Principles for Photography (optics)

Nature of Light

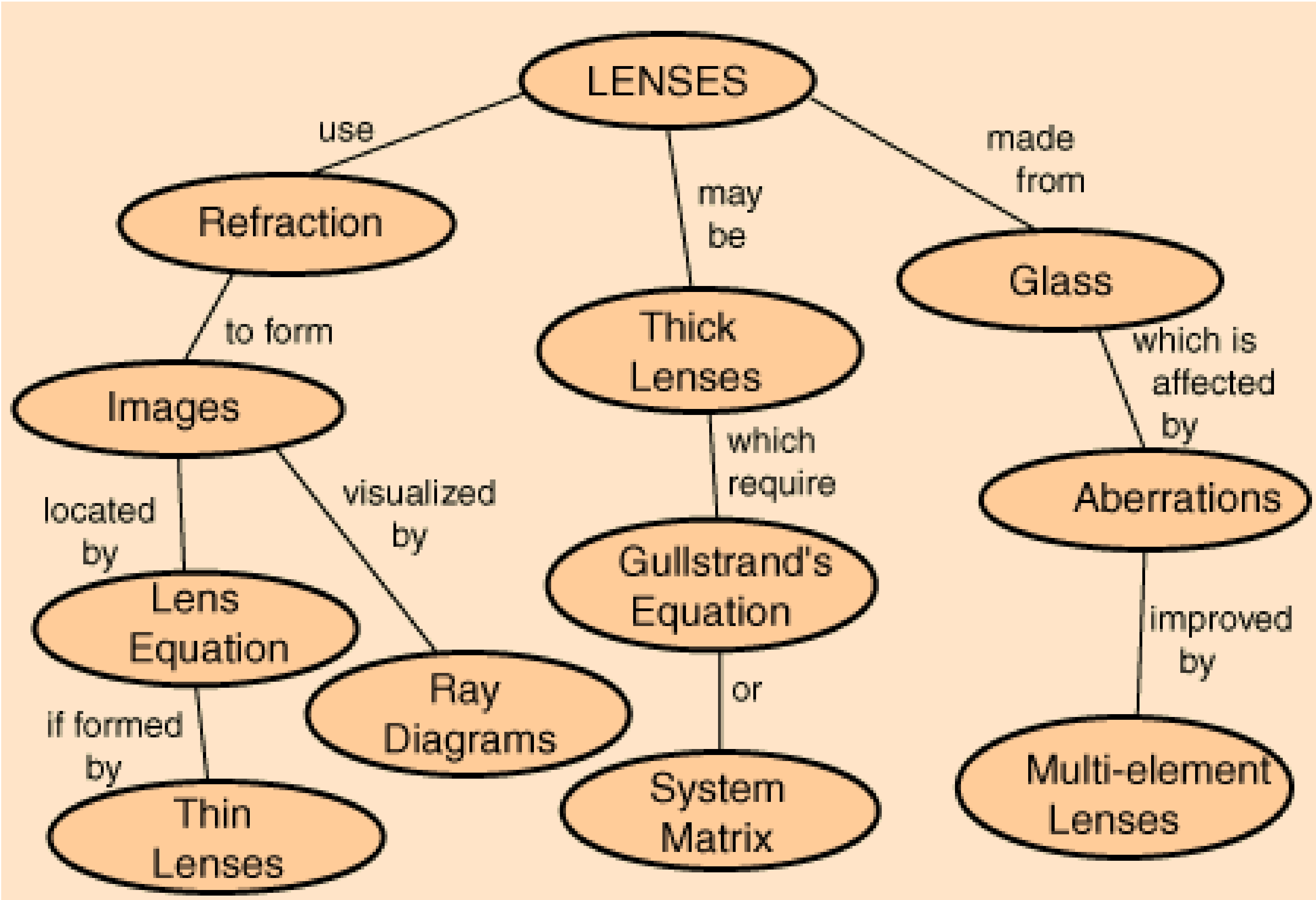
- **Light** is the portion of electromagnetic radiation that is visible to the human eye, responsible for the sense of sight.
- Visible light has a wavelength in a range from about 380 or 400 nanometres to about 760 or 780 nm,
- frequency range of about 405 THz to 790 THz

Nature of light.............

