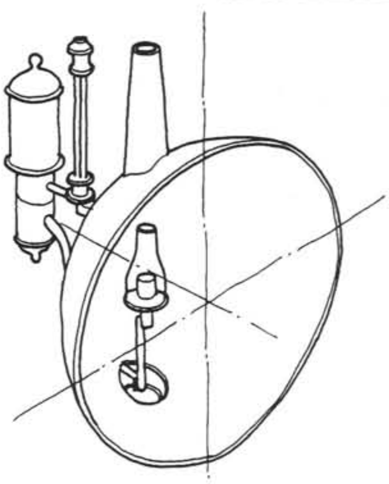
M. Teulere, a member of the Royal Corps of Engineers and Bridges and Roads of France, is credited as being the first to have written of the advantages of parabolic reflectors. In 1783 he recommended the use of parabolic reflectors with Argand lamps on a revolving frame for the Corduan Lighthouse.

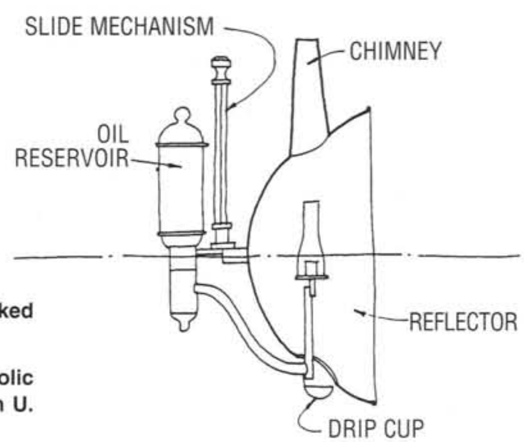
Using parabolic reflectors not only improved the power of light, but provided a characteristic which differentiated one lighthouse from others on the coast. This new lighting method was adopted by Trinity House of England. The Northern Lighthouse Board of Scotland, under the direction of Thomas Smith, placed a reflector system in the old castle of Kinnairdhead. Smith stated he had invented the reflector system he used, which consisted of facets of mirror glass placed in a parabolic dish constructed of plaster.

The marrying of the Argand lamp and the parabolic reflector, about 1784, was a giant step forward in providing a strong light. The reflector system is also known as the Catoptric System. The lamp provided a steady flame from a wick needing only to be trimmed and adjusted a few times during the night. The parabolic reflector directed the light rays, which struck its surface, out to the mariner in a horizontal cone. By placing many lamps backed by reflectors around a frame, a steady white light could be seen all around the horizon. By situating four banks of three or four lamps to a side and rotating the frame a flashing characteristic was produced. The reflectors were, generally, constructed of copper and coated with silver.

Around 1810 a retired ship captain, Winslow Lewis, sold the rights of his lamp and reflector system to the U. S. Government. It was the same system Argand and others had developed in Europe many years before. Lewis modified the apparatus by adding a convex, green lens in front of the lamp. This greatly reduced the range due to the shape and color. Lewis received the government contract to construct the lamps and reflectors and install them in America's lighthouses. Additionally he won contracts to construct light stations. Over the years many complaints were lodged about Winslow Lewis's apparatus and his towers. The towers, usually constructed of rubble stone, and with poor mortar, fell down. His parabolic reflectors were described by one inspector as "about as parabolic as a baby's wash tub."







Top — An elaborate array of lamps backed by parabolic reflectors.

Above — The Argand Lamp and parabolic reflector. All drawings on this page from U. S. Lighthouse Society archives.

Lenses

In 1819 a young French engineer, Augustin Fresnel, developed a successful dioptric apparatus or lens. His first lens consisted of dioptric prisms placed above and below bulls eyes. The prisms refracted the light from a central source (the oil lamp) twice into a horizontal pencil beam. This produced a flash as the lens rotated. Because it wasn't practical to use dioptric prisms above a 45 degree angle, Fresnel installed mirrors at the top of the lens apparatus to reflect more of the light to the mariner. This is known as the Dioptric System.

