

CONTROLLING LIGHT

Over less than astronomical distances, light travels in straight lines moving outward from its source at a speed of approximately 186,200 miles per second (approximately 3×10^8 meters per second) if it is traveling in a vacuum. Its speed is negligibly slower in air. It continues traveling in straight lines until it is absorbed by something in its path or deviated from that path. Light emanating from a source disperses in proportion to the square of the distance from the source and decreases in brightness in inverse proportion to that distance (Figure 7.1). This is known as the law of squares. Its effect is to rapidly diminish the usefulness of radiating light as distance from the source increases.

Law of squares

Collection

The basic objective of all luminaires is to gather up (collect) as much of the light being radiated from the lamp as possible and redirect it to

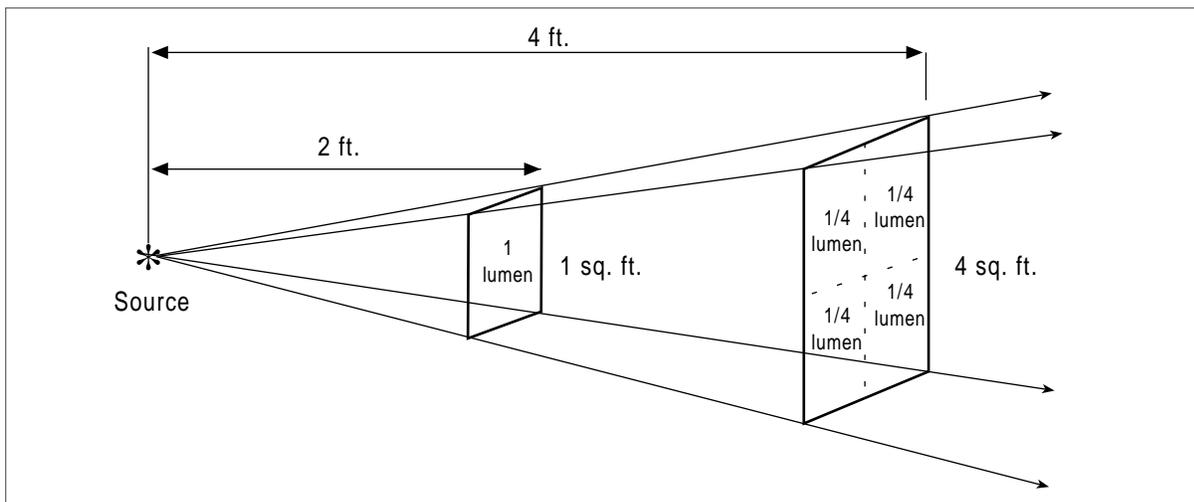


Figure 7.1. Law of Inverse Squares. Light radiates from a source such that its brightness decreases by the inverse of the square of the distance from the source. Note that if there is a brightness of one lumen at a distance of two feet from the source, the brightness will be one-quarter lumen at a distance of four feet

where it is needed. Reflectors and lenses are the means used in the theatre to effect this control. When the light from the source cannot be usefully directed, it must be blocked off to avoid lighting areas that should not be lit. This is wasteful and usually results in the conversion of the wasted light into heat where heat is not wanted.

Heat from "waste"
light

In theory, the illumination engineer begins with a perfect point source that radiates light spherically. In fact, no source is really a point and the light does not radiate equally in every direction. Nevertheless most theatrical sources, incandescent or high intensity discharge lamps, can be treated as if they were point sources but better results can be had by adjusting the reflectors that collect the light to account for the size and shape of the filament or arc. However the radiation from the source is configured, the illumination engineer must solve the basic problem of collecting and re-directing it in a way that makes use of as much as possible. This is done by engineering a combination of reflectors and lenses to fit the situation. This engineering is made more difficult by the need for theatrical luminaires to operate over a wide range of distances with a broad assortment of beam sizes and characteristics. Additionally, theatrical budgets will not allow the use of highly precise and expensive optical elements.

Reflection, Refraction and Diffraction

There are three ways of altering the path of a beam of light not counting those phenomena observed in distant space:

1. Reflection: The path of the light beam is altered by being bounced off a surface.
2. Refraction: The path of the beam is altered by its passage from a medium of one optical density to one of different density.
3. Diffraction: The path of the beam is altered grazing an edge.

Reflection and refraction are constantly used in the engineering of stage lighting luminaires, often both in the same fixture. Diffraction is rarely encountered in stage lighting except when its results are reported in spectrograms of color media.

Reflection

Although reflectors vary widely in their appearance and their effect on light striking them, they all work according to the Law of Specular Reflection: the angle of incidence equals the angle of reflection, and they are in the same plane. The phrase, "and in the same plane," means that the outgoing rays are always on the same plane as the incoming rays, not skewed off at an angle. This law is illustrated in Figures 7.2A and 7.2B. The following terms apply:

Law of specular
reflection

Point of incidence: the point on the reflector where the ray of light hits;
Normal: a line perpendicular to the surface at the point of incidence. If the reflector is a plane surface, the normal will be perpendicular to that surface. If the reflector is curved, as it often is in luminaires, the normal will be perpendicular to a tangent at the point of incidence;

