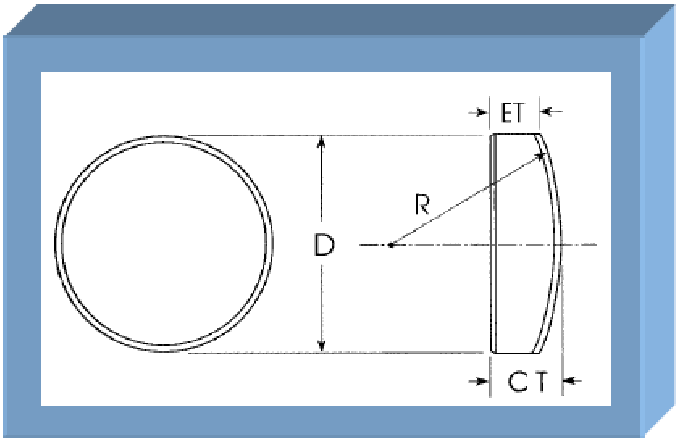
Lenses Design Basics

a) Convex lenses

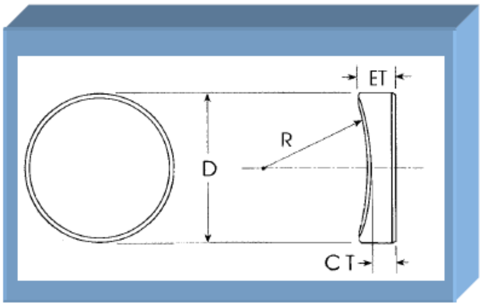
Convex lenses are optical imaging components with positive focus length. After going through the convex lens, parallel beam of light becomes convergent.
Both surfaces of Biconvex lenses are spherical. If the radii of both surfaces of the lens are equal, the lens is called biconvex symmetrical, if the radii are different - we have unsymmetrical biconvex lens. The special kind of the latter is plane-convex lens, in which one radius equals ∞.



Optimal selection of radii depends on material, and required magnification of the lens. There is no possibility to eliminate chromatic aberrations of single lens, which depend on the relationship between index of refraction and wavelength used. It means that when the wavelength is changed, any existing arrangement of single lenses has to be adjusted.
Plano- convex lens is a special kind of unsymmetrical positive lens, where one surface is plane, and radius of the other depends on refraction index of the glass used, and the required refracting power. The planoconvex lenses are usually used for focusing plane parallel beam (Placing convex side of the lens next to the collimated beam minimize the spherical aberration).

b) Concave lenses

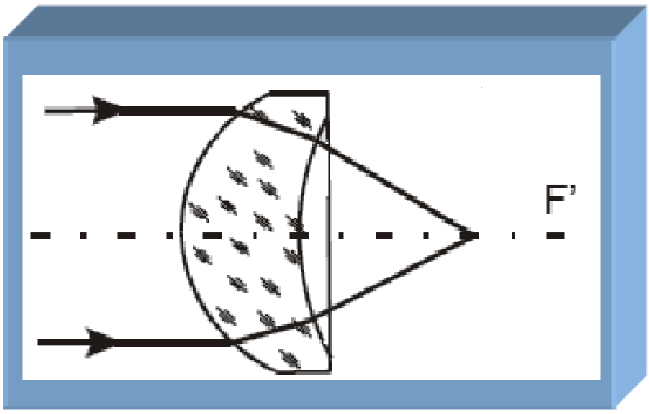
Single concave lenses spread, optical imaging elements with negative focal length. Collimated beam of light going through the lens becomes divergent and thus the image obtained is virtual. It can be observed through the lens in the incident direction of the light, only.
Biconcave lenses have two spherical, concave surfaces. When the radii of both surfaces are equal - we call the lens symmetrical biconcave lens; if however, they differ - then we get unsymmetrical biconcave lens. Special version of unsymmetrical biconcave lens is plano-concave lens, in which one of the radii of curvature equals = ∞ which means that one of the surfaces is plane.