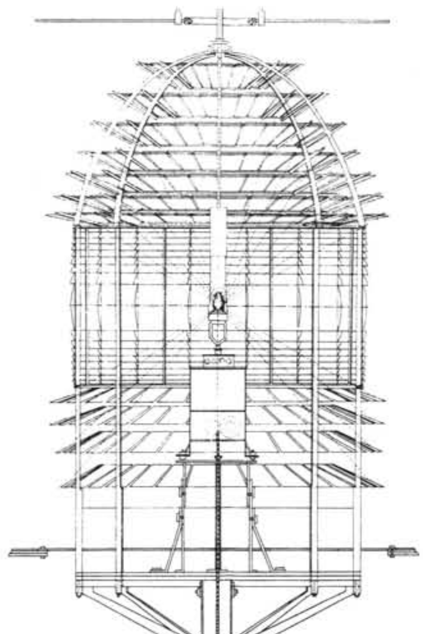
The Fresnel lenses we are familiar with today employ both catadioptric prisms and dioptric prisms. This creates what is known as the Catadioptric System. The first of the modern Fresnel lenses was made in 1842. It was a fixed 3rd Order lens and installed in the Gravelines Lighthouse of France. The following year a 1st Order lens was fitted with catadioptric prisms. The first rotating, or annular, lens was constructed by Henry Lapaute, of Paris, for the Aily Lighthouse.

The catadioptric prisms, installed at the top and bottom of lenses, refract the light from the central lamp to an inside face of the prism. From here the rays are reflected to the front and then refracted again in a horizontal line to the horizon. The development of the catadioptric lens allowed approximately 85% of the light rays to be captured and redirected to the mariner.

At the mid point of the 19th century there were three types of lenses and six orders. The principal manufacturers were Henry Lapaute, Francois Soeil & Tabouret, L. Sautter, Barbier & Fenestre (all from Paris, France), and the Chance Brothers of England. We understand that an Austrian firm also made Fresnel lenses and the Russians state they began making them at the end of the 19th century.

For many years the companies of France furnished the world with lenses, as well as lantern rooms and prefabricated towers. The English firm of Chance Brothers started manufacturing lenses and lighthouse apparatus in 1850. By the end of the century, Chance Brothers was engaged in as much foreign lighthouse construction as the French companies combined. The 19th century and early 20th century lighthouses of Australia, India, several African countries, Japan, and China were all constructed by Chance Brothers. French companies built lighthouses in Greece, Spain, Portugal, Puerto Rico, and several South American countries. Most Fresnel lenses in America are French, but, around the turn of the century, our Lighthouse Service purchased prefabricated lantern rooms from Chance Brothers.

Augustin Fresnel. Photograph courtesy of the Smithsonian Institute.



Fresnel's first lens appeared like this with glass reflectors at the top and bottom in lieu of the catadioptric prisms. Drawing from U. S. Lighthouse Society archives.

Types

Fixed - shows a steady white light all around the horizon. In some cases, where it isn't necessary to provide light in one direction (over land), the prisms of the lens may only extend 180 or 270 degrees around the optic. Often when prisms aren't needed on the land side of the lens, glass or brass reflectors are installed to redirect the light rays back towards sea, providing even more candle power in one sector or direction.

Flashing - a lens consisting of annular, or curved, dioptric and catadioptric prisms, both over and under a bullseye. All the elements focus the light into pencil beams. As the lens rotates, the mariner sees a flash when the center of the bullseye (and its accompanying dioptric and catadioptric prisms) passes his view. Then there is darkness until the next panel passes. A rotating lens may have as few as two back to back panels, termed a clam shell or bivalve lens, or as many as 24 panels. The speed of the optic determines the number of flashes per minute. A 24 panel lens rotating at one half revolution per minute will provide a flash, or characteristic, every 5 seconds.

Some lenses provide unique characteristics — for example, two bullseyes close together produce what is called a group flash. Some lenses have been constructed to furnish a 'numbered' characteristic. Minots Ledge Lighthouse off Cohasset, Massachusetts shows a 1 - 4 - 3 characteristic (one flash, darkness, four flashes, darkness, three flashes, then a long period of darkness before starting over). This has long been known as the "I (1) - Love (4) - You (3)" light.

Fixed Varied with Flash - Type A - A fixed lens showing a steady white light all around the horizon with a flash panel, or several flash panels, mounted on rollers or chariot wheels. When the flash panel passes in front of the mariner, the steady white light becomes an intense flash. The advantage of this lens is that the mariner always has a light in sight, but also sees a characteristic identifying a particular lighthouse.

Fixed Varied with Flash - Type B - A rotating lens with horizontal prisms (a fixed rotating lens) with occasional bullseyes and annular prisms. As the fixed, or horizontal, prisms of the lens rotates, the mariner sees a steady light. When the bullseye portion crosses his vision, he sees a flash.