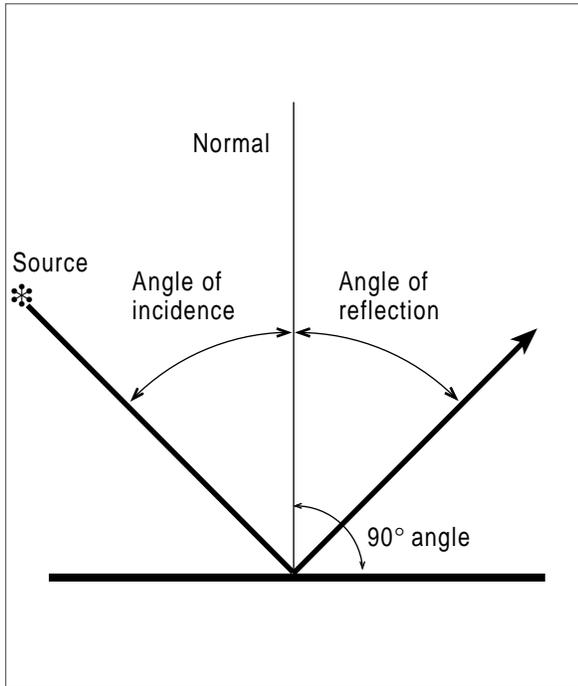


Figure 7.2A. The Law of Specular Reflection. The angles of incidence and reflection are measured from the normal, not the surface which may not be a plane. These angles are equal and the rays are in the same plane.

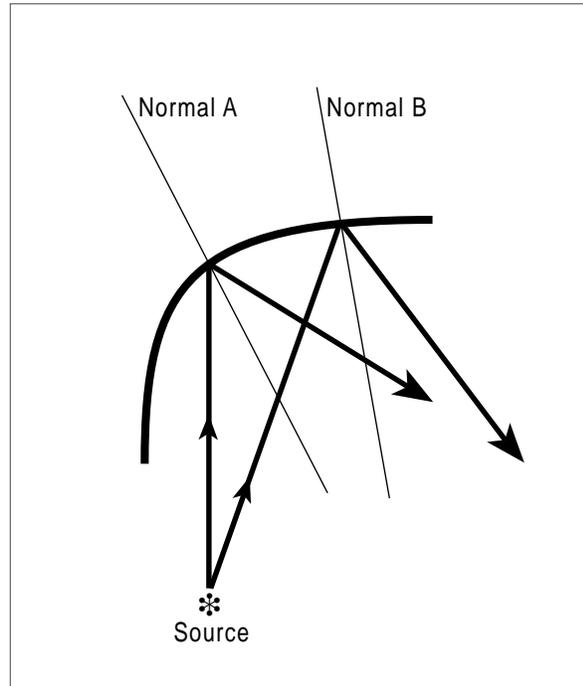


Figure 7.2B. Specular Reflection from an Uneven Surface. Note that a separate Normal is established at each point of incidence. Angles of incidence and reflection are equal as measured from that normal.

Angles of incidence and reflection

Angle of incidence: the angle between the normal and the incoming light ray;
Angle of reflection: the angle between the normal and the outgoing ray.

Specular reflection

Specular Reflection

Reflectors which obviously follow the law of reflection, are often called "specular" reflectors, a term derived from the Latin "speculum," meaning "mirror." Mirrors, highly polished metal surfaces and the surface of a still pond of water are common examples. Specular reflection affords the most precise control over light. For example, it is the basis of the collection and control of light from distant stars caught in astronomical telescopes.

First and second surface mirrors

In the case of mirrors made of glass or plastic, it is important to note that there are two types: first-surface and common or second-surface reflection. First surface mirrors have the reflective metal coating (silver or aluminum) applied to the top surface of the glass plate. The glass in this case becomes a "substrate," merely a support for the working surface. Obviously this arrangement places the delicate metal coating at risk and special steps must be taken to protect it. Common household mirrors avoid this problem by placing the reflective material on the back of the glass and coating its back surface for additional protection. While this makes a durable mirror, it also means that the mirror is capable of producing double reflections, one from the front surface of the glass and the second from the metallic coating on the rear. This can produce unacceptable confusion in precision optical equipment.

Metal mirrors

Metal mirrors made of highly polished aluminum or other highly reflective materials, avoid this problem completely; they automatically reflect from their front surfaces. Dichroic mirrors, a special class of specular reflectors in which the surface coating selectively reflects various wavelengths of light, will be detailed below.

Diffuse, Spread and Mixed Reflection

Diffuse reflection (Figure 7.3) imparts maximum dispersion to any beam of light striking the surface, however controlled and defined that incident beam may be. The best example of such a reflector, ignoring durability, is a piece of clean white blotting paper. Each point on its surface will reflect whatever light strikes it as though that point were a source of light sending forth spherical radiation. None of the directional quality of the incident beam remains in the reflected light.

Diffuse reflection

Modern diffuse reflectors used on stage are made of specially surfaced aluminum. They are found in many varieties of floodlighting equipment such as in modern borderlights, cyclorama lights and floodlights. If kept clean, these reflectors are highly efficient.

Diffuse reflection also abounds on stage scenery. Most surfaces painted with scene paint are diffuse reflectors as are most fabrics with the exception of satins. Generally stage painters purposely avoid the gloss of enamels and varnishes except where specially required, because varnished or enameled surfaces can produce mixed reflection (below).

Scene paint is a diffuse reflector.

