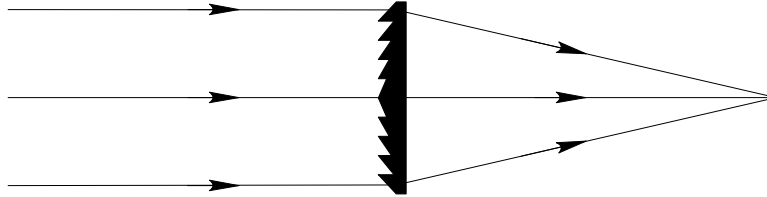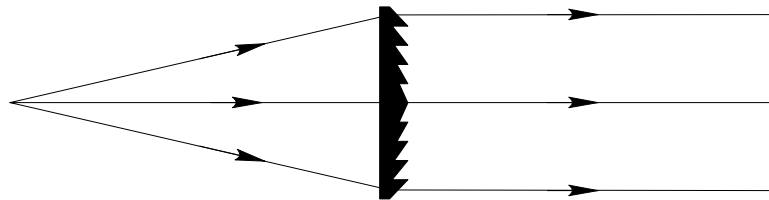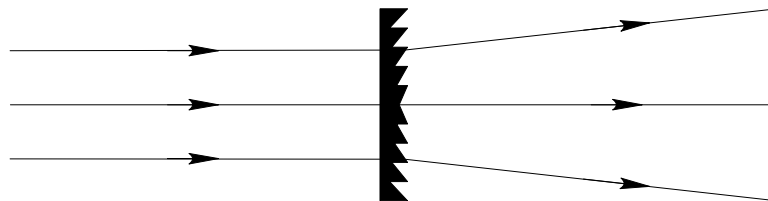# FRESNEL LENSES

Positive Focal Length Fresnel Lens Used as a Collector

Positive Focal Length Fresnel Lens Used as a Collimator

Negative Focal Length Fresnel Lens Used as a Diverger

# HIGH QUALITY FRESNEL LENSES IN A VARIETY OF SIZES & FOCAL LENGTHS

The Fresnel Lens

Centuries ago, it was recognized that the contour of the refracting surface of a conventional lens defines its focusing properties. The bulk of material between the refracting surfaces has no effect (other than increasing absorption losses) on the optical properties of the lens. In a Fresnel (point focus) lens the bulk of material has been reduced by the extraction of a set of coaxial annular cylinders of material, as shown in Figure 1. (Positive focal length Fresnel lenses are almost universally plano-convex.) The contour of the curved surface is thus approximated by right circular cylindrical portions, which do not contribute to the lens' optical properties, intersected by conical portions called "grooves." Near the center of the lens, these inclined surfaces or "grooves" are nearly parallel to the plane face; toward the outer edge, the inclined surfaces become extremely steep, especially for lenses of low f–number. The inclined surface of each groove is the corresponding portion of the original aspheric surface, translated toward the plano surface of the lens; the angle of each groove is modified slightly from that of the original aspheric profile to compensate for this translation.

The earliest stepped-surface lens was suggested in 1748 by Count Buffon, who proposed to grind out material from the plano side of the lens until he was left with thin sections of material following the original spherical surface of the lens, as shown schematically in Figure 2a). Buffon's work was followed by that of Condorcet and Sir D. Brewster, both of whom designed built-up lenses made of stepped annuli. The aspheric Fresnel lens was invented in 1822 by Augustin Jean Fresnel (1788–1827), a French mathematician and physicist also credited with resolving the dispute between the classical corpuscular and wave theories of light through his careful experiments on diffraction. Fresnel's original lens was used in a lighthouse on the river Gironde; the main innovation embodied in Fresnel's design was that the center of curvature of each ring receded along the axis according to its distance from the center, so as practically to eliminate spherical aberration. Fresnel's original design, including the spherical-surfaced central section, is shown schematically in Figure 2b). The early Fresnel lenses were cut and polished in glass – an expensive process, and one limited to a few large grooves. Figure 3 shows a Fresnel lens, constructed in this way, which is used in the lighthouse at St Augustine, Florida, USA. The large aperture and low absorption of Fresnel lenses were especially important for use with the weak lamps found in lighthouses before the invention of high-brightness light sources in the 1900s. The illustrated system is catadioptric: the glass rings above and below the Fresnel lens band in the center of the light are totally-internally-reflecting prisms, which serve to collect an additional fraction of the light from the source. The use of catadioptric systems in lighthouses was also due to Fresnel.

Until the 1950's, quality Fresnel lenses were made from glass by the same grinding and polishing techniques used in 1822. Cheap Fresnel lenses were made by pressing hot glass into metal molds; because of the high surface tension of glass, Fresnel lenses made in this way lacked the necessary detail, and were poor indeed.

In the last forty years or so, the advent of optical-quality plastics, compression and injection molding techniques,
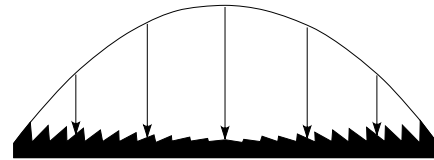
Figure 1 Construction of a Fresnel lens from its corresponding asphere. Each groove of the Fresnel lens is a small piece of the aspheric surface, translated toward the plano side of the lens. The tilt of each surface must be modified slightly from that of the original portion of aspheric surface, in order to compensate for the translation.

a)   b)
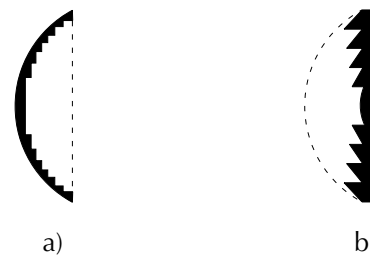
Figure 2 Early stepped–surface lenses. In both illustrations the black area is material, and the dashed curves represent the original contours of the lenses. a) shows the lens suggested by Count Buffon (1748), where material was removed from the plano side of the lens in order to reduce the thickness. b) shows the original lens of Fresnel (1822), the central ring of which had a spherical surface. In Fresnel's lens, the center of curvature of each ring was displaced according to the distance of that ring from the center, so as to eliminate spherical aberration.
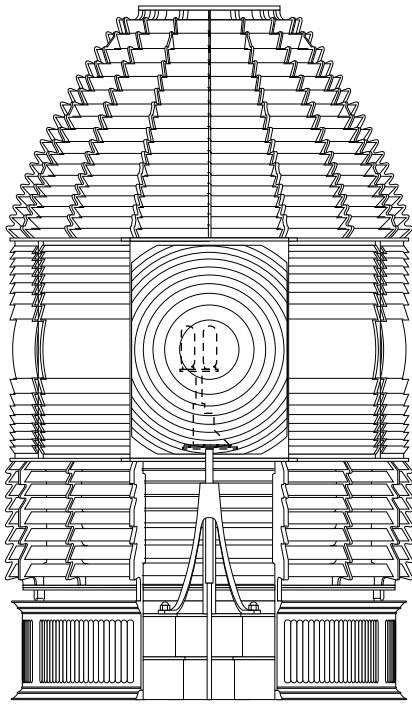
Figure 3 The light from the St Augustine, Florida (USA) light-house, showing the glass Fresnel optical system used in the lighthouse. The optical system is about 12 feet (3.5 m) tall and 7 feet (2 m) in diameter.
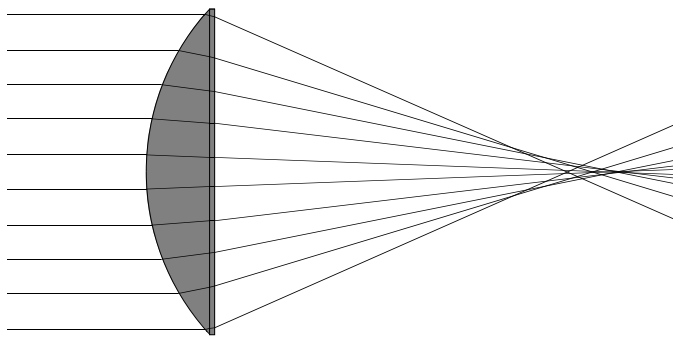
Figure 4 Illustration of longitudinal spherical aberration. The rays shown were traced through an *f*/1.3 spherical-surface lens; the focus is evidently spread out over a considerable distance along the optical axis.

and computer-controlled machining have made possible the manufacture and wide application of Fresnel lenses of higher optical quality than the finest glass Fresnel lenses. Modern computer-controlled machining methods can be used to cut the surface of each cone precisely so as to bring all paraxial rays into focus at exactly the same point, avoiding spherical aberration. Better still, newer methods can be used to cut each refracting surface in the correct aspheric contour (rather than as a conical approximation to this contour), thus avoiding even the width of the groove (typically 0.1 to 1 mm) as a limit to the sharpness of the focus. Even though each groove or facet brings light precisely to a focus, the breaking up of the wavefront by the discontinuous surface of a Fresnel lens degrades the visible image quality. Except in certain situations discussed later, Fresnel lenses are usually not recommended for imaging applications in the visible light region of the spectrum.