Means of Rotation

Early lenses revolved on chariot wheels. These were metal wheels situated around the perimeter of the lens approximately 3 inches in diameter. When the Industrial Revolution got up to steam, ball bearings were used. At some point in the mid 19th century, the Chance Brothers of England devised a means of rotating the heavier lenses on beds of mercury.

Colored Lenses

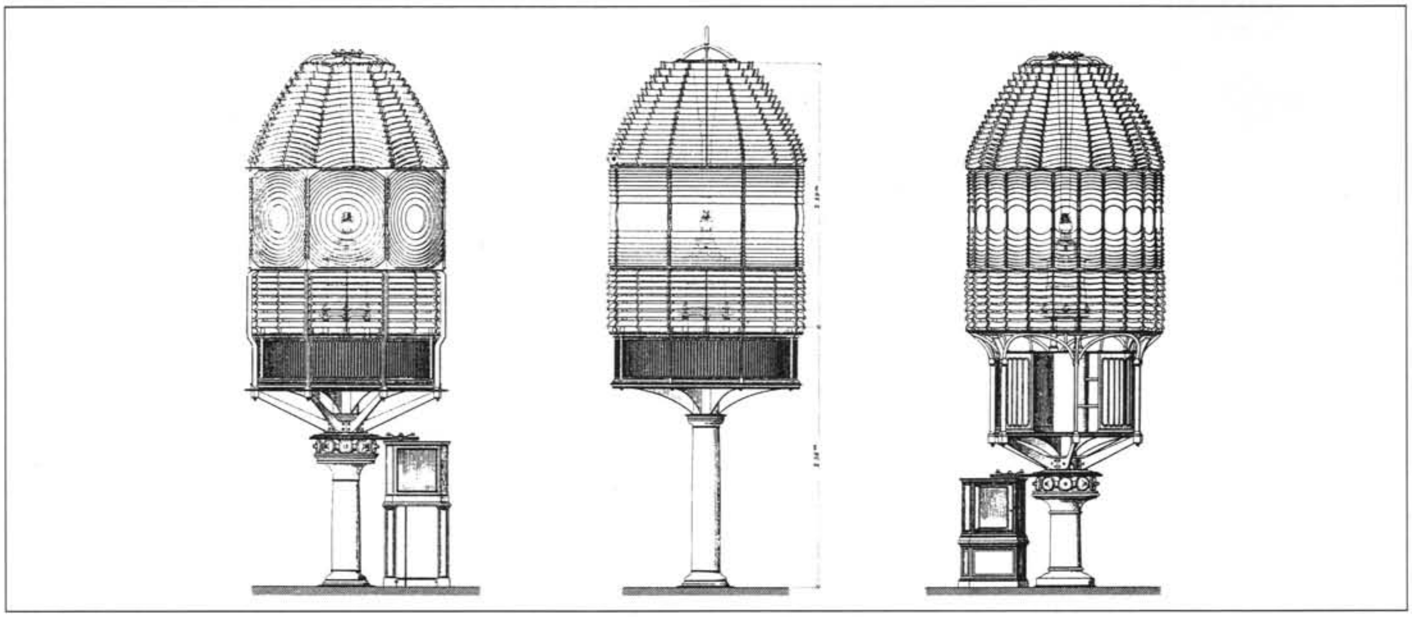
The use of colored lenses was not widely practiced. A red or green lens will lose over 70% of its light strength due to color. In some cases various lighthouse authorities placed color panels, usually red, to show a danger bearing. As the mariner enters a harbor and the normally white light turns to red, he knows he is off course and must adjust to see only the white light again. In a few cases, rotating lenses have been equipped with a red panel over every other flash panel. This provides a characteristic described as a red and white flash. Having the red panel over every third flash panel would provide a characteristic of two white flashes and one red flash. Since a colored lens will not be seen at a great distance, it is usually not used for major seacoast lights. If a colored segment is used in this instance, the Light List will show differing ranges for the colors (i. e. white light visible at 18 miles, red to 14).

Range

Range is determined by candlepower. The lamp providing the light, and the lens redirecting it, provide range. Other elements come into consideration also. First, no matter how powerful a light, it cannot be seen at a great distance if it sits too low to clear the curvature of the earth.

Secondly, the cleanliness of the lens and the lantern room windows come into play. Eight percent of light is lost going into a clear, clean plate of glass and another eight percent is lost coming out. Obviously more light is lost if the glass is dirty.