Spread Reflection

After striking a spread reflector, incident light is dispersed over a wide but controllable area, retaining some of its original directional characteristics (Figure 7.4). Spread reflectors are often made by treating an aluminum surface in a manner that leaves fine striations, or lines. Light striking such

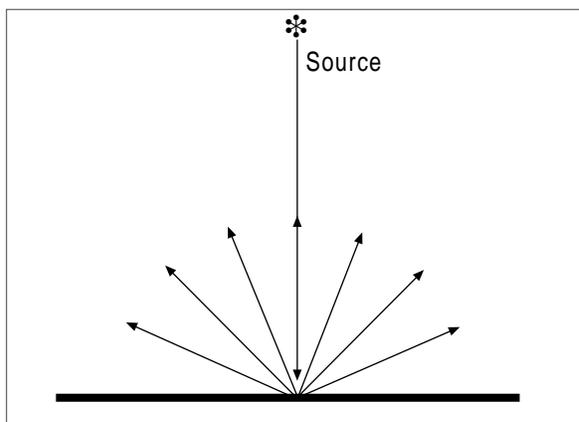


Figure 7.3. Diffuse Reflection. Note that the light is reflected equally along every possible angle from the point of incidence. (The length of the arrows represents the amount of light reflected along each path.)

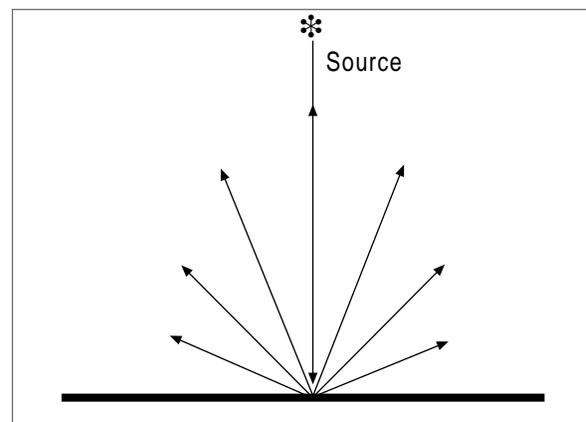


Figure 7.4. Spread Reflection. Note that the light is reflected selectively from the point of incidence. More is directed back along the path of incidence than in any other direction. (The length of the arrows represents the amount of light reflected along each path.)

a surface will disperse more in the plane perpendicular to the striations than that parallel to them. This affords the designer of the reflector quite precise control over the degree of spread and diffusion the reflector causes.

Spread reflectors are found in a variety of lighting equipment where a flood of light is needed but with control over the distribution of that light. For example, cyclorama lighting equipment is usually mounted much closer to the top of the cyclorama than the bottom. Carefully designed spread reflectors provide one way of equalizing the distribution over the cyc from top to bottom. This problem may also be solved by the use of glass roundels molded to have controlled spread characteristics.

Mixed Reflection

Mixed reflection

Unlike diffuse and spread reflection, which find useful applications on stage, mixed reflection is usually detrimental. It consists of a combination of diffuse and specular reflection usually produced by a highly polished but transparent surface such as a varnished table top. The diffuse portion, which comes from the underlying parts, does not create a problem. The specular portion, which comes from the polished surface, can produce distracting patterns of reflected light on setting walls or other background surfaces. Sometimes these patterns even include upside-down shadows of moving actors. Multiple reflections are likely if more than one light source strikes the offending surface.

Satin

One positive application of mixed reflection is found in satin fabrics. The glossy surface of the satin reflects light specularly with its color unchanged. The underlying fabric reflects diffusely altering the color of the reflected light unless the satin is white. The result is the rich shimmer often desired in costumes and in some drapery.

Eliminating mixed reflection

Clearly, mixed reflection from varnished surfaces must be controlled: Assuming that the luminaires cannot be reangled, the solution is to alter or cover the surface causing the reflection. If the offending surface is a desk or table, it may be possible to have the property personnel provide a cover or table spread for it that will “kill” the reflection. In some cases a good coat of flat scene paint will do the job. If, however, the furniture is borrowed or rented, painting will be out of the question and a spread may not always be appropriate. Another possibility is to give the offending surface a heavy coat of a furniture polish that dries into a dull coating. The polish is left in this condition—and even renewed if it begins to produce the reflections again—until the show is over when the furniture is polished back to its original shiny best. If the offending surface is a varnished stage floor, the best solution is to put down a ground cloth, a canvas floor covering, for the duration of the run. Note that proper stage floors are never varnished or otherwise finished with a reflective surface for exactly this reason.

Ground cloth

Describing the Efficiency of Reflectors

Reflector efficiency, which can vary from near-zero (black velour) to near-perfect (highly polished aluminum), is usually stated as a simple percentage figure arrived at by comparing the amount of white light incident to

the reflector to the amount reflected. If, for example only half of the light is reflected, the reflective efficiency would be 50%. Since ordinary aluminum reflectors used in luminaires do not selectively reflect visible wave lengths, efficiency by wave length is seldom a concern. Therefore the reflector's efficiency is simply stated for white light.

Controlling Light: Refraction

Refraction may be simplistically defined as the bending of a ray of light when it passes through a surface separating two different light transmitting materials. For example, light traveling through the surface separating water from air, the surface of a pool, for example, will be bent. This causes the bent appearance of a straight stick thrust partly into the water. Another example of refraction is the bending of light when it passes through a surface separating glass from air. For instance, an imperfect piece of window glass will impart a wavy quality to things viewed through it—the result of refraction. To the lighting artist or technician the most important refraction is that which happens when light passes through a lens. In order to understand this effect more fully, we must use the exact language of the physicist. First, some terms must be defined:

Bending light waves

Medium: any material that will, at least to some degree, transmit light.