The characteristics of the aspheric "correction"
The grinding and polishing techniques used in the manufacture of conventional optics lead to spherical surfaces. Spherical surfaces produce optics with longitudinal spherical aberration, which occurs when different annular sections of the optic bring light rays to a focus at different points along the optical axis. This phenomenon is illustrated for a positive focal length, plano-convex conventional lens in Figure 4 (in all optical illustrations in this brochure, light is taken to propagate from left to right). The lens illustrated is a section of a sphere with 1" (25 mm) radius of curvature, 1.6" (36 mm) in diameter; the index of refraction of the material is 1.5, typical both for optical glasses and for our plastics materials. The focal length of the illustrated lens is thus 2" (50 mm), and the aperture is *f*/1.3. As is evident from the figure, the longitudinal spherical aberration is very strong. Single-element spherical lenses are typically restricted to much smaller apertures (higher *f*–numbers) than this, because longitudinal spherical aberration of the magnitude shown in Figure 4 is generally unacceptable. Figure 5 shows an aspheric lens of the same focal length and *f*–number; note that the surface contour is modified from the spherical profile in such a way as to bring rays passing through all points on the lens to a focus at the same position on the optical axis. A lens made with the aspheric profile illustrated in Figure 5, therefore, exhibits no longitudinal spherical aberration for rays parallel to the optical axis.

Since Fresnel lenses are made from the beginning to the correct aspheric profile, the notion of "correcting for spherical aberration" is not meaningful for Fresnel lenses. The lenses are more accurately characterized as "free from spherical aberration." The combination of the aspheric surface (which eliminates longitudinal spherical aberration) and the thinness of the lens (which substantially reduces both absorption losses in the material and the change of those losses across the lens profile) allows Fresnel lenses with acceptable performance to be made with very large apertures. In fact, Fresnel lenses typically have far larger apertures (smaller *f*–numbers) than the *f*/1.3 illustrated in Figure 4.

Figure 6 compares an aspheric plano-convex lens with an aspheric Fresnel lens (the Fresnel lens' groove structure is

3

highly exaggerated in all the illustrations). The conventional asphere is characterized by two principal planes; an effective focal length (EFL), f, measured from the principal plane nearer the plano side; and a back focal length, f_b, measured from the plano side of the lens. In a plano-convex Fresnel lens, the separation between the principal planes is inconsequential, so that f is measured from the grooved surface of the Fresnel lens.

Many of the spherical-surface lenses in common use are biconvex, often with the same curvature on the two sides. Such lenses exhibit substantial spherical aberration, and other aberrations as well, but are symmetric in their properties. In almost all instances, Fresnel lenses are plano-convex. This fact, along with their aspheric profiles and their low f–numbers, leads to strongly asymmetric behavior. Figure 7 shows a typical Fresnel lens – one correct for the case of grooves toward a collimated beam, plano side toward the focus. (This type of Fresnel lens is referred to as grooves "out." The terminology arises from the use of a Fresnel lens to focus energy on a detector inside a box, since in this case the grooves are on the outside of the box.) The figure depicts the two possible orientations of the lens; that is, proper application and reversed.

Conjugates and orientation of Fresnel lenses

The two points, one on either side of a positive focal length lens, at which light is focused are called "conjugates." Nearly all the Fresnel lenses in Fresnel Technologies' catalog are correct for the case of conjugates of the focal length and infinity, with the grooved side toward the infinite conjugate. Our #0.1, however, is correct for conjugates of the focal length and infinity, with the infinite conjugate on the smooth side. There are many cases which require conjugates other than the focal length and infinity – copy lenses, relay lenses, field lenses, and condenser lenses are common examples. In these cases both of the foci are at finite distances from the lens; hence the term "finite conjugates." Several of our Fresnel lenses are correct for finite conjugates, and are so indicated in the table of specifications. Most of these are correct for conjugates in the ratio 3:1, with the grooved side toward the longer conjugate. The values of the conjugates for a given focal length f may be determined from the equation $1/f = 1/i + 1/o$ (where i and o are the image and object distances, i.e. the conjugates), and are found to be $4f$ and $4f/3$ for the conjugate ratio 3:1. Even though a lens may be designed for conjugates in some particular ratio, it can be used at other finite conjugate ratios as well. The error introduced is usually reasonably small.

Fresnel lenses are normally fabricated so that they are correct for the case of grooves toward the collimated beam, plano side toward the focus (grooves "out"). They can, however, be fabricated so that they are correct for the case of grooves toward the focus, plano side toward the collimated beam (grooves "in"). In this case, there is no refraction at all on the plano side for a collimated beam traveling parallel to the optical axis. In the grooves "out" case, both surfaces refract the light more or less equally. The case of grooves toward the collimated beam ("out") is the optically preferred case. The main difference is that in the grooves "in" case, the grooves at the outer periphery of the lens are canted at much
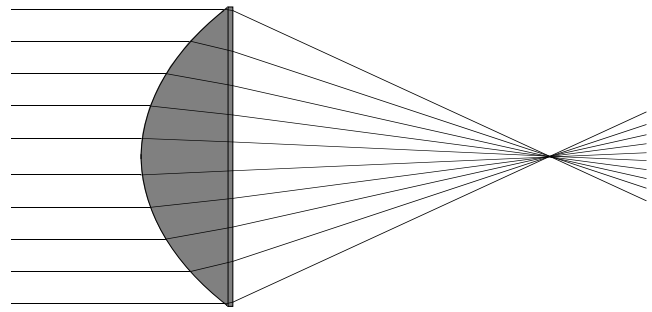
Figure 5 Illustration of the superior focus of an aspheric lens. The lens shown has the same focal length and aperture as the spherical lens shown in Figure 4, yet longitudinal spherical aberration is entirely absent. Note that it is possible even to make aspheric lenses with f–numbers smaller than one.
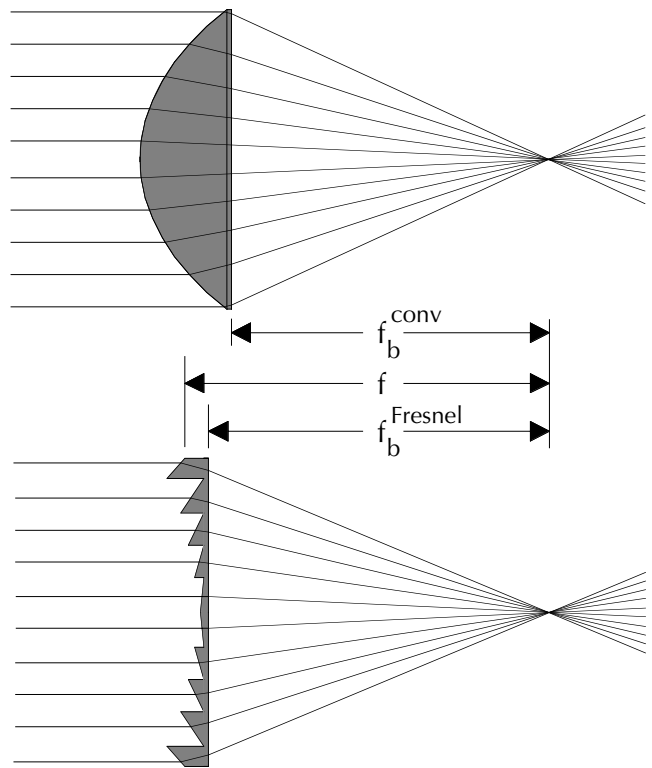
Figure 6 Comparison between an aspheric conventional lens and an aspheric Fresnel lens, illustrating the optical quantities discussed in the text.

smaller angles to the plano surface than they would be in spherical or grooves "out" lenses. Because the angles made with the plano surface are relatively small toward the periphery of the lens, any small warpage or tilt of the lens surface, or any small deviation of a light ray from parallelism with the optical axis, leads to a very large deviation from the ideal in the angle between the light ray and the lens surface. These errors lead directly to a decrease in the collection efficiency of a grooves "in" lens relative to a grooves "out" lens of the same focal length and f–number.