- Primary properties of light are intensity, propagation direction, frequency or wavelength, polarization, and phase
- Speed, about 300,000,000 meters per second (300,000 kilometers per second) in vacuum
- One of the fundamental constants of nature.

Nature of light...........

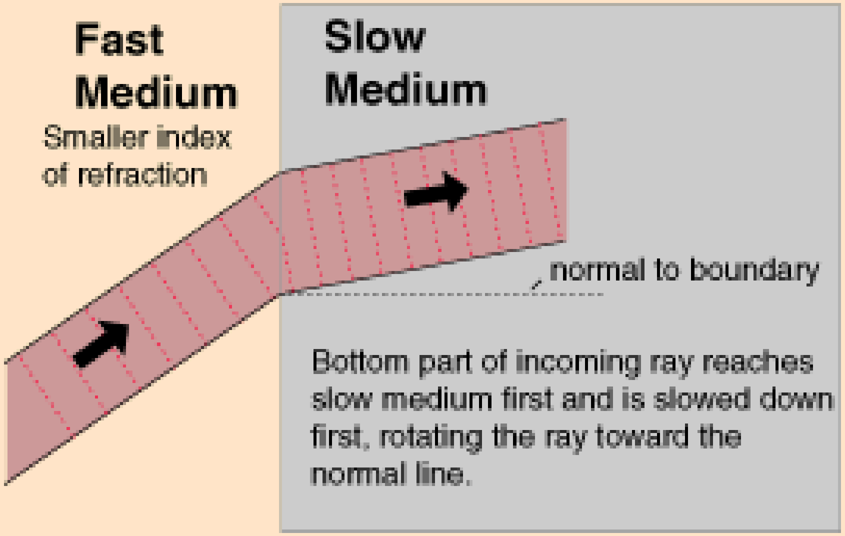
- Light exists in tiny "packets" called photons
- exhibits properties of waves and particles.
- Study of light(optics)
- Important research area in many disciplines.


LENSES
use
made from
may be
Refraction
Glass
to form
Thick Lenses
which is affected by
Images
which require
Aberrations
visualized by
located by
Gullstrand's Equation
Lens Equation
improved by
Ray Diagrams
or
if formed by
System Matrix
Multi-element Lenses
Thin Lenses

Refraction of Light

Refraction is the bending of a wave when it enters a medium where it's speed is different. The refraction of light when it passes from a fast medium to a slow medium bends the light ray toward the normal to the boundary between the two media. The amount of bending depends on the indices of refraction of the two media and is described quantitatively by Snell's Law.

Refraction is responsible for image formation by lenses and the eye.