Note that refraction deals with light that actually passes through the medium, not that which is stopped and absorbed or simply reflected away. Therefore the rules of refraction apply equally to the murkiest piece of glass or plastic that light can pass through or to the finest optical plate.

Optical density: refers indirectly to the speed of light in a medium. You will recall that the speed of light in a vacuum is about 186,200 miles per second. The speed of light when it travels through any matter that will allow its passage is less than that figure. For example, light is minimally slowed when passing through air and slowed considerably when passing through glass. Optical density is expressed by the index of refraction.

Index of refraction: A number which expresses the ratio between the speed of light in a vacuum and its speed in any other medium. Thus the index is 1.000 for a vacuum and a larger number for other media. For example, the index of refraction for air is 1.000293, for water 1.333, for various kinds of glass 1.5 to 1.9, and for diamond, 2.419. Note that this index is always a number greater than 1. This arithmetically expresses the fact that light travels slower in all other media than it does in a vacuum.

Normal: A line drawn perpendicular to the point where the light strikes a surface separating two kinds of media. As with reflection, the normal to a point on a curved surface is the vertical to the tangent at the point of incidence.

Using these terms, it is now possible to cite a more scientifically accurate definition: *Refraction is the bending of light rays caused by their passage through a surface separating a medium of one optical density from one of different optical density, provided that the light rays are not traveling along a normal.*

Refraction varies with wave length.

Refraction makes lenses work

Refraction through optical plate

Refraction is differential by wave length. This means that the bending of the light rays will always be the same for a given wave length and set of media, but will vary as the wave length varies. Differential refraction makes it possible for a prism to sort out light waves according to their length, producing a spectrum. Unfortunately it also causes chromatic aberration, a flaw that puts fringes of color around images formed by simple lenses.

Refraction is of great importance to the lighting designer and technician because it describes the operation of all of the many lenses used in lighting and scenic projection. In the world of physics refraction is evident in a wide variety of cases where light, visible or otherwise, passes from one to another of the many thousands of materials that transmit it. Fortunately theatre designers and technicians can limit their concern to those cases where light passes from air to glass or to certain plastics sometimes used to make lenses and to the reverse of that passage—back to air.

Figure 7.5 illustrates one of the simplest examples of refraction—light passes from air-to-glass-to-air when the sides of the glass are plane and parallel to each other. According to the definition of refraction, as long as the beam strikes the glass plate on any path other than along the normal (or at such an acute angle—the “critical angle”—that none of it penetrates the surface eliminating any consideration of refraction), bending

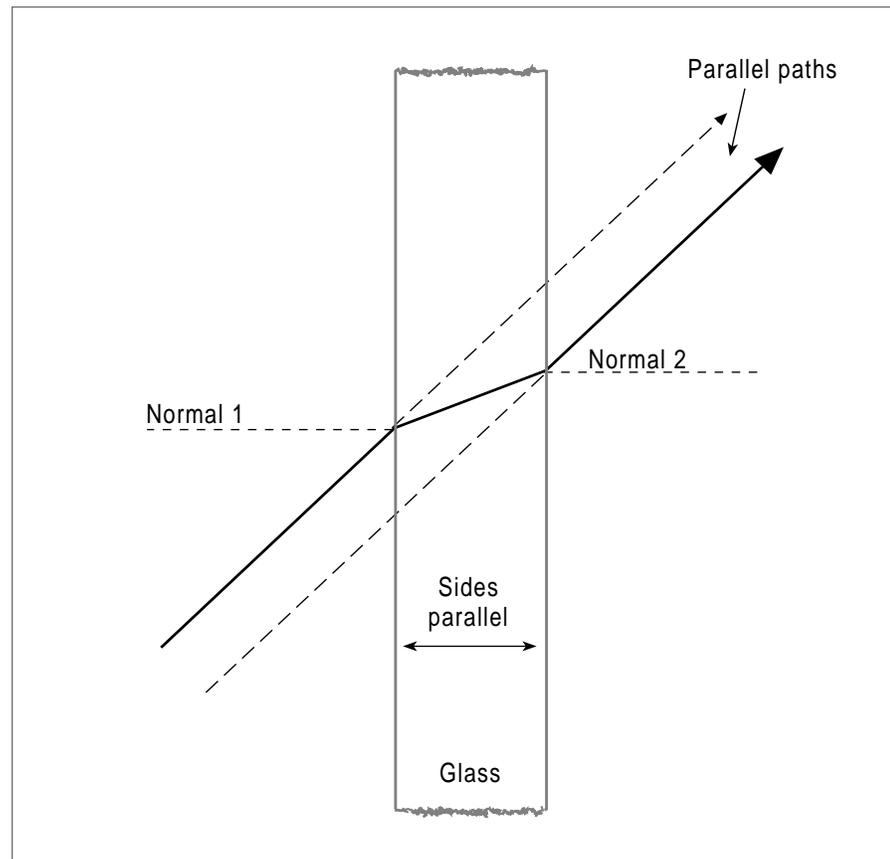


Figure 7.5. Refraction. Diagrams path of a “ray” of light passing through a perfect piece of plate glass. Note that the new path is parallel to the original but offset from it. The normals are also parallel, being perpendiculars to the parallel planes of the glass surfaces.

will take place at the point of entry. A reverse of this bending will occur where the light beam exits the glass. The amount and direction of bending depend on the ratio between the two indices of refraction and whether the beam is passing from air to glass or vice-versa. The rule governing the direction of the bending is:

If the beam passes from a medium of low optical density to one of higher optical density (such as from air to glass), the beam will be bent toward the normal. If the passage is from high optical density to low, the bending will be away from the normal.