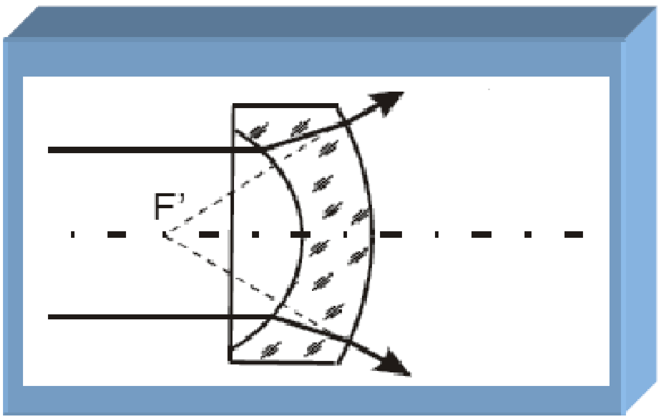
Biconcave unsymmetrical lenses with minimized spherical aberration are called best form lenses. These lenses should be adjusted in such away that
they face the beam of smaller divergence with the shorter radius side.
The special version of biconcave unsymmetrical lens is plano-concave lens. Single plano-concave lens is mainly used for expansion of laser beam or for divergence beam of light collimation.

c) Meniscus (Concave-convex lenses)

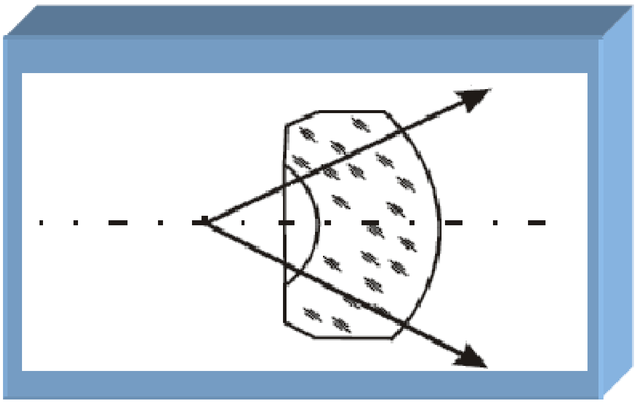
One surface of meniscus lenses is concave, while the other - convex one. A meniscus lens is almost always used in combination with other kinds of lenses to build systems with focal length shorter or longer than that of the original lens.
1. Positive meniscus lens focuses a beam of light.



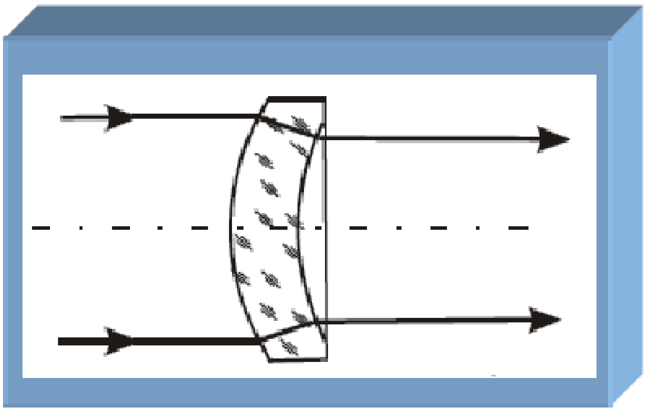
2. Negative meniscus lens diverges a beam of light.



3. zero-meniscus lens have both surfaces concentric. The lens does not change the divergence of the beam.

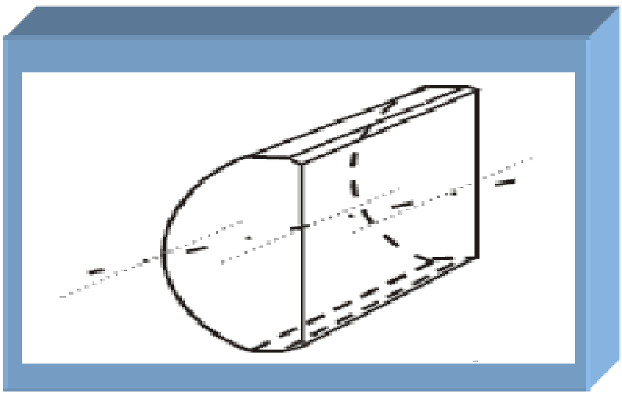


4. Zero meniscus lens also does not change the divergence of the beam, but makes it shift parallel.



d) Cylindrical lenses

Cylindrical lenses are optical imaging components with one of the surfaces being cylindrical instead of spherical. The second surface in this kind of lenses is usually flat. As the cylindrical surface deflects the rays in one direction only, it transforms the point image not into a point as in the case of spherical lenses, but into a line.

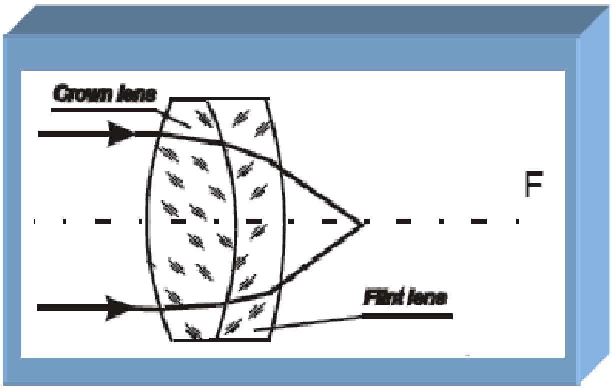


One can use the cylindrical lenses in illuminating systems of line detectors or slotted diaphragms in spectroscopy, in medical techniques for making pattern indicators in scanners.

e) Achromats

Achromats are optical components composed of lenses produced from different materials for correction of chromatic aberrations. An achromat, which consists of two lenses, is called achromatic doublet.