A third case which is sometimes encountered is that of a Fresnel lens which is correct for grooves "out," used with its grooves toward the focus (grooves "out" turned grooves

"in"). In this case, the focal length of the lens is shortened somewhat due to the larger groove angles of a grooves "out" lens, and the off-axis behavior of the lens is improved somewhat. The improvement in off-axis behavior comes directly from the effect discussed above: the larger groove angles of the grooves "out" lens make it less susceptible to small misalignments than the equivalent grooves "in" lens. As always, a compromise is necessary. In the case of a grooves "out" lens turned grooves "in," rays traveling through the lens at large distances from, but parallel to, the optical axis may be totally internally reflected. (Total internal reflection occurs for angles of intersection between a light ray and the normal to a surface larger than the critical angle $\theta_c = \sin^{-1}(n/n')$, where the ray is traveling from a medium of index of refraction n into a medium of index of refraction n'. It is evident that total internal reflection only occurs for $n' > n$, since in the case $n' < n$ θ_c is greater than $\pi/2$ and therefore not physically meaningful.) This phenomenon makes the portion of a grooves "out" lens turned grooves "in" lens past about $f/1$ useless. The phenomenon is easily observed as an apparent "silvering" of the outer portion of a grooves "out" lens when its grooves are turned to face the shorter conjugate. Total internal reflection does not occur for grooves "out" lenses used in their correct orientation because the only large-angle intersection between the light and the lens surface occurs at a transition from low to high refractive index.

Figure 7 Illustration of the strong asymmetry of the aspheric Fresnel lens. The illustrated lens is correct for the grooves facing the longer conjugate (grooves "out"). When it is turned around so that the grooves face the shorter conjugate (grooves "out" turned grooves "in"), on-axis performance suffers. As discussed in the text, however, in the case where the grooves must face the shorter conjugate, a grooves "out" lens turned grooves "in" has some advantages over a lens correct for grooves "in."
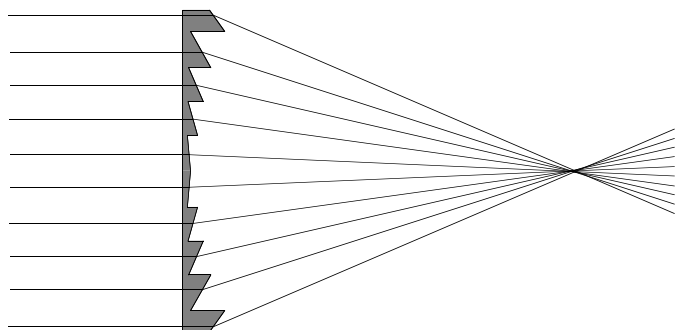
Figure 8 Aspheric Fresnel lens correct for the grooves facing the shorter conjugate (grooves "in").

Materials
Our standard materials for visible light applications are acrylic, polycarbonate and rigid vinyl. These materials are suitable for some near infrared applications as well, as discussed later in this brochure. Figure 9 shows useful transmission ranges for a variety of plastics materials. Materials suitable for infrared applications are described in detail in our POLY IR® brochure.

The first step in choosing a material is to match the material to the spectral domain of the application. Other considerations include thickness, rigidity, service temperature, weatherability, and other physical properties listed in the table of properties on the next page.

Acrylic
Optical quality acrylic is the most widely applicable material, and is a good general-purpose material in the visible. Its transmittance is nearly flat and almost 92% from the ultraviolet to the near infrared; acrylic may additionally be specified to be UV transmitting (UVT acrylic) or UV filtering (UVF acrylic). The transmittance of our standard acrylic materials between 0.2 µm and 2.2 µm is shown in Figure 10 for a thickness of 1/8" (3.2 mm). Standard acrylic thicknesses are 0.060" (1.5 mm), 0.090" (2.3 mm), and 0.125" (3.2 mm).

Rigid vinyl
Rigid vinyl has a number of characteristics which make it both affordable and very suitable for certain applications. It has a high index of refraction; it is reasonably inexpensive; and it can be die-cut. However, polycarbonate has very similar properties, without the problems associated with rigid vinyl, and its use is encouraged over that of rigid vinyl in new applications. Rigid vinyl has about the same temperature range as acrylic and is naturally fire-retardant. The transmittance of rigid vinyl between 0.2 µm and 2.5 µm is shown in Figure 11 for a nominal thickness of 0.030" (0.76 mm). Standard thicknesses for rigid vinyl are 0.010" (0.25 mm), 0.015" (0.38 mm), 0.020" (0.51 mm), and 0.030" (0.76 mm).

Polycarbonate
Polycarbonate is spectrally similar to acrylic, but is useful at higher temperatures and has a very high impact resistance. The transmittance of polycarbonate between 0.2 µm and 2.2 µm is shown in Figure 12 for a nominal thickness of 1/8"

UVT acrylic

polycarbonate

general purpose acrylic

rigid vinyl

UVF acrylic

POLY IR® 6

POLY IR® 5

POLY IR® 1,2

POLY IR® 4 ,7

POLY IR® 3

| 200 nm | 400 nm | 750 nm | 1 µm | 3 µm | 10 µm | 30 µm | 40 µm |

| Ultraviolet | Visible | Near Infrared | Middle Infrared | Far Infrared |
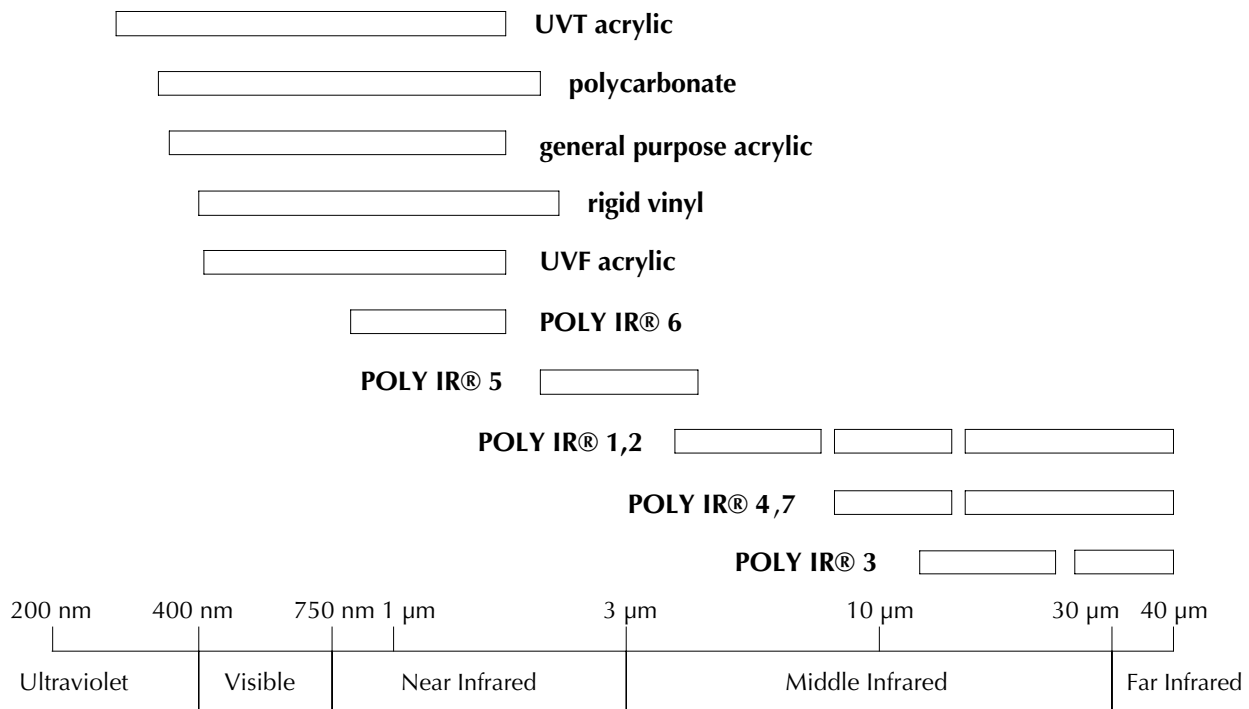
Figure 9 Useful transmission ranges for various plastics materials. Note that the wavelength scale is logarithmic. For acrylics, polycarbonate, and rigid vinyl in our standard thicknesses, the transmittance is greater than 80% in the indicated wavelength ranges. For POLY IR® materials in our standard thicknesses, average transmittance typically varies from 40% to 90% in the indicated wavelength ranges. For the POLY IR® materials, gaps in the ranges indicate the presence of strong infrared absorptions. Please see our brochure on the POLY IR® materials for more spectral details.

