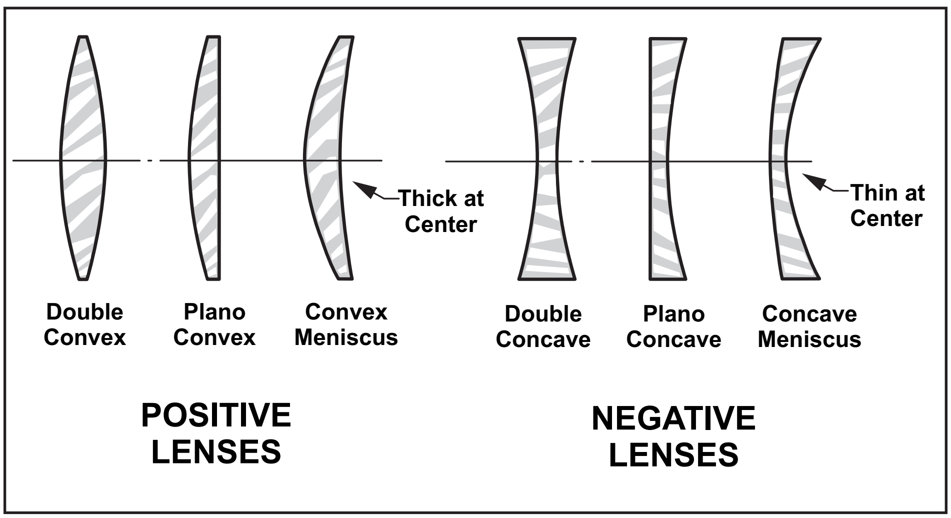
LENSES

An Optics Primer

The pictures made in photography are greatly influenced by the types of lenses used to form the images. Short focal-length lenses exaggerate 3-dimensional space while long focal-length lenses flatten space. Some portrait lenses are designed to have considerable *spherical aberration* to achieve an airy, soft focus appearance.

While the science of lens-making is extremely complicated, some basic optical principles are easily understood by the working photographer. The following is a short primer of lens terms and properties that should prove useful.



Positive and Negative Lenses

All lenses fall into two broad categories - *positive* or *negative* lenses. Positive lenses are identified by their thick center compared to the edges, while negative lenses have a thin center.

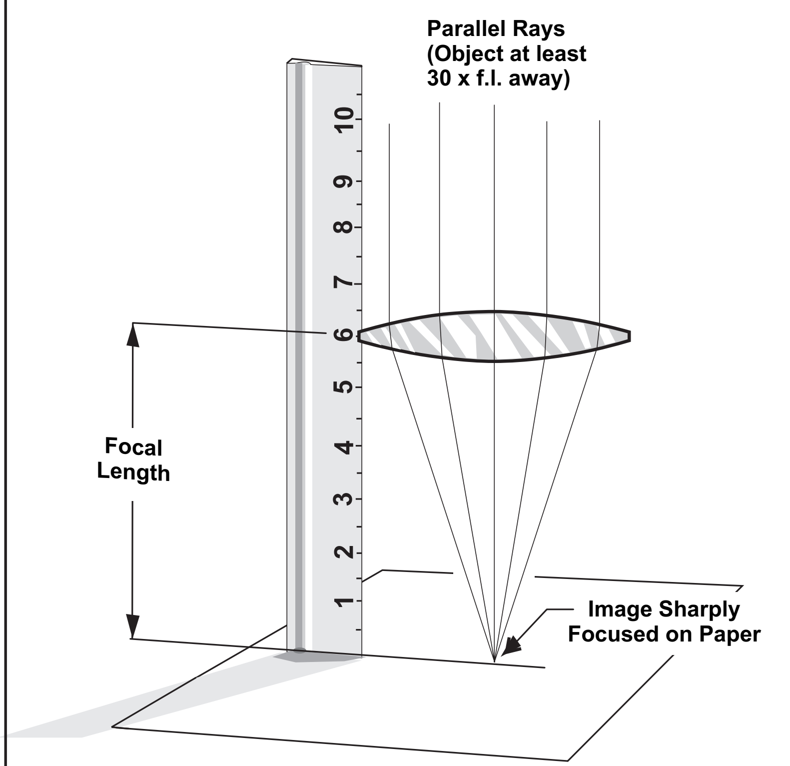
Positive lenses *converge* light rays to form an image of an object, while negative lenses *diverge* light rays and do not form projected images.