Note that the normal referred to is the one at the point where the beam enters or leaves the glass. This bending is illustrated in Figure 7.5. Note that the bending (angle D) all takes place at the surface. Once inside the glass, the light travels in a straight line until it encounters the second surface which separates glass from air. Here another bend takes place which is equal to and opposite in direction to the first bend, i.e., the beam will bend away from the normal at the point of exit. The bending is equal to the bend at the entry because the optical densities are the same; only their order is reversed. The only condition under which the second bend will not take place is when the first bend puts the light beam exactly on the normal to its point of exit. In this case there will be no second bend.

Bending takes place at surfaces.

The effect of these bending actions, as long as the sides of the glass plate are plane and parallel, is that the beam is offset but continues on in the same direction from which it entered. The amount of bending may be exactly calculated, if necessary, although this calculation will be beyond the needs of theatre lighting personnel.

Absorption and Surface Reflection

It is important to note that not all of the light striking the surface of a medium which transmits light will be refracted. Even the most perfectly transparent of media will absorb some of the light as it passes through. Also, the amount of light which passes through the separating plane will depend on the angle at which the light approaches the separating surface. If that angle is less than a certain minimum known as the *critical angle*, all of the light will be reflected according to the laws of reflection and remain within the first medium. At angles greater than the critical angle part of the light will penetrate the separating surface following the law of refraction but another part will be reflected. As the angle of incidence approaches perpendicular, most, but still not all, of the light will pass through the surface following the laws of refraction. Note that the surface reflection can take place either when light passes from a medium of low density to one of higher density (air/glass) or the reverse (glass/air). The latter situation is often called *internal reflection*.

Critical angle

Surface reflection

Internal reflection

How Refraction Makes Lenses Work

Prism

Whenever the two sides of a piece of glass or plastic, i.e., a medium of optical density higher than air, are not parallel, bending occurs in the manner illustrated in Figure 7.6. Note how the nonparallel sides have the effect of arranging the normals at the points of entry and exit so that the bending at these two points adds together instead of cancelling as it would if the sides were perfectly parallel. A prism is a piece of glass with plane sides which are intentionally not parallel to each other. Although prisms are seldom used in the theatre, their light-bending function will serve as our introduction to lenses, which are much used.

Three conditions control the amount of bending that takes place when light rays are refracted:

1. *the ratio between the indices of refraction of the two media involved* (The greater the difference between the indices, the greater the deviation. The index of refraction of glass depends on its chemistry.);
2. *the angle between the normal at the point of entry into the denser medium and the normal at the beam's departure* (This is a factor of the geometry of the media, which in theatre comes down to the curvature of the surfaces of the lenses involved.);
3. *the wavelength of the light passing from one medium to the other* (Short wavelengths—blue and violet—will be bent more than long rays—reds and oranges.).

Altering any one or more of these variables will change the amount of refraction. Designers of lenses alter both the shape of the lens and the chemistry of the glass to achieve their goal. However, altering the composition of the glass is limited in applications where heat is involved because only a certain types of glass can withstand heat without cracking. Heat considerations also eliminate the use of many plastics which otherwise have favorable optical characteristics.

Lenses as “infinite”
prisms

From Prisms to Lenses

It is but a step from Figure 7.6, which shows the optical effect of prisms, to that of a plano-convex lens. Refer to Figure 7.7. Note how the lens can be considered to be an infinite series of prisms. The effect on each ray of light is the same as it would be if the light were striking a prism at the point of incidence, instead of the curved surface of the lens. Note that lenses and prisms are two-way devices: The effect on a beam of light is the same whichever way it passes through the lens.

Focal length

The light bending (refractive) power of lenses could be described in terms of the curvature of their sides, the composition of the glass and, of course, the wavelength of the light to be bent. This is awkward. Therefore the concept of *focal length* has been developed. This number describes the way in which the lens will bring parallel rays of light into a focus. This is normally done with white light although focal length can also be established for a specific wavelength if this is needed.

Before a formal definition of focal length can be cited, its terms need definition. Note that these definitions, while complete enough for application to theatrical needs, are by no means accurate enough to satisfy the