	Acrylic	Rigid vinyl	Polycarbonate
Index of refraction	1.49	1.54	1.586
Tensile modulus (10^3 PSI)	325—470	350—600	345
Flexural modulus (10^3 PSI)	390—470	300—500	340
Hardness	M80–M100 (Rockwell)	D65–85 (Shore)	M70–M72 (Rockwell)
Thermal expansion (10^{-6}/°C)	76	76	68
Service temp., °C	80	70	120
Specific gravity	1.19	1.45	1.20
Effect of sunlight	none	yellows	yellows slowly

Physical properties of some materials available from Fresnel Technologies, Inc.
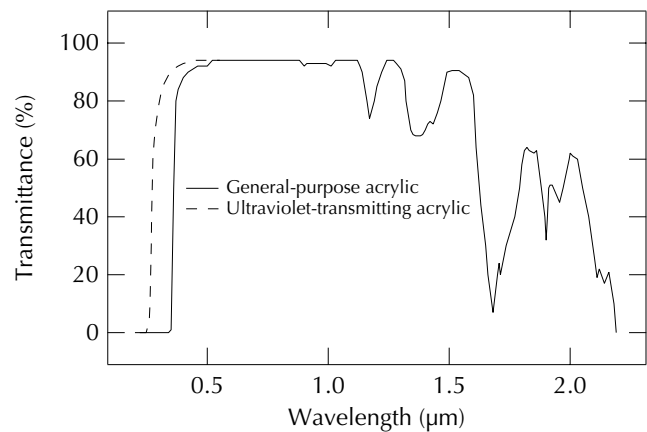
Figure 10 Transmittance of general purpose acrylic and ultraviolet transmitting acrylic as a function of wavelength. Sample thickness =1/8" (3.2 mm) nominal.
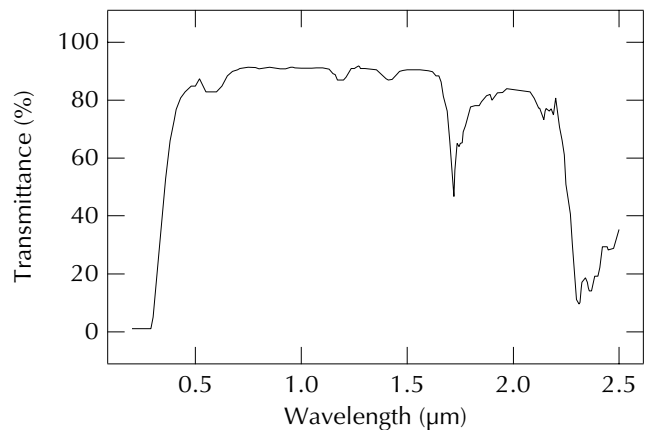
Figure 11 Transmittance of rigid vinyl as a function of wavelength. Sample thickness = 0.030" (0.76 mm) nominal, 0.028" actual.
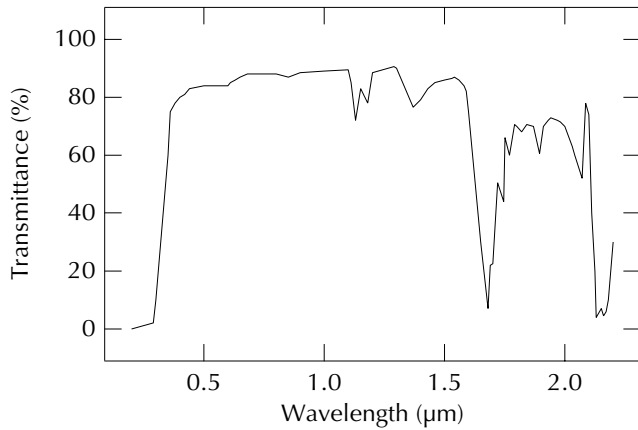
Figure 12 Transmittance of polycarbonate as a function of wavelength. Sample thickness = 1/8" (3.2 mm) nominal.
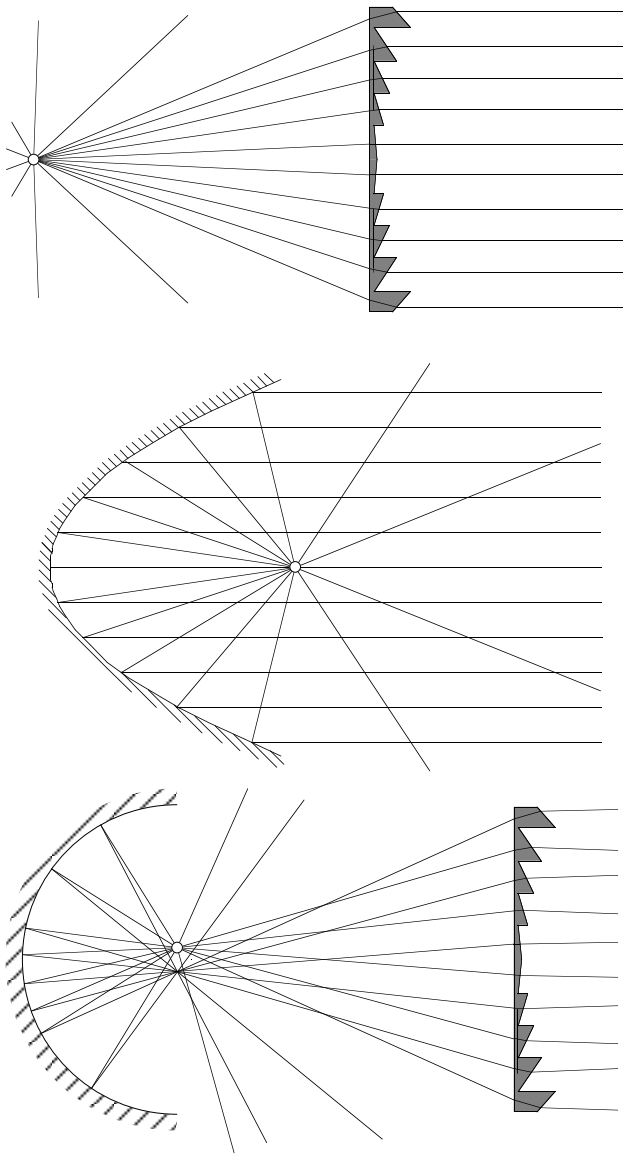
Figure 13 The three typical configurations for producing a collimated beam of light: lens only, mirror only, and a combination of lens and mirror.

(3.2 mm). Standard thicknesses available in polycarbonate are 0.010" (0.25 mm), 0.015" (0.38 mm), 0.020" (0.5 mm), 0.030" (0.76 mm), 0.040" (1 mm), 0.050" (1.3 mm), 0.060" (1.5 mm), and 0.125" (3.2 mm).

Focal length in a given material

The focal lengths listed in the table at the end of this brochure are the effective focal lengths in optical grade acrylic. The effective focal length is different when a lens is manufactured from a different material, but is easily calculated. The effective focal length in any other material is

$$EFL = \frac{1.49 - 1}{n - 1} EFL_{acrylic} \quad ,$$

where n is the refractive index of the material in question.

Typical Fresnel Lens Applications

Collimator

Producing a collimated beam from a point source could be said to be a perfect application for Fresnel lenses. In this case the spatial distribution of light from the point source tends to favor the central portion of the lens, so that the total lens transmittance can be as much as 90%. The best optical results are obtained when the grooved side faces the longer conjugate.

In practice, the point source is never actually a point source, but is extended, so that the imperfection of the conical approximation to the aspheric groove shapes is never noticed.

Figure 13 shows the three cases usually encountered in collimation: lens only, mirror only, and lens/mirror combination. Note that adding a lens to the mirror-only case would produce extremely poor results. The mirror must be specially designed to image the light source very near itself.