Even though negative lenses can't form an image alone, they are often combined with positive lenses to provide an image with reduced aberrations.

Most modern photographic lenses are made of 4 or more individual lens elements combined together to highly correct the resulting image.

Lens Focal Length

Lens *focal length* is the distance from the center of a lens to the projected image of a distant object. (This definition holds for positive lenses only because negative lenses don't project an image.)



FINDING
FOCAL LENGTH

The focal length of a simple dime-store lens can be estimated easily by using a ruler and a light bulb across a room. The focal length is simply the distance from the lens to the projected image of the light bulb.

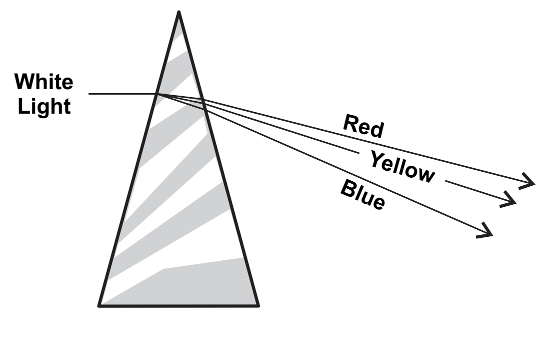
If the ruler reads out in inches, the focal length measurement will be in inches. A millimeter ruler will give you the focal length in the more common metric system.

A rough measurement of focal length can be made of "normal" camera lenses by measuring the distance between the projected image at the camera focal plane and the physical center of the lens. (Keep in mind that clever lens designers often make very short or very long lenses with the "optical center" actually outside of the lens, so the above measurement technique might give misleading results with these lenses.)

Prism

A *prism* is commonly used to separate white light into its component colors. The spectacular result is similar to the common rainbow, where airborne water drops act as a prism. Note that the red colored rays are the least affected by the prism's effect. The blue rays are deflected most by the prism. Red light has a longer wavelength than blue, and it doesn't bend or scatter as easily as the blue.

This explains why sunsets are predominantly red. The red rays are not scattered as much as blue rays after passing through the thick atmosphere, and more easily reach the viewer.



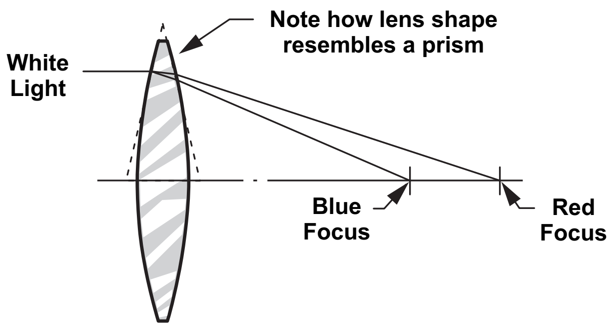
PRISM

Longitudinal Color

Longitudinal color is a spreading of the spectrum due to the prism-like lens shape. A prism breaks light into its component colors, and a simple positive lens is remarkably prism-like in cross section. Because the different colors focus at different points, an image of something containing several colors is not critically sharp.

If film or electronic sensors were not sensitive to all the colors of the spectrum, the aberration wouldn’t matter. In fact, the earlier blue-sensitive films would provide a sharper image than modern emulsions when used with a lens having excessive longitudinal color.

A similar approach using narrow-pass color filters can be employed with panchromatic film or electronic sensors.