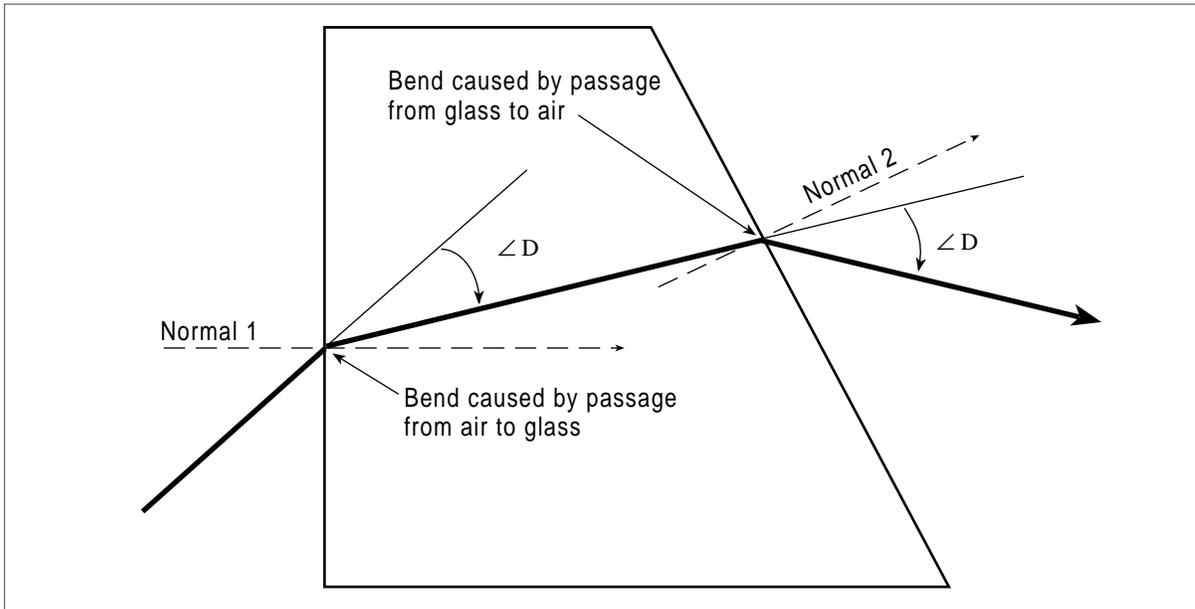


Figure 7.6. Refraction Through a Prism. Note the effect on the light “ray” when the sides of the glass are not parallel. Normals 1 and 2 are perpendicular to their related surface but are not parallel to each other. Angles “D” are also equal and the bending rule—*toward* the normal when the passage is from a medium of low density to one of high density and *away* from the normal when the passage is from high density to low—is the same. However the effect is drastically different. The path of the “ray” is deviated by an amount equal to twice angle “D.”

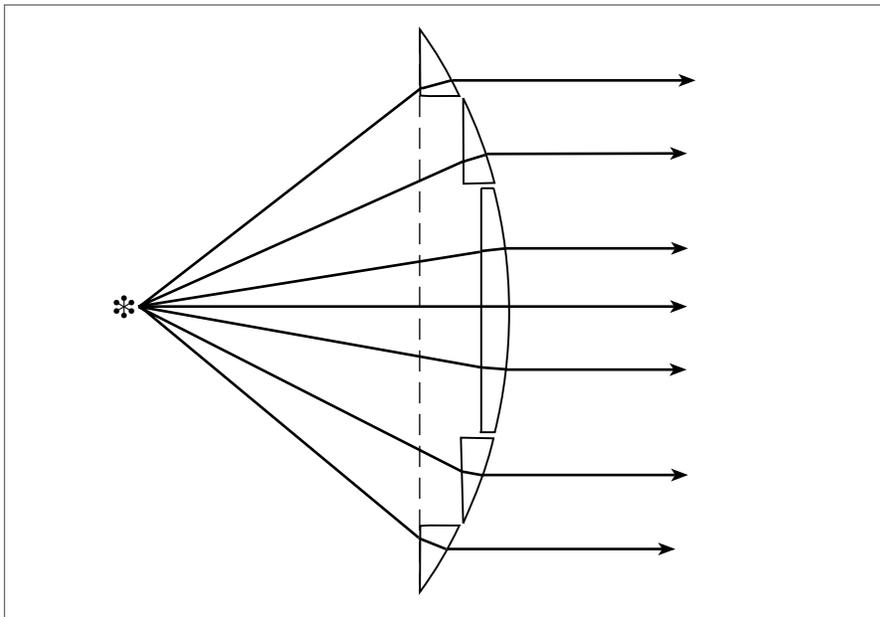


Figure 7.7. Lens as Infinite Prism. A lens may be regarded as an infinite series of prisms which refract light as diagrammed in Figure 7.6. Note that a step lens utilizes this pattern to create a very practical lens.

field of precision optics:

Principal foci: the points on either side of a lens where parallel beams of light are brought to a focus.

Optical center: This is often described as the plane on which the bending performed by a lens seems to take place if the bending from both surfaces were combined. The optical center may be approximately located by setting up the lens on an optical bench, determining the two principal foci and then locating the plane exactly half way between them. In the case of a plano-convex lens, the optical center can