Collector

Focusing a collimated beam of light at a point is another popular use of Fresnel lenses, and one for which Fresnel lenses are at least adequate. Again, the grooved side toward the infinite conjugate is the optically preferred configuration. Because the collimated beam is assumed to be uniform, there is a substantial loss through the lens in this case for marginal rays. The loss is caused by the increasing angles of incidence and emergence as the margin of the lens is approached. It can be predicted using Fresnel's equations, which describe the reflection and transmission of light at an interface between media of differing refractive index. The loss due to reflection is graphed as a function of the angle between the incident ray and the (plane) interface in Figure 14.

There are two additional losses which must be considered in demanding applications. One is due to the unavoidable width of the vertical step between grooves. This loss is generally reasonably small in well-made Fresnel lenses, but light scattered from the step brightens the focal plane and thereby reduces the contrast of an image.

The other loss is due to shadowing and blocking effects caused by the vertical step. This loss does not exist for rays parallel to the optical axis striking grooves "in" lenses, but is present in all other cases. For rays making a large angle (20°

or greater) with the optical axis, it can be the most significant loss. Furthermore, blocked rays are also likely to increase the overall brightness of the focal plane.

These losses must be evaluated by considering in detail the geometry of the lens and its relationship to the focal plane and the incoming rays. Fresnel Technologies, Inc. has had substantial experience in solving problems of this sort, and invites your inquiries.

Condenser

This application usually demands a lens designed for finite conjugates, although it is often optically so undemanding that a lens made for conjugates of the focal length and infinity will work as well. It calls for focusing a light source within a projection lens. Typical examples include overhead projector lenses and the condensers of slide projectors. The lamps usually have large filaments, and the projection lenses are large as well. Occasionally, in order to make the filament structure less obvious in the projected image, the condenser lens will even be frosted.

The optical designer may sometimes be called upon to use a condenser lens which is impractically "fast" – that is, its diameter is greater than twice its focal length ($<f/0.5$). In this case, it is possible to pair two Fresnel lenses, grooves together, to form a two-lens element with a focal length equal to the geometric mean of the two focal lengths used in the pair. The lenses in this pair must individually be correct for conjugates of their focal length and infinity, with the infinite conjugate on the grooved side. Extreme care must be taken to ensure that the lenses have exactly the same groove density and that they are well centered with respect to each other, or moiré patterns will degrade the function of the combined lens. The paired Fresnel lens will always be correct for finite conjugates, and the conjugates will simply be the focal lengths of the individual lenses. The focal lengths need not be equal, so that conjugate ratios other than 1:1 are easily achieved. It is impossible, however, for the paired lenses to be correct for conjugates of the focal length and infinity; that would require that one "lens" be simply a plano–plano sheet.

Field lenses (Fresnel screen "brighteners")

A Fresnel lens can be used to redirect the light at the edges of a frosted rear-projection display screen toward the viewer's eyes, thus eliminating the "hot spot" often observed in such screens by brightening the edges of the display. Screens of this type include camera focusing screens. The grooves must face the light source in this application; the grooves often must therefore face the *shorter* conjugate, an exception to the usual rule.

Conjugates for the field lens should be the distance from the projector lens on the grooved side, and the distance to the viewer on the frosted side. Fresnel Technologies, Inc. can supply suitable lenses with the plano side either optically polished or frosted.

Magnifiers

An aspheric lens is an ideal magnifier from several points of view. When used at its conjugates, there is no distortion of the image (a rectangular grid remains a rectangular grid after
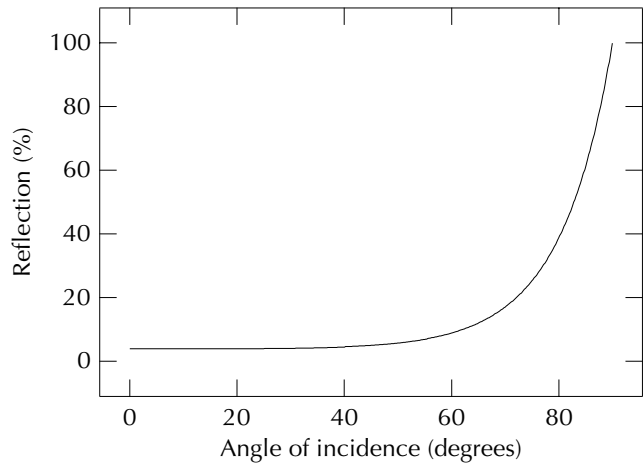
Figure 14 Loss due to reflection as a function of the angle of incidence. The angle shown is that between the incident ray and the normal to the surface. The losses shown are for unpolarized light, and are obtained by incoherently averaging the losses for light polarized parallel to and perpendicular to the plane of incidence.

magnification). If the lens is large enough for the object to be viewed with both eyes, the view is stereoscopic.

Magnifiers are used to form an image larger than the normal image of an object on the retina of the eye. The largest sharp retinal image for the unaided eye is formed when the object is at a distance of 25 cm from the eye; for most people, this is the distance of most distinct vision. Placing a magnifier between the object and the eye permits the object to be moved closer to the eye, and the eye is able to focus on the virtual image formed, preferably, at the distance of most distinct vision. The angular magnification, M, is the ratio of the angle θ' subtended by the image to the angle θ subtended by the object. From the thin lens equation,

$$M = \frac{\theta'}{\theta} = \frac{250\text{mm}}{f} + 1 \quad,$$

where f is the lens' focal length. This is usually taken as

$$M = \frac{\theta'}{\theta} = \frac{250\text{mm}}{f} \quad,$$

true for a virtual image at infinity. A magnifier with a focal length of 50 mm will then have a power of 5X.

Because they can be made large, Fresnel lenses are generally used to magnify objects slightly, perhaps as little as 1.2 or 1.5X. One usually expects to see the entire object at once within the Fresnel lens, so that the lens must then be 1.2 or 1.5 times the size of the object in both length and width.

Please observe caution when using a Fresnel lens as a magnifier around strong light sources, lasers, and in sunlight.

Imaging

Fresnel Technologies, Inc. does not generally recommend its Fresnel lenses for image formation in the visible region of the spectrum, but there are some important exceptions.

Imaging generally demands some substantial field of view, or the image is uninteresting. With simple plano-convex lenses, coma degrades the image only a degree or so off axis. Chromatic aberration blurs the image as well. As in camera or copy lenses, the faster the lens (the smaller the f–number), the worse the problem becomes – and the small f–numbers of Fresnel lenses are very tempting.

The important exceptions include two cases: rays precisely parallel to the axis of the lens (laser rangefinder, for example) and imaging onto a large detector (for instance, a pyroelectric detector or a thermopile).

Imaging can be treated as a generalization of collection.

Near-infrared applications
All of the above applications remain relevant into the near infrared, and the preferred materials (acrylic, polycarbonate, and rigid vinyl) from the visible region can be used to about 1.3 µm without difficulty. The refractive index of each of these materials is slightly lower there, but our plastics are not strongly dispersive.

Process monitoring at 3.4 µm
All hydrocarbons – solids, liquids, and gases – exhibit a strong absorption of 3.4 µm radiation. (3.4 µm is the wavelength of the C–H stretch.) POLY IR® 5 is specially formulated to contain no hydrogen, and is thus free of the C–H stretch absorption. It can be used to monitor hydrocarbons in a wide variety of applications: uses have ranged from methane monitoring above landfills to process control on production lines.

Passive infrared applications
The collection of infrared radiation emitted by humans and other warm-blooded animals has become a major application area for Fresnel lenses. This application requires that the lenses be transparent between approximately the wavelengths of 8 µm and 14 µm, the region of maximum contrast betwen warm bodies and typical backgrounds.

Passive infrared applications are discussed in our brochure on POLY IR® infrared-transmitting materials, and in the notes accompanying our passive infrared lens array data sheets.

Thermometry
Optical pyrometry can be extended toward infrared wavelengths (and therefore lower temperatures) with appropriate sensors and optics. Fresnel lenses made from our POLY IR® infrared-transmitting materials are used with a variety of bolometers and thermopiles. Our POLY IR® 1 and 2 materials are most appropriate for higher temperatures (shorter wavelengths); they can be used for lower-temperature applications as well. Our POLY IR® 4 material is also useful there, particularly in white. Please refer to our POLY IR® infrared-transmitting materials brochure for more information.