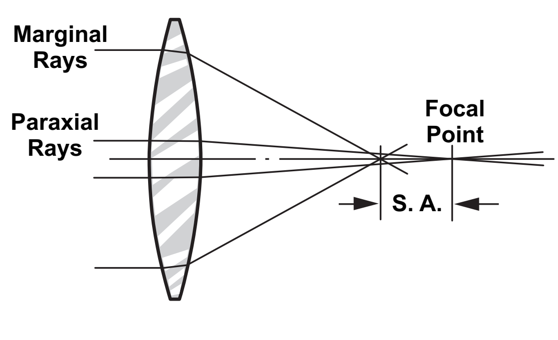
LONGITUDINAL COLOR

Spherical Aberration

Often the rays that pass through the center of a lens focus at a different point from the rays that pass through the edge of the lens. Called *spherical aberration*, this creates a soft-focus effect that is often sought after by portrait photographers.

Some specialized modern lenses are deliberately designed with a substantial amount of spherical aberration in order to provide a flattering soft-focus effect. The Rodenstock Imagon for medium format and view cameras is this type of lens.

Because the effect is caused by the difference between the rays passing through the center and the outer parts of the lens, it is easy to see that spherical aberration is decreased by stopping down the lens to a small aperture. Stopping down allows light rays to pass through the center only, and the aberration is reduced.



SPHERICAL ABBERATION

If you wish to experiment with soft-focus effects without spending much money, you could try using a dime store magnifying lens mounted on a light-tight tube.

You could actually telescope two tubes together to provide some focus control. The shortest distance the lens will be from the film plane is its focal length. As you focus on nearer objects, you will have to extend the lens in its telescoping tube.

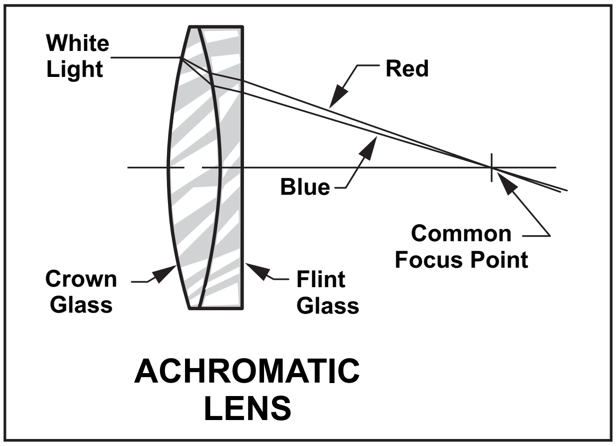
If you intend to make portraits, use a longer lens to avoid perspective problems. You can estimate the focal length of a lens in the store by projecting the image of the store lights onto a nearby surface, and estimating the lens-to-image distance.

A 100 mm (100 mm = 3.94 inches) lens would focus the image at approximately 4 inches from the lens. Its f/number can be found by dividing the focal length by the lens diameter.

In our 100 mm (4 inch) example, if the diameter was 2 inches, then the f/number would be 4 inches divided by 2 inches = f/2. Just remember to use the same system for both measurements to find the correct f/number - don’t mix millimeters and inches.

Achromatic Lenses

An *achromatic lens* (sometimes called an *achromat*) is a lens design comprised of a positive and a negative lens cemented together to provide a substantial degree of correction for longitudinal color and spherical aberration. While they are not entirely free of aberrations, they are a substantial improvement over simple lenses.



If desired, they can be ordered from Edmund Scientific, 101 E. Gloucester Pike, Barrington, NJ 08007 in a variety of focal lengths for just a few dollars each.

If used stopped down (by using a thin metal or cardboard disk with a hole in the center), they should provide reasonable images, especially when using the longer focal-length versions. A 3 or 4 inch (75 or 100 mm) achromatic lens might make an inexpensive 35 mm darkroom enlarger lens with reasonable performance.