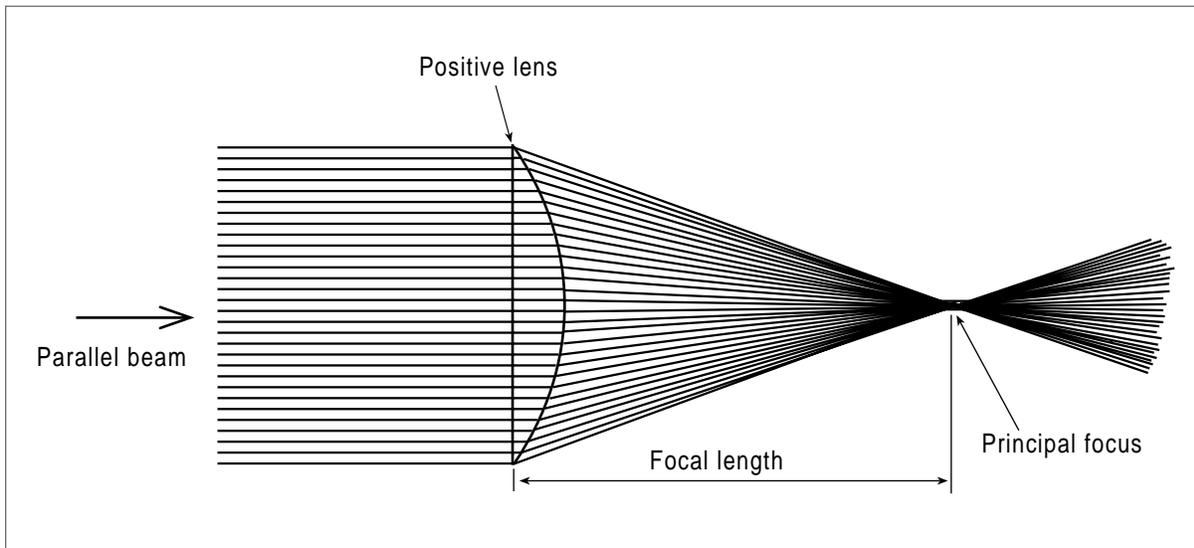


Figure 7.8. Focal Length. This drawing illustrates the standard conditions that determine the focal length of a positive lens. Parallel light is passed through the lens which brings these beams to a focus at the *Principal focus*. The distance from the principal focus to the optical enter of the lens, stated in inches or millimeters, is the focal length. (Note that the optical center of a plano-convex lens such as the one shown can, for stage purposes, be considered to be its plane side.)

generally be considered to be the plane side of the lens.

Optical axis: A line passing through the two principal foci and the center of the lens. All of the elements of an optical system must normally be lined up on the optical axis with the plane representing the optical center perpendicular to it.

Definition of focal length

Locating the principal focus

Figure 7.8 illustrates the standard set of conditions stipulated in the definition of focal length: *The focal length of a lens is the distance from its optical center to either of its principal foci.* This distance can be stated in either inches or centimeters. Optical experts use a precision device known as an optical bench to determine focal length. This is simply a precisely machined, very rigid metal bar upon which various optical devices can be mounted and moved back and forth until they are properly adjusted and measurements can be taken. An optical expert might set up an optical bench to replicate the conditions illustrated in Figure 7.8. A device known as a *collimator*, which produces parallel rays of light would be aimed through the lens onto a target. When the parallel rays are brought to an accurate focus, the distance from the focal point to the flat side of the lens would be measured. This will give the approximate focal length. If greater accuracy is needed or the lens is of a more complex variety (convex-convex or compound lenses in barrels for example), the locations of the collimator and the target can be reversed to find the second principal focal point. One half of the distance between the two principal foci will give a better approximation of the focal length than the single reading taken from one side. While these two readings will suffice for most theatrical purposes, much more accurate measurements are necessary for precision optical work.

Finding the focal length of a PC lens

Fortunately the lighting technician does not need an optical bench to determine the focal length of spotlight lenses which are crude optical devices normally made only in focal lengths measured in even inches. Instead of a collimator, the theatre worker need only find a source of light at a consider-

able distance away, which will make its rays relatively parallel. A light at the end of a long hallway will do. Simply bring the distant light into focus on a piece of paper and measure the distance from the flat side of the lens to the paper. This can even be done with a fragment of a broken lens, enabling the technician to order a replacement. Note that it makes no difference which way the light is passed through the lens; the distance between the principal focus and the flat side (the approximate optical center) will remain the same.

Efficiency of Lenses

Clearly, the larger the diameter of a lens, the more light it will pass through. The kind and quality of the glass also make a significant difference. The efficiency (and a number of other characteristics mainly of interest to photographers) of photographic and projection lenses is described by an "*f*" number. This is calculated by dividing the focal length of the lens by its *effective diameter*.

Effective diameter

Photographers select a lens by its focal length, which will determine the size of the image it will make and by the "*f*" number which determines the brightness of the image it will cast on the film, i.e., its speed. The brighter the image, the faster the shutter speed can be set and the greater the possibility of stopping action in the picture. Smaller *f* numbers indicate faster lenses.

Spotlight lenses are normally described by their diameter and focal length, not by their *f* number. Nevertheless it can be instructive to determine the *f* number of a simple plano-convex lens and discover the effect of reducing its effective diameter. Consider a 6 x 12 lens: It is 6 inches in diameter and has a focal length of 12 inches. Thus its *f* number is 12 divided by 6 or 2. This would be a rather fast photographic lens. However, if the mounting ring takes one-quarter inch off the radius of the lens (a rather compact mounting), the effective diameter is reduced to 5.5 inches and the *f* number becomes 12 divided by 5.5 or 2.18. This repre-