Thirdly, transmissivity is a factor. Transmissivity is the 'normal' quality of the air in a particular location, during clear periods — without rain, snow, or fog. Areas with that are perfectly clear are assigned a factor of 1. Areas of Lake Superior, away from cities, have a very high percentage of transmissivity. A city like Los Angeles has a low percentage of .60, while Hawaii has a high transmissivity factor of .91. When figuring the range of a particular optic or lens, one multiplies



THE THREE BASIC TYPES OF FRESNEL LENSES

Left — FVF (Fixed Varied with Flash). The bottom, straight catadioptric prisms produce a steady fixed light all around the horizon as the lens rotates. The center bullseyes, flanking dioptric prisms, and upper catadioptric prisms produce a flash when the center of each section passes the mariner's eye. Thus, the mariner sees a steady white light, occasionally interrupted by a flash.

Center — Fixed Lens. This lens produces a steady light all around the horizon.

Right — Flashing lens. The bullseyes and dioptric prisms of the center section and the catadioptric prisms of the top and bottom sections produce a flash as the lens rotates. The lens (or lighthouse) appears dark between flashes.

Note the clockworks mechanisms to the side of the left and right lenses. Descending weights power a clockworks arrangement located in each of the boxes. The left and right lenses rotate on chariot wheels. Other styles of lenses rotate on ball bearings or mercury floats. Drawings from U. S. Lighthouse Society archives.

the candlepower by the transmissivity of the area. A 1,000 candlepower lens at Los Angeles will produce only 600 candlepower. Of course inclement conditions, like rain, drastically reduce the range. Heavy fog cannot be penetrated by even the most powerful optic, hence fog signals and radio beacons.

Fourthly, speed of rotation is a factor. The human eye can detect a lens which rotates slowly and produces a flash every 20 seconds better than a lens rotating quickly and producing and flash every 20 seconds. A slowly revolving lens brings a bit of a 'loom' of light to the viewer before the flash helping the mariner locate the light, as well as seeing it at a greater distance.

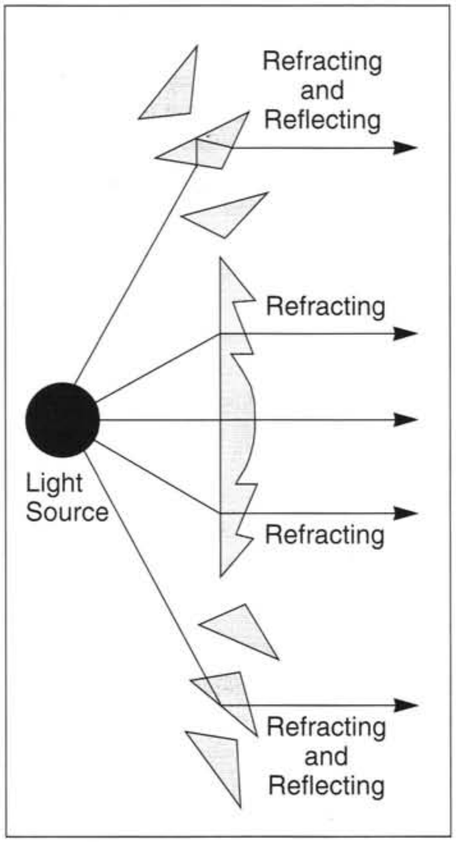
Lens Orders (sizes)

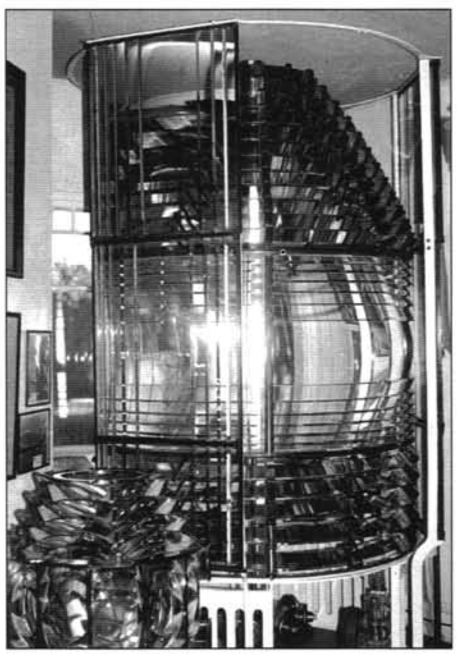
Six sizes of lenses, or Orders, were settled on at some point around the middle of the 19th Century. The 1st Order was the largest, and most powerful, and the 6th the smallest. A 1st Order lens is slightly over 6 feet in diameter and the prisms are approximately 10´ feet high (1st Orders do vary in height). With the pedestal and clockworks an entire 1st Order apparatus stands about 19 feet high. The 6th Order has a diameter of 12 inches and is 18 inches high.