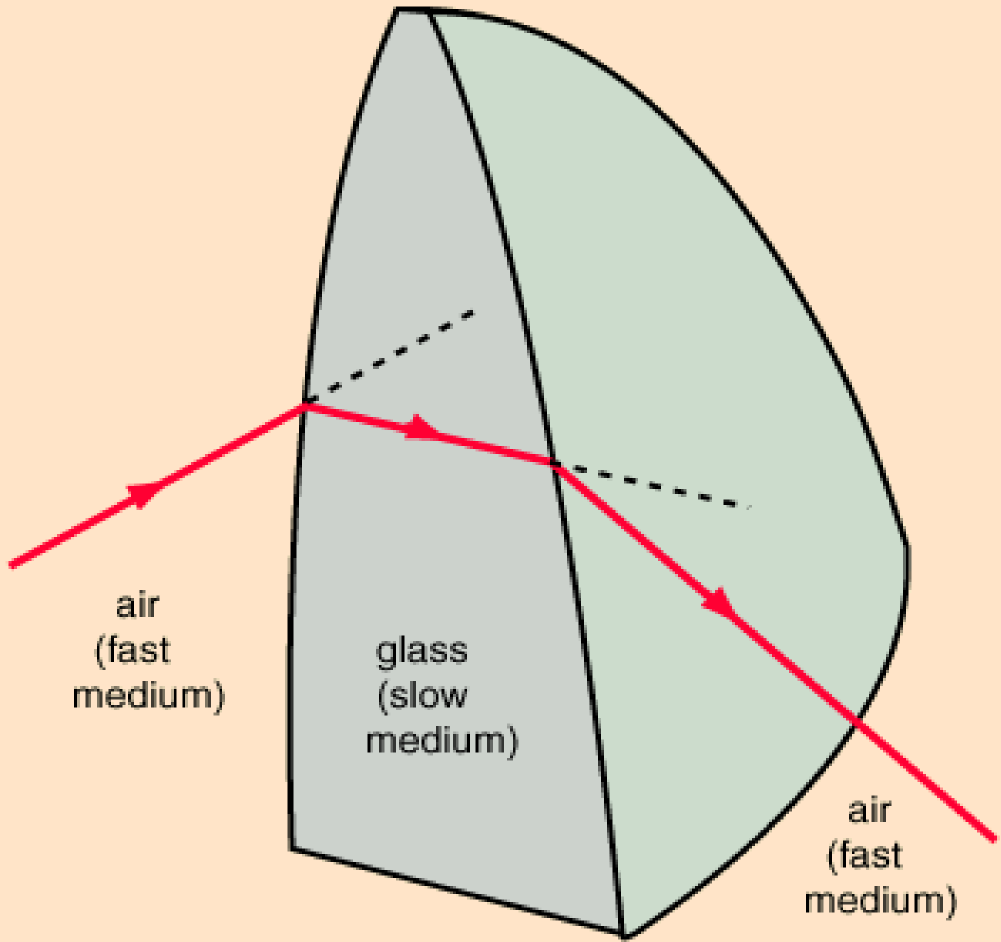


As the speed of light is reduced in the slower medium, the wavelength is shortened proportionately. The frequency is unchanged; it is a characteristic of the source of the light and unaffected by medium changes.

Refraction by a Convex Lens

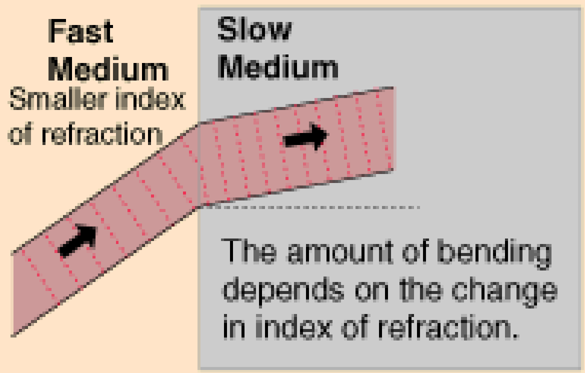
Refraction bends the light downward upon entering the glass because the bottom part of the ray hits the slow medium first.

Light travels more slowly in glass than in air. The amount of bending depends upon the index of refraction of the glass.



Index of Refraction

The index of refraction is defined as the speed of light in vacuum divided by the speed of light in the medium.



$$n = \frac{c}{v}$$

The indices of refraction of some common substances are given below with a more complete description of the indices for optical glasses given elsewhere. The values given are approximate and do not account for the small variation of index with light wavelength which is called dispersion.

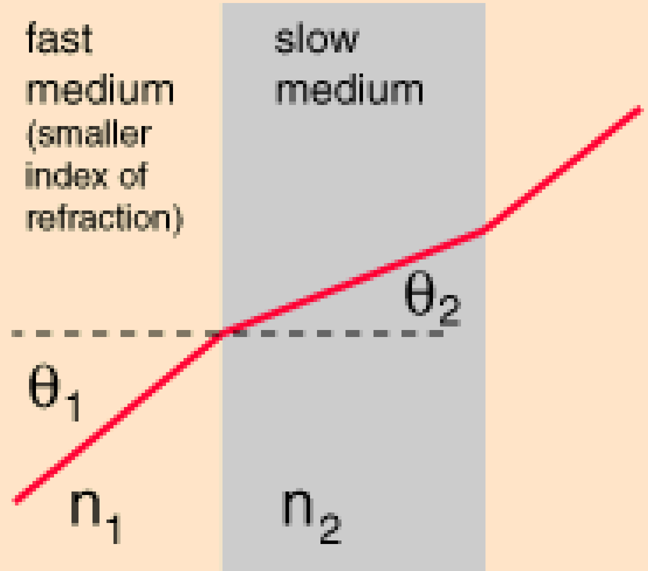
Vacuum	1.000	Ethyl alcohol	1.362
Air	1.000277	Glycerine	1.473
Water	4/3	Ice	1.31
Carbon disulfide	1.63	Polystyrene	1.59
Methylene iodide	1.74	Crown glass	1.50-1.62
Diamond	2.417	Flint glass	1.57-1.75