Solar Energy Collection
Fresnel lenses have often been used as concentrators for photovoltaic cells or arrays of cells in solar energy devices. We can certainly recommend them for this application,

though reflectors and nonimaging concentrators are often superior. However, Fresnel Technologies, Inc. does not manufacture any Fresnel lenses with uniform energy distribution over typical photovoltaic cell areas; our products all have a damaging "hot spot" in the focal plane. We therefore do not recommend our own products for this application; neither do we manufacture mirrors or nonimaging collectors useful for solar devices.

Please use caution with our Fresnel lenses in sunlight. The sun's image can easily ignite flammable materials quickly, and can damage materials which are not flammable. These cautions particularly apply to clothing, skin, and eyes, in both sunlight and laser light.

Special Optics
Fresnel Technologies, Inc. offers several types of optical elements related to Fresnel lenses. These include:

Cylindrical Fresnel lenses
A cylindrical Fresnel lens is a collapsed version of a conventional cylindrical lens. These lenses can be used in any application which requires focusing in only one dimension of the focal plane. In some cases, two separate cylindrical lenses may be combined to obtain different focal properties in the x and y dimensions of the focal plane; these configurations are representative of one type of anamorphic optic. A variety of cylindrical Fresnel lenses is available, with typical f–numbers between $f/1$ and $f/2$. Both positive and negative focal lengths are available.

Fresnel prism (array of prisms)
A Fresnel array of prisms is made up of many small prisms, each with the same vertex angles as the large prism mimicked by the array. This type of array allows the redirection of light with the advantage of constant transmission over the entire array, instead of the varying losses of a comparably capable conventional prism. The lack of bulk may also be used to advantage when redirection of light is required and space is limited. Not all the incident light emerges on the other side of the array, because some undergoes multiple reflections or refractions at various surfaces, or is totally internally reflected. For our item #400, a collimated beam of light incident on the smooth side is tilted by 20°. The angle of minimum deviation, as defined in optics texts, is 15°.

Hexagonal lens arrays
We manufacture two types of lens arrays with closely-packed hexagonal lenslets: those with conventional lenslets and those with Fresnel lenslets. Fresnel lenslets are appropriate for larger apertures and shorter focal lengths, where the thickness and weight of conventional lenslets would be prohibitive.

Rectangular lens arrays
All of our catalogued rectangular lens arrays are arrays of Fresnel lenses, and they are all actually square arrays. We offer some types correct for the infinite conjugate on the smooth side, as well as the more usual circumstance of the infinite conjugate on the grooved side. All are made using Fresnel lenses with aspherically contoured groove surfaces

and constant groove depths. Rectangular lens arrays can be used to illuminate an area evenly with a matching array of light emitting diodes, or to track motion via an array of photodiodes. They can be cut into strips to form linear arrays.

Lenticular arrays

A lenticular array is a closely-packed array of conventional cylindrical lenslets. These arrays are quite suitable as one-dimensional diffusers, and some are acceptable for 3D photography (the focus must be located at the back (plano) side of the array). Light striking the lenticular array is diffused only in the direction across the cylindrical lenslets; there is no diffusion along the lenslets. As the f–number of the lenslets decreases, the angle of diffusion increases depending on the relative size of the light source as compared with the lenslet spacing. A variety of diffusion angles are possible as our arrays have lenslet f–numbers ranging from $f/1.2$ to $f/5.4$. Often it is desired to diffuse light in more than one dimension. For this case, we offer crossed lenticular arrays, such that the same or a different lenticular array can be molded on the back side of the sheet.

Special Products

Fresnel Technologies, Inc. through its predecessors has manufactured Fresnel lenses since the 1960s and has gained extensive experience in custom lens fabrication. A large variety of standard lens products is offered, and these standard products may be modified to suit individual needs at a small additional cost. Fresnel Technologies, Inc. also offers custom lens array systems which may be developed to achieve certain performance requirements. Some of the custom services provided are:

Lens Frosting
Specific Modification of Standard Lenses
Diffusing Surfaces
Custom Lens Array Tooling and Production
Cutting of Lenses and Lens Arrays to Custom Shapes
Custom Material Development

We invite your inquiries about these services.

Bibliography

A good entry level reference on optics, both geometrical and physical, is E. Hecht, *Optics*, 3nd edition, Addison-Wesley (Reading, MA), 1997.

A more advanced treatment of optics can be found in *Principles of Optics*, Max Born and Emil Wolf, 7th edition, Cambridge University Press (Cambridge, UK), 1999.

For a thorough discussion both of the limitations of imaging optical systems in the collection of radiant energy and of the nonimaging collectors which can be used to collect energy efficiently, see W.T. Welford and R. Winston, *High Collection Nonimaging Optics*, Academic Press (San Diego), 1989.

A very interesting article describing an 1822 monograph on lighthouse lenses by Fresnel is B.A. Anicin, V.M. Babovic, and D.M. Davidovic, Am. J. Phys. 57, 312 (1989).

Lighthouse lens illustration (Figure 3) created with Canvas 3.5, courtesy Deneba Software, Miami, Florida, USA and the St Augustine Lighthouse and Museum, St Augustine, Florida, USA.

The Fresnel Technologies Product List

At the end of this brochure are listed the standard stock optical elements that Fresnel Technologies Inc. offers in optical quality acrylic. In the list values for optical quality acrylic material only are shown; some of the specifications apply also to other materials. Fresnel size refers to the size of the optical active area. Overall size refers to the dimensions of the optical element, possibly including a border for mounting purposes. All 11" x 11" overall size items have a 1.2" (31mm) x 45° chamfer at each corner. Thickness is specified for the border area (not the grooved area) and carries a tolerance of ±40%. Much improved tolerances are possible: please contact our factory for assistance. The single piece prices listed are current at the catalog copyright date, and may be changed at any time. Contact us for the latest pricing and for quantity discounts, which can be substantial.

Many of our positive focal length Fresnel lenses are offered either as blanks with overall size tolerances of ±0.050" or as well centered disks with tolerances on the diameter of ±0.005" in the sizes less than 7" (180 mm) and ±0.008" in the larger sizes, centered to 0.010" to the optical axis. Improved tolerances can be held, and other cuts can be accommodated as special orders. The negative focal length Fresnel lenses listed are the only ones that are offered as stock items; a negative focal length version of most of our positive focal length Fresnel lenses is available as a special order.

The grooves and the optical axis plane of items #72–85.1 lie in the direction of the second dimension listed for the Fresnel size. There is no border along that dimension, but there is a 1/8" border perpendicular to the grooves, except for item #85.

The sampler sheet (item #160) contains nine 2.5" diameter lenses in an array on a single sheet. The focal lengths of these lenses are: 2.4" (two), 2.6", 2.8", 3.0", 3.3", 3.15", 3.3", 3.6", and 3.9".

The lenticular arrays, items #200–260, are normally supplied with positive focal length lenslets. Negative focal length arrays are also available on special order, and work well as diffusers in some instances. If an array is to be used for 3D photography, please specify this in your order, so that we can send an array with thickness in the proper range.

Item #300 is made of conventional lenslets (the "Fly's-Eye" lens array) and it is suitable for one type of 3D photography, for moiré pattern work, or as a high efficiency diffuser. Item #310, suitable as a diffuser, is made of Fresnel lenses. When used as diffusers, both items diffuse light in all directions. These arrays are normally supplied with positive focal length lenslets, but can be supplied with negative focal length lenslets upon request.

The triangle formed by each prism in items #4xx has angles as shown in the columns marked "Facet angle with base." This refers to the angle that each refracting surface makes with the plano side of the prism array. The thickness is measured from the center of the groove to the smooth side.