Most manufacturers realized a need for a lens less powerful (and less expensive) than a 3rd Order and more powerful than a 4th Order. Thus a 3´ Order was created. The French designated them 3rd Order large, 3rd Order small. At some point toward the end of the 19th Century, the Chance Brothers developed a meso-radial lens with a diameter of 7´ feet and a hyper-radial lens with a diameter of 8' 10". Although very few meso-radials were constructed, several hyper-radials were made and installed at significant points of land like Cape Race, Newfoundland and Makapuu Point, Oahu, Hawaii.

Classes of Lighthouses

Lighthouses may be roughly divided into groups indicating their function. Like lightships, some lighthouses are situated in areas where their signal is intended to show danger, while others invite the mariner to enter (i. e. "this is Boston Harbor"). And, of course, some lighthouses may be situated to perform several functions.





A 2nd Order Fresnel lens from the Petit Manan Lighthouse at the Shore Village Museum in Rockland, Maine. In the case of this FVF lens, three tall panels (one can be seen at left) rotate around the stationary lens. Thus, the characteristic is a steady white light, interrupted by a flash every two minutes. The smaller lens to the left is a 4th Order flashing lens. Photograph by Ken Black courtesy of the Shore Village Museum.

<u>Landfall, or Making, Lights</u> - are those the mariner first sees when approaching a country from overseas. These lighthouses are equipped with the most powerful lenses, 1st or 2nd Order.

<u>Warning Lights</u> - are to announce a reef or shallow water. The lenses may be powerful, but usually are the middle range, 3rd and 4th Orders.

<u>Coasting Lights</u> - are lights the mariner uses to "fix" his position as he navigates along the coast. Usually coasting lights are situated so a mariner may take a bearing on two or three at one time.

<u>Leading Lights</u> - are lights showing the entrance to a harbor or channel. Usually leading lights are Range Lights — two towers placed one behind the other, the rear being taller than the front. The mariner lines up the towers, or their lights, so that one appears over the other. He then knows he is in the middle of the channel or properly positioned to enter a harbor. The geography of several ports in the Great Lakes does not allow the placement of range lights to show the center of the entrance. In those cases the range lights are situated along one of the entrance breakwaters. This requires the mariner to "leave" the range at some point and maneuver into the channel, lest he plow into the breakwater. 4th and 5th Order lenses are usually used for Leading or Range Lights.

<u>Port or Entrance Lights</u> - are small or minor optic (5th and 6th Order) lenses marking the ends of piers.

A particular lighthouse may serve several functions. It may be an entrance light and still warn of a shoal with the addition of a red sector showing where the bad water is.

The State of Maine, with all the off shore islands, the bays, nooks and crannies, is suited for lighthouses with smaller lenses needing only to be seen 8 to 12 miles — 4th and 5th Order lenses. Similarly most of the lighthouses of the Great Lakes were small one family stations equipped with 4th or 5th Order lenses. The North Carolina Outer Banks and most west coast stations were furnished 1st Order lenses.

Illuminants

As mentioned earlier, various combustibles were used over the years: bales of oakum and pitch, wood, coal, candles, gas, and various oils. Oils came into their heyday about 1800. Although various fish oils were used prior to that date, spermaceti (whale) oil became the oil of choice. With the developing Industrial Revolution and an increasing need for lubrication, the price of whale oil skyrocketed, going from about 34¢ per gallon in the 1840s to $2.54 per gallon in the 1850s. Lighthouse authorities scrambled for a substitute. America tried porpoise oil, olive oil, and colza or rape seed (a wild cabbage). Colza looked promising but the government was unsuccessful in convincing farmers to grow it in ample supplies. Our service decided on lard oil, at 89¢ per gallon.

The French conducted extensive studies of the various oils in the 1860s. As might be expected, they found each oil had its good and bad points: some were more expensive, some provided a better light or a long duration, etc.