Snell's Law

Snell's Law relates the indices of refraction n of the two media to the directions of propagation in terms of the angles to the normal. Snell's law can be derived from Fermat's Principle or from the Fresnel Equations.

Snell's Law

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$



Optical Glasses

The most common types of glasses used in optics are crown glasses and flint glasses, designations based on their dispersions. Flint glasses contain lead. These designations are further subdivided by composition and have letter designations and number designations called "glass numbers".

Example data for glasses:

Glass	Glass Number	Density gm/cm^3
Borosilicate BK7	517642	2.51
Crown K5	522595	2.59
Dense barium crown SK4	618551	3.57
Dense flint SF6	805254	5.18

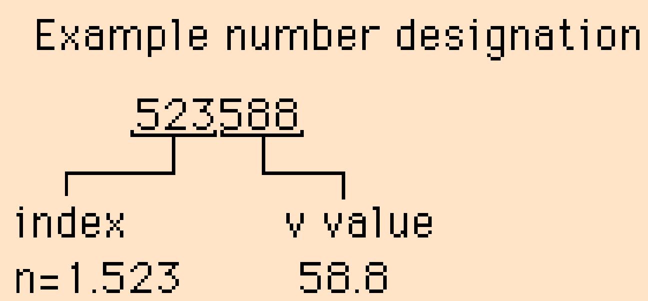
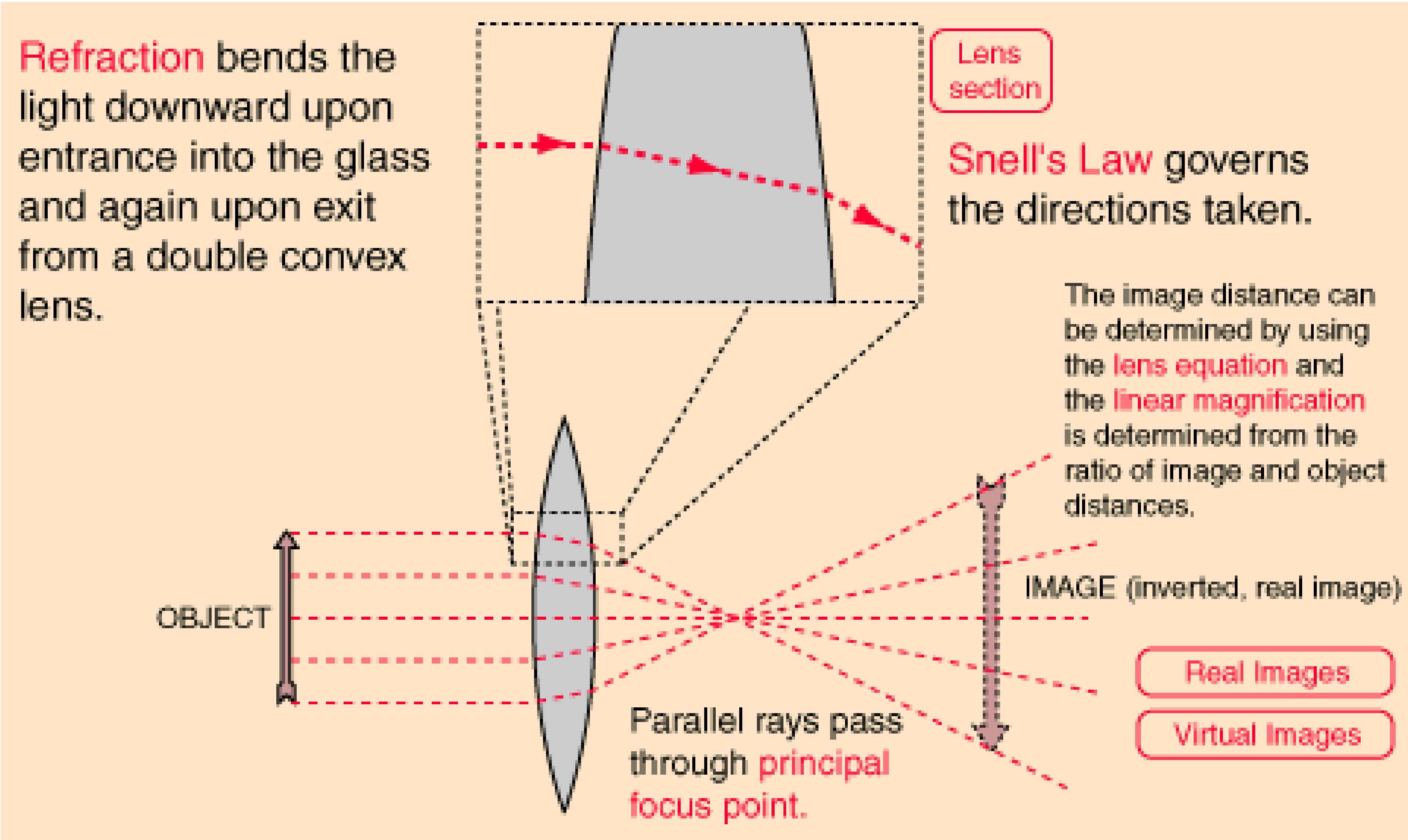
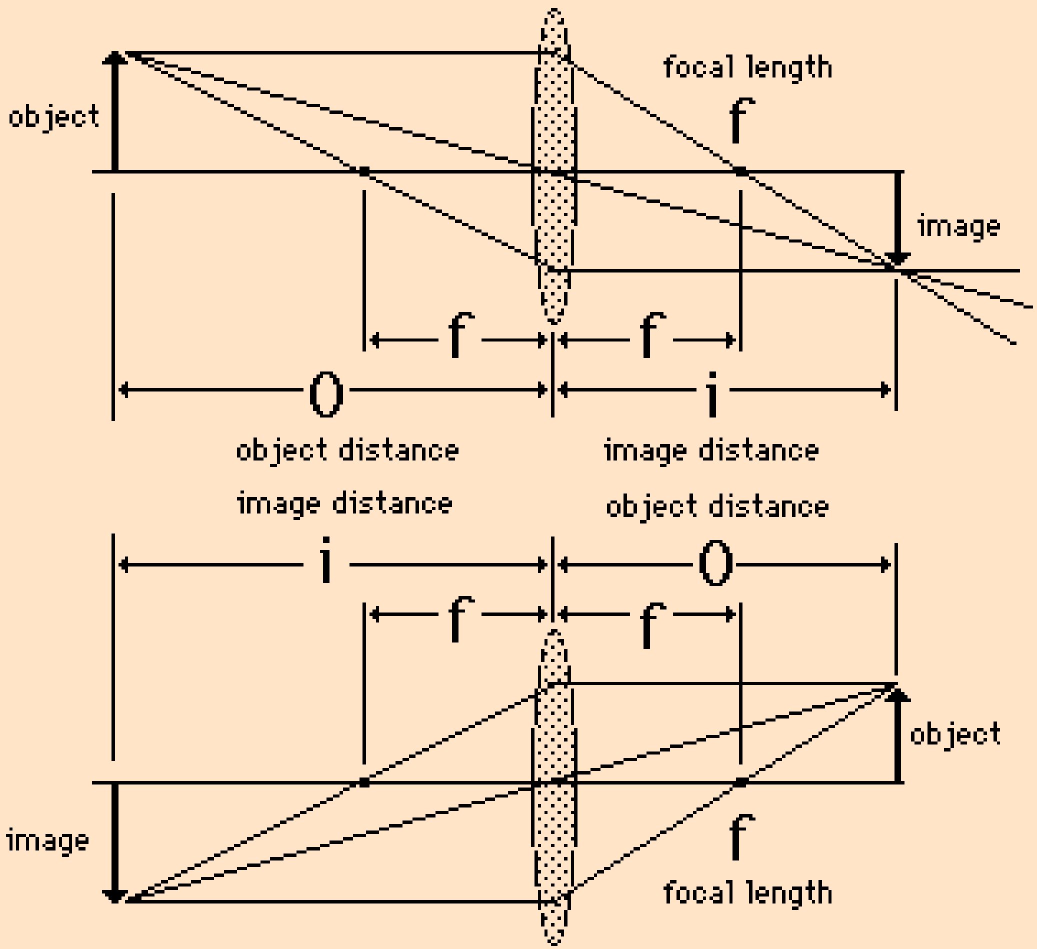