Typical selection of glasses: flint glass + crown glass Achromats work like focusing or diverging lenses, because they can have either positive or negative foci.



Lens Formula

These are some of the insights of fundamentals of lens design

Where,

D: diameter of lens
f_1, f_2: focal length
L_1, L_2: object's size
R_1, R_2: radius of curvature of lens
S_1, S_2: principal point

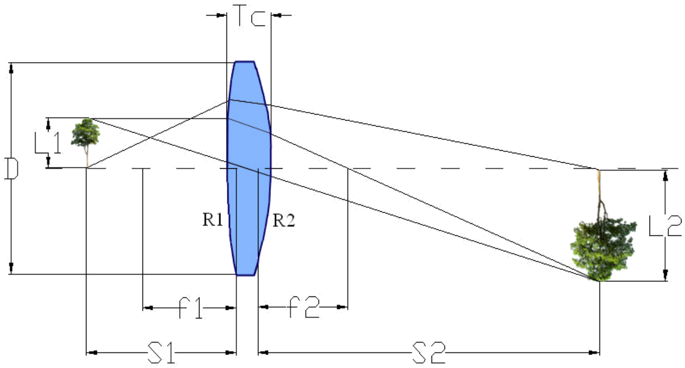
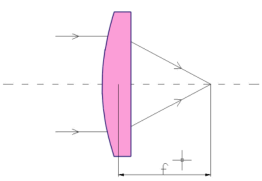


Fig. Typical Representation of light passage through a lens

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \left(\frac{(n-1)}{n}\right)\left(\frac{T_c}{R_1 R_2}\right)\right]$$

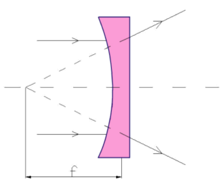
$$M = \frac{L_2}{L_1} = \frac{S_2}{S_1}$$

Simplified formulas of effective focal length of different types of thin lens are given by:



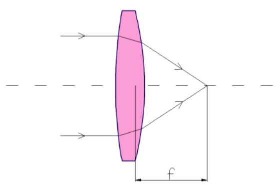
Plano-Convex

$$f = \frac{R}{(n-1)}$$



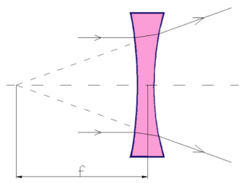
Plano-Concave

$$f = -\frac{R}{(n-1)}$$



Bi-convex

$$\frac{1}{f} = \frac{(n-1)}{R}\left[2 - \left(\frac{(n-1)}{n}\right)\left(\frac{T_c}{R}\right)\right]$$



Bi-concave

$$\frac{1}{f} = -\frac{(n-1)}{R}\left[2 - \left(\frac{(n-1)}{n}\right)\left(\frac{T_c}{R}\right)\right]$$

Technical Definitions

Power: The number of times a lens or lenses multiplies an image with respect to the original size. Low power is recommended for scanning large surfaces. Higher powers are generally used for inspecting small areas.

Field of View: The maximum area seen through a magnifier. The entire field of view may not be in focus. See Flatness of Field.

Flatness of Field: Due to the physical laws of optics, the outer part of the image formed by a lens may be out of focus. The greater the power and curvature of the lens, the more pronounced this problem becomes. Magnifiers with multiple lenses can reduce this problem. The visible area which appears in focus is the flat field.

Working Distance: The distance from the magnifier lens to the object being viewed. As magnification power increases, the working distance decreases.

Aberration: This is a distortion caused by the lens. Spherical aberration is distortion of the image, as explained in Flatness of Field. Chromatic aberration is distortion of colors being viewed, as explained in Color Distortion.

Color Distortion: Lenses produce a prism effect which causes the image to develop false color fringes. This is due to the fact that different colors focus at different points. Achromatic lenses correct this problem by focusing many colors at the same point.

Parallax: Parallax is the apparent misalignment of two different items when viewed from an angle. It is the cause of improper registration when stripping multiple color jobs. Parallax is eliminated when viewing straight down on registration marks instead of from a slight angle.

Coated Lens: A coated lens helps to minimize or eliminate color distortion caused by different colors focusing at different locations. Optimum color viewing is obtained from coated achromatic lenses.