They experimented with cocoanut, olive, spermaceti (sperm whale), English colza, French colza, whale (other than spermaceti) and arachide (peanut) oils. In terms of combustion duration, cocoanut oil proved best, followed by peanut and sperm whale oils. In terms of light intensity for a single wick lamp, olive oil was best, followed by cocoanut and sperm whale oils. For a multi wick lamp, cocoanut was best, followed by the two colzas and olive oil. In resistance to congealing both colzas topped the list, followed by whale oil. The cost factor showed whale oil being the cheapest, followed by colza, cocoanut, peanut, and olive oil. Spermaceti was listed as the most expensive, which was the reason for the study in the first place. The French, like the English, chose colza.

Gas was used at a few lighthouses in England and Ireland in the 19th century and at two lighthouses in this country for a very short period: Presque Isle, Pennsylvania and Beavertail, Rhode Island.

As early as 1858 Trinity House (in charge of British lighthouses) installed an electric light at their South Foreland Light Station. Electric generators were installed and the light was produced by a carbon arc lamp. Their Dungeness station was electrified from 1862 until 1874 when oil was substituted for electricity. In 1865 the French experimented with electricity at their La Harve Lighthouse. However, the 1870s brought earth oil, or kerosene, to the fore and it became the illuminant of choice (called paraffin by the English).

Although electricity was introduced into some American lighthouses around the turn of the century (the first use of electricity in America was at the Navesink Lighthouse near Sandy Hook, New Jersey in 1898), the development of the Incandescent Oil Vapor (IOV) lamps held off electrical installations at many stations. The IOV system mixed kerosene with air, under pressure, creating a fine, volatile mist that soaked a mantle, much like the present day Coleman lantern used in camping. This system produced a brilliant, steady white light and was easily learned by the keepers.

At remote sites, where it would have been prohibitively expensive to install electric power lines, an electric generation system would have to be installed to provide electricity. This system would have been more difficult to learn and to operate. Some American lighthouses are said to have had no electricity as late as 1951.

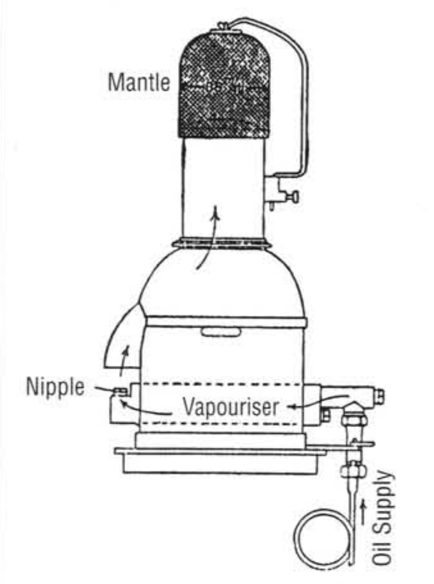
When the world started changing from the multi lamp parabolic reflector system to the single lamp Fresnel Lens system, new lamps had to be devised. As the types of oils used changed, those lamps had to be modified.

There were three basic types of lamps. The first, and simplest, was a capillary action lamp. This type was even used back in the 18th century when solid wicks were placed in oil and capillary action drew the oil up the wick. Some small order Fresnel lenses (5th and 6th Orders) used capillary action style lamps with single hollow wicks.

The second type was the constant level lamp. By placing the oil reservoir above the wick, gravity was used to keep the oil level constant. At the top of the reservoir was an air hole that could be adjusted to control the speed, or amount, of the oil flow.

The third type of lamp employed was the mechanical moderator lamp. This lamp was mostly used in 1st, 2nd, and 3rd Order lenses. It employed a large oil tank (about five gallons) under the lamp. A weighted plunger in the tank pushed the oil out a small tube at the bottom and up to the wicks — usually four concentric wicks for a 1st Order lens. A valve was regulated so that three times as much oil passed through the wicks as was burned. Excess oil dripped back down a tube into the oil tank. When the plunger reached bottom it was wound back up by means of a chain and crank.