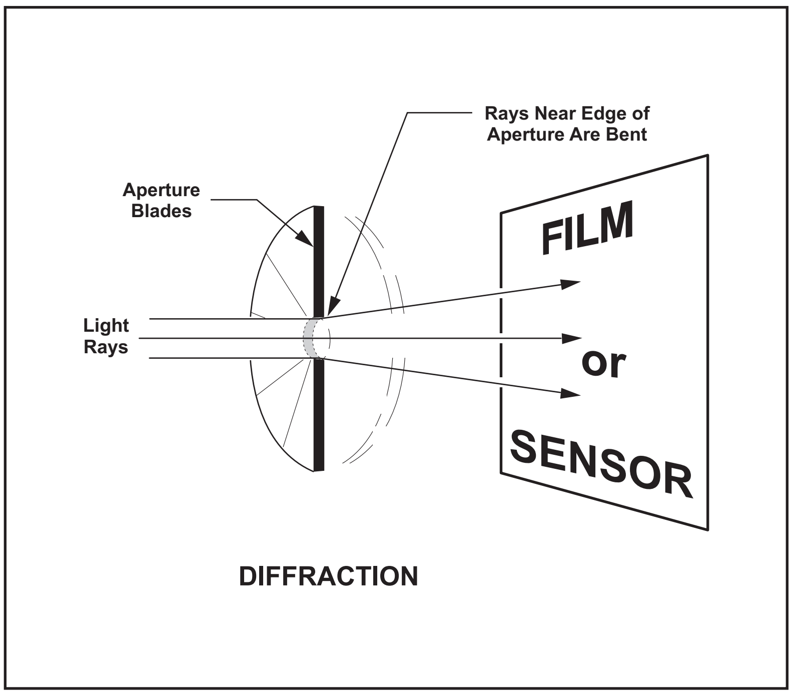
Diffraction

Light rays that pass near an object are bent from their otherwise straight-line path, resulting in a phenomena called *diffraction*. The slight spreading of light rays due to the camera's aperture has profound implications for photography. Because its effect is unavoidable, diffraction imposes an upper limit on the sharpness of any lens.

A theoretically perfect lens can resolve no more than its *diffraction limit*.

Diffraction, while always present, is a small percentage of total aberrations in a wide open lens. A large aperture allows many rays to pass straight through the center unaffected. Lens aberrations including spherical aberration, astigmatism, lateral and longitudinal color, contribute far more to lowered image quality when a lens is used wide open. As a lens is stopped down however, the smaller aperture allows fewer central rays to pass, and the diffracted rays have a proportionally greater effect on the image. At very small apertures, diffraction is the predominant image-degrading effect.

Diffraction is the reason that most lenses have a "best" aperture at which they are sharpest. As a lens is stopped down, the real-world lens aberrations are reduced, but diffraction increases. At some point in the process, the sharpness gained by reducing lens aberrations is offset by the loss caused by diffraction. Beyond this point, a lens will not get sharper by closing down the aperture. It will in fact get worse!



After the point of maximum sharpness, lenses should be stopped down no more than necessary to obtain sufficient depth of field for best results.

An old photographer's rule of thumb is that most lenses are sharpest when closed down two stops from wide open. Another rule of thumb states that lenses have significant diffraction effects when used at an aperture smaller than the focal length (in millimeters) divided by 4. If a lens is stopped down more than this amount, then visible image degradations are likely. As an example, a 50 mm. f/2 lens would likely be sharpest at f/4 (two stops smaller than f/2), and would suffer from significant diffraction effects at apertures smaller than f/11 (50 divided by 4).

While diffraction effects with lenses have been discussed, diffraction also is the limiting factor in producing sharp images with pinhole photography. As the size of the pinhole is reduced, the resulting image is sharpened - until a point. That point is where diffraction begins to have a degrading effect on image quality. In fact, diffraction is the cause of the characteristic pinhole soft-image.