Item #	Focal Length inches	mm	Fresnel Size inches	mm	Overall Size inches	mm	Thickness inches	mm	Grooves per inch	mm	Conjugate (inches) groove	flat	Well Centered Overall Size inches	mm	Price Each (USD) Blank	Well Cent.
0.1*	0.2	5	0.19	4.8	0.6 x 0.6	15 x 15	0.06	1.5	400	15.7	0.2	∞	0.5	12.7	17.00	19.00
0.2*	0.4	10	0.5	12.7	1 x 1	25 x 25	0.06	1.5	250	9.8	∞	0.4	0.7	17.8	18.00	20.00
0.3*	0.6	15	1.0	25	1.5 x 1.5	38 x 38	0.06	1.5	200	8	∞	0.6	1.2	30.5	19.00	21.00
1*	0.85	22	1.3	33	2 x 2	51 x 51	0.06	1.5	200	8	∞	0.85	2	51	22.00	24.00
2*	1.0	25	1.0	25	1.5 x 1.5	38 x 38	0.06	1.5	100	4	∞	1.0	1.2	30.5	19.00	21.00
2.2*	1.0	25	1.3	33	2 x 2	51 x 51	0.06	1.5	200	8	∞	1.0	2	51	20.00	22.00
3*	1.3	32	2.0	50	2.3 x 2.3	58 x 58	0.06	1.5	125	5	∞	1.3	2.3	58	21.00	23.00
3.1	1.5	38	2.0	50	2.3 x 2.3	58 x 58	0.06	1.5	125	5	∞	1.5	2.3	58	21.00	23.00
3.2*	1.7	44	2.6	66	3 x 3	77 x 77	0.06	1.5	125	5	2.27	6.8	2.8	71	23.00	25.00
3.3*	2.0	51	2.0	50	2.5 x 2.5	64 x 64	0.06	1.5	110	4	∞	2.0	2.3	58	20.00	22.00
4	2.4	61	2.5	63	3 x 3	77 x 77	0.06	1.5	125	5	∞	2.4	2.8	71	20.00	22.00
5	2.6	66	2.5	63	3 x 3	77 x 77	0.06	1.5	125	5	∞	2.6	2.8	71	25.00	27.00
6	2.8	70	1.2 x 3.3	30 x 84	1.5 x 4	38 x 102	0.06	1.5	100	4	∞	2.8			14.00	
7	2.8	70	4.0	101	5 x 5	125 x 125	0.06	1.5	100	4	∞	2.8	4.5	114	33.00	35.00
8	2.8	70	2.5	63	3 x 3	77 x 77	0.06	1.5	125	5	∞	2.8	2.8	71	25.00	27.00
9	3.0	77	2.5	63	3 x 3	77 x 77	0.06	1.5	125	5	∞	3.0	2.8	71	25.00	27.00
10	3.15	80	2.5	63	3 x 3	77 x 77	0.06	1.5	125	5	∞	3.15	2.8	71	25.00	27.00
11	3.3	83	2.5	63	3 x 3	77 x 77	0.06	1.5	125	5	∞	3.3	2.8	71	25.00	27.00
12	3.6	91	2.5	63	3 x 3	77 x 77	0.06	1.5	125	5	∞	3.6	2.8	71	25.00	27.00
13	3.9	100	2.5	63	3 x 3	77 x 77	0.06	1.5	125	5	∞	3.9	2.8	71	25.00	27.00
15	3.0	76	6	152	6.7 x 6.7	170 x 170	0.06	1.5	100	4	∞	3.0	6.5	165	58.00	61.00
15.18*	3.7	94	4	102	5 x 5	127 x 127	0.06	1.5	100	4	∞	3.7	4.5	114	35.00	38.00
15.2*	4	102	4	102	5 x 5	127 x 127	0.06	1.5	100	4	∞	4	4.5	114	36.00	39.00
16	5	127	2.5 x 2.5	64 x 64	2.5 x 2.5	64 x 64	0.06	1.5	125	5	∞	5			28.00	
17	5	127	4	101	5 x 5	127 x 127	0.06	1.5	125	5	∞	5	4.5	114	38.00	41.00
18	6	152	6	152	6.7 x 6.7	170 x 170	0.06	1.5	125	5	∞	6	6.5	165	56.00	59.00
18.2	6	152	6	152	6.7 x 6.7	170 x 170	0.06	1.5	25	1	∞	6	6.5	165	57.00	60.00
18.4	6	152	6	152	6.7 x 6.7	170 x 170	0.06	1.5	100	4	12	12	6.5	165	58.00	61.00
20	7	178	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	50	2	∞	7			75.00	
20.2	7.3	185	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	50	2	∞	7.3			76.00	
21	7.9	200	2.6	63	3 x 3	77 x 77	0.06	1.5	25	1	∞	7.9	2.8	71	28.00	31.00
22*	8	203	10	254	10.4	265	0.06	1.5	100	4	∞	8			76.00	
23*	8	203	10	254	10.4	265	0.06	1.5	200	8	32	10.7			76.00	
24	8.2	210	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	50	2	∞	8.2			60.00	
25	8.4	213	12	305	12.5	315	0.09	2.3	50	2	∞	8.4			130.00	
25.2	8.4	213	13.2	337	14.5	370	0.11	2.8	50	2	∞	8.4			136.00	
25.4	8.6	218	13.1	333	14.5	370	0.11	2.8	50	2	∞	8.6			135.00	
25.6*	9	229	10	254	10.4	265	0.06	1.5	100	4	∞	9			76.00	
25.7*	9	229	10	254	10.4	265	0.06	1.5	200	8	36	12			78.00	
26	9.2	235	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	50	2	∞	9.2			72.00	
27	10	254	5	127	5.5 x 5.5	140 x 140	0.06	1.5	100	4	∞	10	5.5	140	55.00	58.00
29	10	254	6	152	6.7 x 6.7	170 x 170	0.06	1.5	25	1	∞	10	6.5	165	52.00	55.00
30	10	254	6	152	6.7 x 6.7	170 x 170	0.06	1.5	100	4	∞	10	6.5	165	55.00	58.00
31	12	305	6	152	6.7 x 6.7	170 x 170	0.06	1.5	50	2	∞	12	6.5	165	58.00	61.00
32	12.5	318	10	254	10.4	265	0.06	1.5	120	4.7	50	16.7			76.00	
33	12.5	318	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	120	4.7	50	16.7			72.00	
36	12.8	324	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	50	2	∞	12.8			72.00	
37	13.8	350	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	64	2.5	∞	13.8			75.00	
40	16	406	7	178	7.4	190	0.06	1.5	300	11.8	∞	16			50.00	
41	16	406	14	356	14.5	370	0.11	2.8	50	2	∞	16			140.00	
42	16.5	419	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	50	2	66	22			65.00	
46	18	457	8.5 x 10.5	216 x 267	8.5 x 10.5	216 x 267	0.09	2.3	143	5.6	∞	18			55.00	
46.2	18	457	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	143	5.6	∞	18			72.00	
47	18	457	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	50	2	∞	18			75.00	
48.2	18	457	16 x 16	405 x 405	16 x 16	405 x 405	0.11	2.8	143	5.6	∞	18			190.00	
48.4	18	457	18	457	18.5	470	0.11	2.8	143	5.6	∞	18			220.00	
51	19	483	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	50	2	∞	19			75.00	
52	19.5	495	10	254	10.4	265	0.06	1.5	50	2	∞	19.5			76.00	
52.2	19.5	495	10.5	267	12	305	0.09	2.3	50	2	∞	19.5			78.00	
53	23	581	12	305	12.5	315	0.11	2.8	25	1	∞	23			110.00	
54	24	610	10.5 x 10.5	267 x 267	11 x 11	280 x 280	0.09	2.3	200	8	∞	24			75.00	
56	24	610	12.9	327	14	355	0.11	2.8	200	8	∞	24			135.00	

Positive Focal Length Aspheric Fresnel Lenses   * in the item number indicates aspheric grooves; all others have conical grooves

The lens' cylindrical axis is aligned along the second (longer) dimension

Item #	inches	mm	inches	mm	inches	mm	inches	mm	inch	mm	groove	flat	inches	mm	Blank	Well Cent.
72	0.25	6.4	0.25 x 6	6.4 x 152	0.5 x 6	12.7 x 152	0.06	1.5	200	8	∞	0.25			18.00	
72.1	0.25	6.4	0.25 x 11.88	6.4 x 302	0.5 x 11.88	12.7 x 302	0.06	1.5	200	8	∞	0.25			25.00	
73	0.38	9.6	0.38 x 5.95	9.6 x 151	0.65 x 5.95	17 x 151	0.06	1.5	200	8	∞	0.38			18.00	
73.1	0.38	9.6	0.38 x 11.94	9.6 x 303	0.65 x 11.94	17 x 303	0.06	1.5	200	8	∞	0.38			25.00	
74	0.5	12.7	0.5 x 5.95	12.7 x 151	0.75 x 5.95	19 x 151	0.06	1.5	200	8	∞	0.5			18.00	
76	0.75	19	0.75 x 11.9	19 x 302	1 x 11.9	25 x 302	0.06	1.5	200	8	∞	0.75			27.00	
77	1	25	1 x 3	25 x 77	1.25 x 3	32 x 77	0.06	1.5	175	6.9	∞	1.0			23.00	
80	2	51	2 x 2.7	50 x 69	2.25 x 2.7	57 x 69	0.06	1.5	200	8	∞	2.0			28.00	
80.1	2	51	2 x 12	50 x 305	2.25 x 12	57 x 305	0.06	1.5	200	8	∞	2.0			38.00	
83	3	76	3 x 4	77 x 102	3.25 x 4	83 x 102	0.06	1.5	80	3.1	∞	3			30.00	
85	6	152	3 x 3	77 x 77	3 x 3	77 x 77	0.06	1.5	65	2.6	∞	6			25.00	
85.1	6	152	3 x 4	77 x 102	3.25 x 4	83 x 102	0.06	1.5	65	2.6	∞	6			31.00	