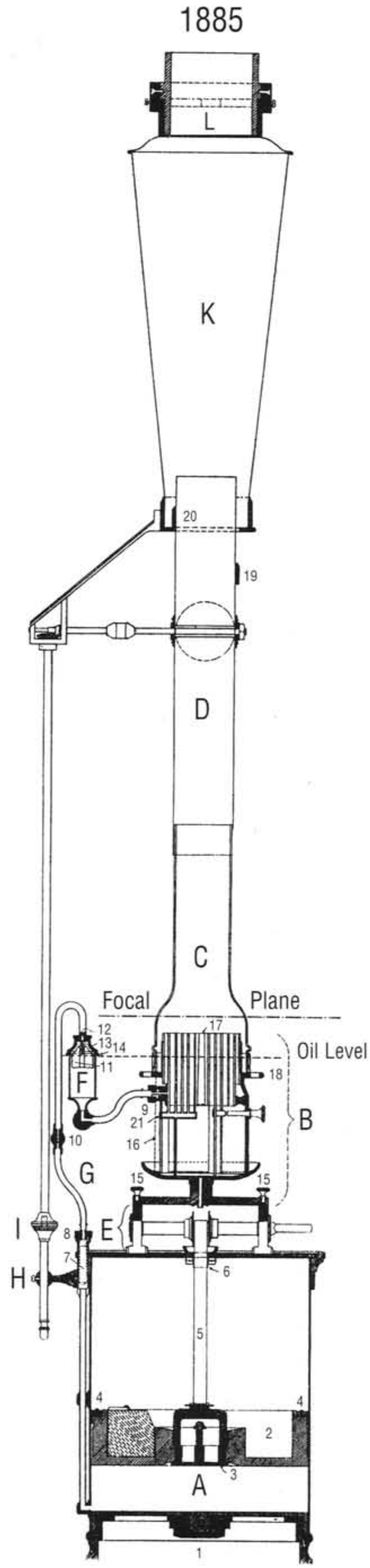
A rare whale oil fueled spider lamp. The capillary action of the solid cotton wicks brought oil from the container to the flame. Photograph courtesy of the Shore Village Museum.



The I.O.V. (Incandescent Oil Vapor) lamp. Drawings from U. S. Lighthouse Society archives.

Legend to Drawing At Right

A	Supply Reservoir
B	Burner
C	Chimney
D	Damper Tube
E	Bridge
F	Float Chamber-Brass
G	Supply Tube
H	Holder To Damper Attachment
I	Damper Attachment
K	Connecting Tube
L	Crown Piece
1	Tripod
2	Plunger
3	Plunger Valve
4	Packing Ring
5	Chain
6	Chain Guide Roller
7	Supply Tube Strainer
8	Supply Tube Nut
9	Burner Nut
10	Faucet
11	Float
12	Float Pin
13	Float Support
14	Float Chamber Cap
15	Burner Screws
16	Gauze
17	Conical Air Tube
18	Chimney Holder
19	Damper Tube Locks
20	Damper Tube Locks
21	Cleaning Tube Nut



After the Fresnel lens came into use in 1822, most European countries adopted it. Our Lighthouse Service, under the 5th Auditor of the Treasury, Stephen Pleasonton, continued to use the Argand lamp backed by reflectors. Mr. Pleasonton thought the Fresnel type lens too expensive. The Fresnel lens was, in the long run, far less expensive than a multiple array of reflectors. One lamp, in lieu of 24 or more for a major seacoast light, meant less oil. Also the Fresnel lens would, with proper care, last forever. The reflectors, with constant polishing, had the silver plating worn off and also became bent out of shape — if they were ever parabolic to begin with.

Consumption of oil per year
1st Order lamps - 2,300 gallons
2nd and 3rd Order lamps - 685 gallons
3½ Order lamps - 286 gallons
4th Order lamps - 243 gallons
5th and 6th Order lamps - 155 gallons

As you can see, the amount of oil used drastically drops as smaller lamps are used in the smaller lenses.

After American mariners had navigated in European waters under the "bright lights" of the Fresnel system they clamored for improvements to the woeful American lighthouses. But Pleasonton remained adamant, even in the face of several Congressional investigations. Finally, the hue and cry grew so loud that an ad hoc committee, called the U. S. Lighthouse Board, was formed. For over a year they investigated aids to navigation systems all over the world and conducted inspection of our light stations. What they found wasn't a pretty sight. "Keeper, a retired blacksmith, doesn't think it's necessary to light the lamps until it gets good and dark," "keeper absent, 12 year old boy in charge," "lantern leaks, house needs paint, no spare lamps on hand" and on and on.

Stephen Pleasonton was removed and the Board became the ruling body of the Lighthouse Service. Keepers after 1852, when the Board was made official, had to be able to read and write. Instructions were issued and, best of all, the Fresnel lens was adopted. By the outbreak of the Civil War all American lighthouses had Fresnel lenses in their lantern rooms.