Image formation

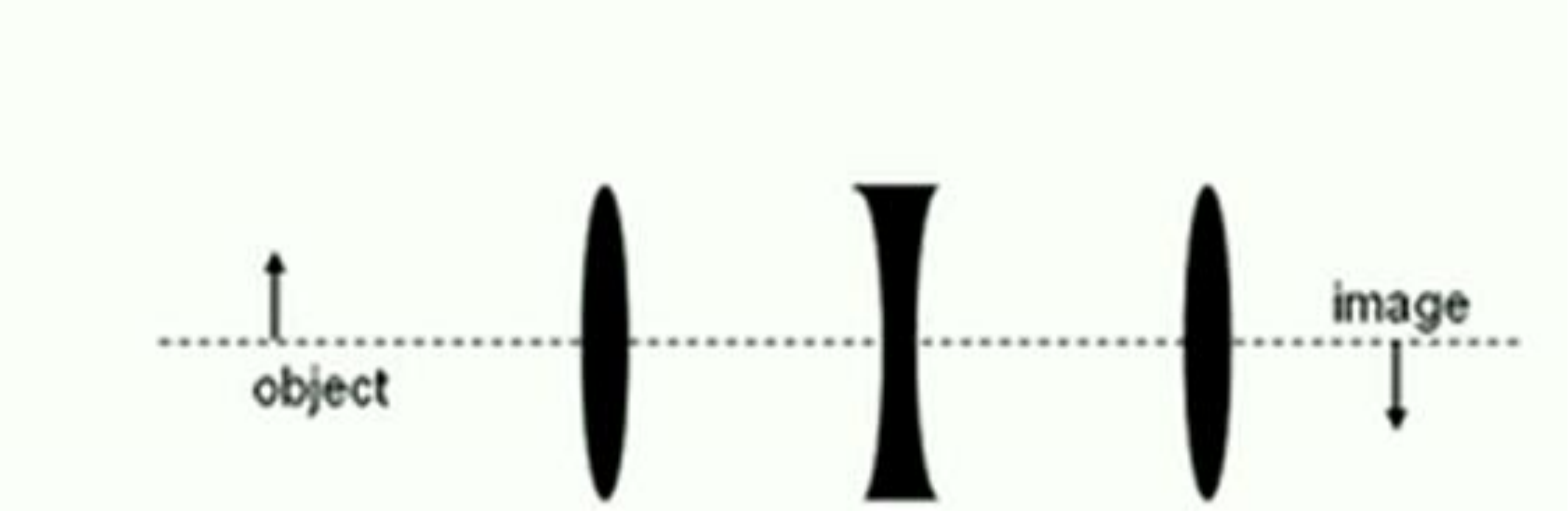


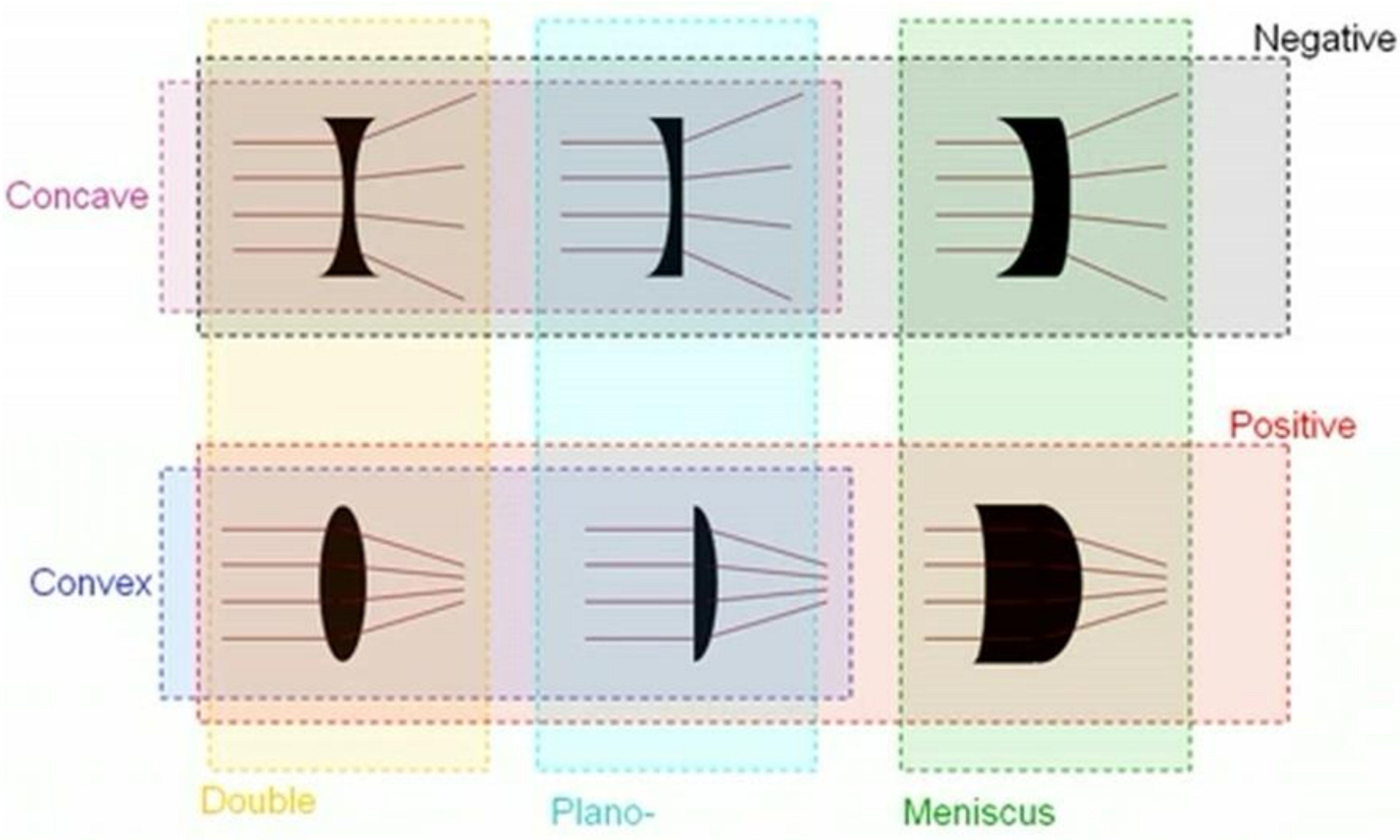
Conjugate Points



The object point and image piont of a lens system are said to be conjugate points. Since all the light paths from the object to the image are reversible, it follows that if the object were placed where the image is, an image would be formed at the original object position.