Cylindrical Fresnel Lenses

Item #	inches	mm	inches	mm	inches	mm	inches	mm	inch	mm	groove	flat	inches	mm	Blank	Well Cent.
86	-3	-76	1.2 x 1.6	30 x 41	1.5 x 2	38 x 50	0.06	1.5	100	4	∞	-3			15.00	
88	-9.1	-231	13.2	337	14.5	370	0.11	2.8	50	2	∞	-9.1			135.00	
90	-16.5	-419	10	254	10.4	264	0.06	1.5	50	2	∞	-16.5			65.00	

Negative Focal Length Aspheric Fresnel Lenses

Item #	Focal Length inches	mm	Fresnel Size inches	mm	Overall Size inches	mm	Thickness inches	mm	Grooves per inch	mm	Conjugate (inches) groove	flat	Axis offset (in.)	Price Each (USD)
145	12.5	318	7	178	7	178	0.06	1.5	125	5	∞	12.5	0.5	165.00
148	17	432	8.3	211	8.3	211	0.06	1.5	200	8	∞	17	1.5	105.00

Off–axis Fresnel Lenses

Item #					Overall Size inches	mm	Thickness inches	mm	Grooves per inch	mm	Conjugate (inches) groove	flat		Price Each (USD)
160					11 x 11	280 x 280	0.09	2.3	125	5	∞	indiv. F.L.		75.00

Nine Lens Sampler Sheet

Lenslet cylindrical axis is aligned along first dimension

Item #	Focal Length inches	mm	Fresnel Size inches	mm	Overall Size inches	mm	Array Thickness Diffuser (in.)	3D Photography (in.)	Lenses per inch	mm	Price
200	0.41	10.4	9 x 12	229 x 305	9.75 x 13	248 x 330	0.090±40%	Not applicable	3	0.12	65.00
202	0.090	2.3	15 x 15	381 x 381	15 x 15	381 x 381	0.090±40%	0.090±0.010	53	2.1	160.00
204	0.085	2.2	11 x 11	279 x 279	11 x 11	279 x 279	0.085±40%	0.085±0.010	64	2.5	74.00
206	0.085	2.2	10 x 12	254 x 305	10 x 12	254 x 305	0.085±40%	0.085±0.010	64	2.5	75.00
208	0.085	2.2	12 x 10	305 x 254	12 x 10	305 x 254	0.085±40%	0.085±0.010	64	2.5	76.00
240	0.015	0.38	17 x 17	432 x 432	17 x 17	432 x 432	0.060±40%	Not applicable	108	4.3	180.00
260	0.010	0.25	12 x 12	305 x 305	12 x 12	305 x 305	0.060±40%	Not applicable	142	5.6	75.00

Lenticular Arrays

Item #	Focal Length inches	mm	Array Size inches	mm	Overall Size inches	mm	Thickness inches	mm	Lenslet Mean Diam (in.)	Lenslet Type	Lenslets/sq. in.	Price
300	0.12	3	8 x 10	203 x 254	8 x 10	203 x 254	0.12	3	0.09	Conventional	134	55.00
310	1	25	8.05 x 10.5	204 x 267	8 x 11	203 x 279	0.06	1.5	0.94	Fresnel	1.5	55.00
360	0.12	3	6 x 6	152 x 152	6 x 6	152 x 152	0.06	1.5	0.039	Conventional	714	55.00

Hexagonal Lens Arrays

Item #	Angles of Minimum Deviation		Prisms are aligned along longer dimension inches	mm	Overall Size inches	mm	Thickness inches	mm	Facet angle with base		Prisms per inch	mm	Price
400	15°	-	4 x 3	102 x 77	4 x 3	102 x 77	0.06	1.5	30°	90°	25	1	25.00
420	36°	36°	3.5 x 2.5	89 x 64	3.7 x 2.7	94 x 69	0.06	1.5	60°	60°	40	1.6	25.00
430	25°	25°	4.3 x 4	109 x 102	4.5 x 4.2	114 x 107	0.06	1.5	45°	45°	125	5	30.00
440	14°	38°	8.25 x 4	209 x 102	8.4 x 4.2	213 x 107	0.06	1.5	28°	62°	20	0.78	35.00
450	21°	28°	8.25 x 4	209 x 102	8.4 x 4.2	213 x 107	0.06	1.5	40°	50°	20	0.78	35.00

Array of Prisms

16 elements in each array

Item #	Focal Length inches	mm	Array Size inches	mm	Overall Size inches	mm	Thickness inches	mm	Groove Depth inches	mm	Lenslet spacing inches	mm	Conjugate (in.) groove	flat	Price
540.4*	0.6	15	2.8 x 2.8	71 x 71	3.5 x 3.5	89 x 89	0.06	1.5	n/a	n/a	0.7	17.8	∞	0.6	18.00
550*	0.85	22	3 x 3	77 x 77	3.5 x 3.5	89 x 89	0.06	1.5	0.006	0.15	0.75	19	∞	0.85	20.00
550.2*	0.85	22	3 x 3	77 x 77	3.5 x 3.5	89 x 89	0.06	1.5	0.006	0.15	0.75	19	0.85	∞	20.00
560*	1.1	28	4 x 4	102 x 102	4.5 x 4.5	114 x 114	0.06	1.5	0.007	0.18	1.0	25.4	∞	1.1	28.00
560.2*	1.1	28	4 x 4	102 x 102	4.5 x 4.5	114 x 114	0.06	1.5	0.007	0.18	1.0	25.4	1.1	∞	28.00
570*	1.65	42	6 x 6	152 x 152	6.5 x 6.5	165 x 165	0.06	1.5	0.010	0.25	1.5	38	∞	1.65	38.00

Rectangular Fresnel Lens Arrays

* in the item number indicates aspheric grooves

Item #	Focal Length inches	mm	Lenslet Type	Overall Size inches	mm	Thickness inches	mm	Lenslets per sq. in.	sq. cm	Lenslet spacing inches	mm	Price
605	0.095	2.4	Conventional	0.5 x 0.5	12.7 x 12.7	0.095	2.4	40000	6200	0.005	0.125	15.00
630	0.13	3.3	Conventional	6 x 6	152 x 152	0.13	3.3	645	100	0.039	1	38.00

Rectangular Conventional Lens Arrays (Microlens Arrays)

Ordering Information

Prices listed are for single-piece quantities. Please contact us for quantity discounts, which can be substantial.

Terms on production are (with approved credit) net 30 days for customers in the USA, Mexico, and Canada. In fact, accounts are due 10 days after invoice date and are past due 30 days after invoice date. If a net 30 account has not yet been or cannot be established, we will require payment in advance or we will ship COD. We also accept VISA, Mastercard and American Express.

We expect payment in advance on all foreign orders. Payment may be made by check, credit card, or wire transfer. A pro forma invoice will be sent when the order is placed. This will include all charges and bank information. We will ship freight collect.

All orders are shipped FOB Fort Worth, Texas. Freight and insurance are your responsibilities.

We have tried hard to make this catalog as free of mistakes as possible, but errors do happen, as do misunderstandings. We will not guarantee the accuracy of the information and data in this catalog, but we give a typical 90-day commercial warranty on our goods. We will cheerfully replace defective or unsatisfactory goods or refund your purchase price as appropriate.

Prices, specifications, and availability of the products in this catalog are subject to change without notice.

Please use fax or email (sales@fresneltech.com) for technical questions, telephone for order placement and inquiry. Lead times may vary.

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