"*f*" number

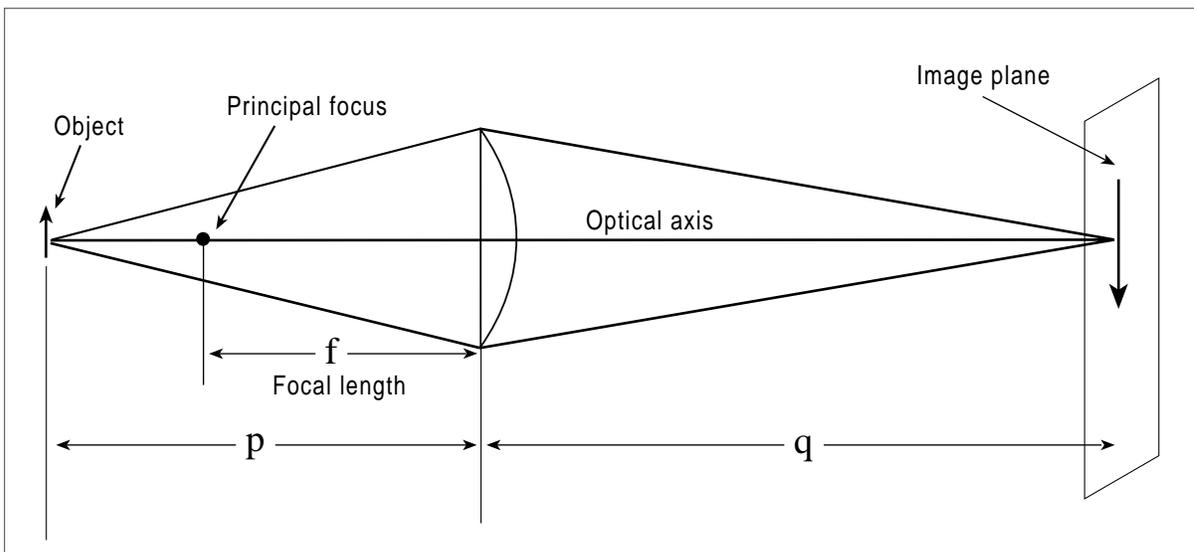


Figure 7.9. Plano-Convex Lens as Objective Lens. The plano-convex lens (or any other positive lens) will form an image of any lighted object located farther from the lens' optical center than the principal focus. Only two rays from a point near the center of the object are traced. Distances "*p*" and "*q*" and the focal length "*f*" are used in the optical formula: $1/p + 1/q = 1/f$.

sents a significant reduction in transmitted light.

Quality objective
lenses

Objective Lenses

An objective lens is a lens operated in a way that causes it to produce an image (Figure 7.9). While any simple positive lens can form an image and sometimes project a usable picture, most objective lenses, designed for use in cameras or projectors, are highly developed masterpieces of the lens maker's art. They are corrected for distortions inherent in a simple lens, such as chromatic and spherical aberration, treated to reduce surface reflections and made of special optical glasses chosen to transmit the most light possible.

Locating the Image

Lens formula

The distance from the lens to the image will vary, moving toward infinity as the slide approaches the principal focus. This relationship between the distance between the image material and the optical center of the lens (which indirectly describes the distance from the principal focus) can be expressed mathematically as:

$$1/p + 1/q = 1/f$$

In which: p = distance from the optical center of the lens to the image material; q = distance from the lens to the focal plane where the sharpest image appears; and f = the focal length of the lens. This formula will prove useful when working with projection equipment.

Depth of Focus

Although there is always one plane on which the image material can be placed to produce the sharpest image on the projection surface and, conversely, a single plane where the image is the sharpest, there is considerable latitude in the focusing process. On either side of the sharpest focal distance is an area where images may still be formed that are practically as good as that at the exact focal plane. The depth of this space measured along the optical axis is known as the *depth of focus* of the lens. In general, the larger the f number of a lens i.e., the slower it is photographically speaking, the greater the depth of focus. Although depth of focus has little relevance to most lighting applications it is important when image projection is the goal. "Doughnuts," disks of metal with holes of various sizes in them, are often added to an ERS to sharpen the image of a gobo. This is the stage equivalent of a photographer "stopping down" the lens (reducing the size of the opening through which the light must pass) and thus increasing its " f " number. The doughnut makes the image sharper but dimmer.

The depth of focus of the objective lens in a sophisticated automated luminaire makes it possible for several image controlling devices to operate effectively in the optical train although they obviously cannot all be at the ideal focal plane. Similarly, scenic projectors (Chapter 16) utilize

lenses designed to be as fast as possible but with adequate depth of focus to accept bulky image devices.

Chromatic Aberration

As already noted, refraction varies with wave length. While this is useful for the purpose of creating a spectrum with a prism, it turns out to be a problem when simple lenses are in use. If the image cast by the lens is sharply focused, it will display color fringes because it is impossible for the lens to focus all of the wavelengths of the visible spectrum on the same plane at the same time. If the lens is being used as a converging lens, the pool of light it produces will display color fringes. If it is functioning as an objective lens, the image will display color fringes throughout. There is no solution to this problem except to mask it by keeping the whole image or pool of light slightly out of focus or by covering the color fringes with light from other sources.

In more sophisticated, and expensive, lenses the chromatic aberration problem is solved by the use of multiple lens elements which are designed to cancel out the aberrations. Such lenses are known as achromatic lenses or achromats.

Color fringes

Achromats

Diffraction

When a beam of light grazes an opaque edge or passes through a slit narrower than its wavelength, it is bent proportional to its wavelength. Thus a surface etched with a series of precisely spaced very fine parallel lines which act as edges, can disperse a beam of light sorting out the beam into its component wavelengths. Such a surface is called a *diffraction grating*.

Gratings can produce wider dispersion of light beams than prisms producing more detailed spectra. Indeed, most spectrometers utilize gratings for exactly this reason.

Diffraction gratings, in the form of mass-produced printed or molded plastic are commonly found as ornaments, as a background security images embossed onto credit cards and even as ornamental foils. All of these gratings evidence their presence by the way they reflect light in varied colors as the observer's angle of view changes.

Theatrical applications of diffraction are presently limited to the use of the ornamental foils for decorative purposes and utilizing spectrograms made by using gratings to analyze the characteristics of theatrical color media.

Diffraction grating