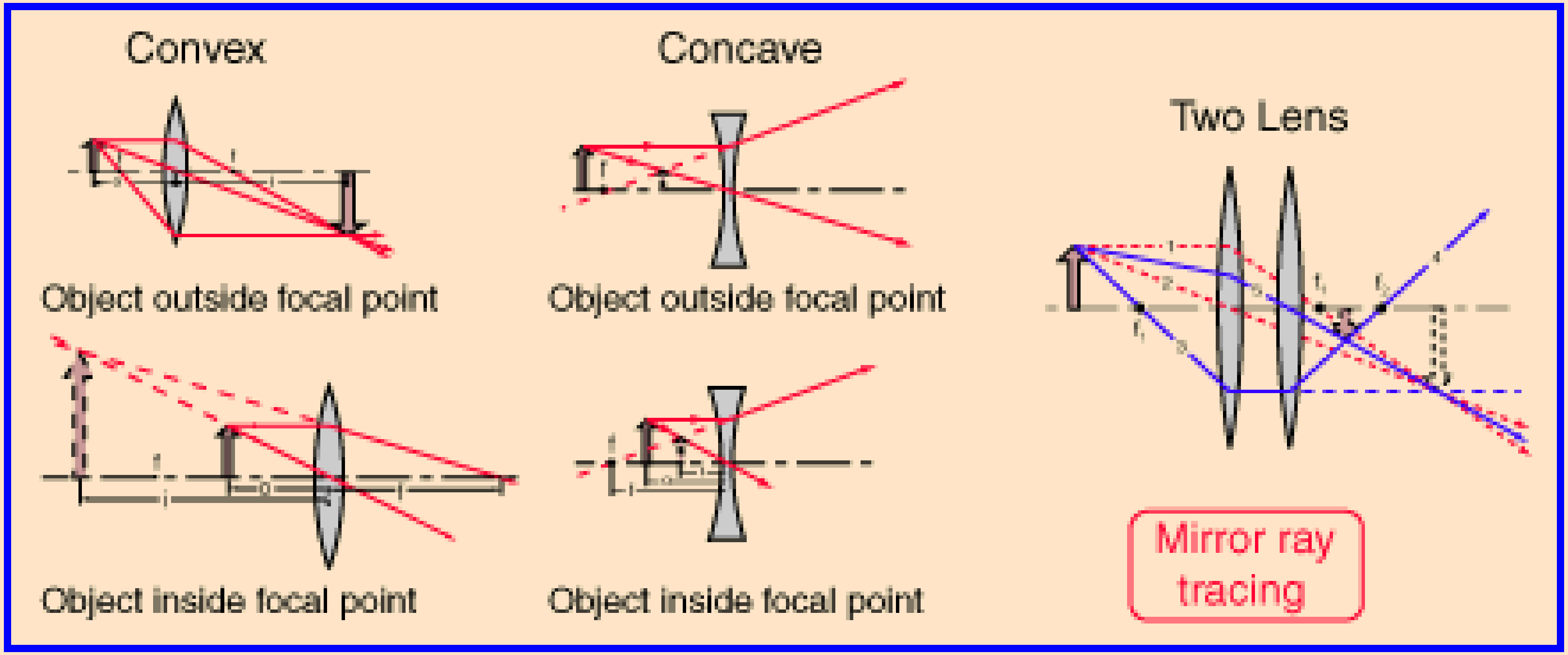
How Lenses manipulate light




Negative
Concave
Positive
Convex
Double
Plano-
Meniscus

Ray Diagrams for Lenses

The image formed by a single lens can be located and sized with three principal rays. Examples are given for converging and diverging lenses and for the cases where the object is inside and outside the principal focal length.

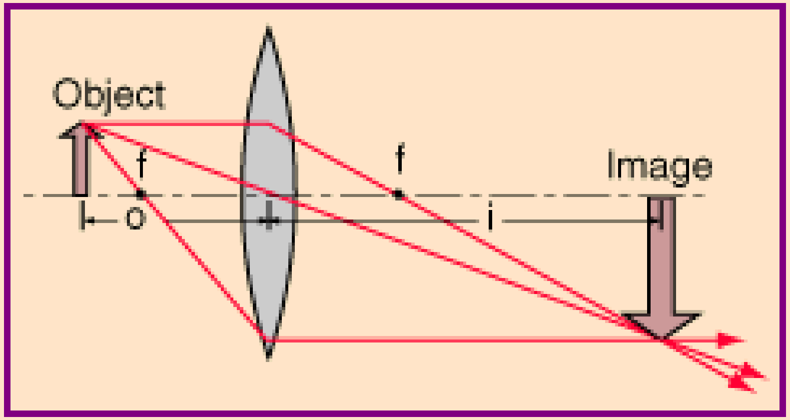


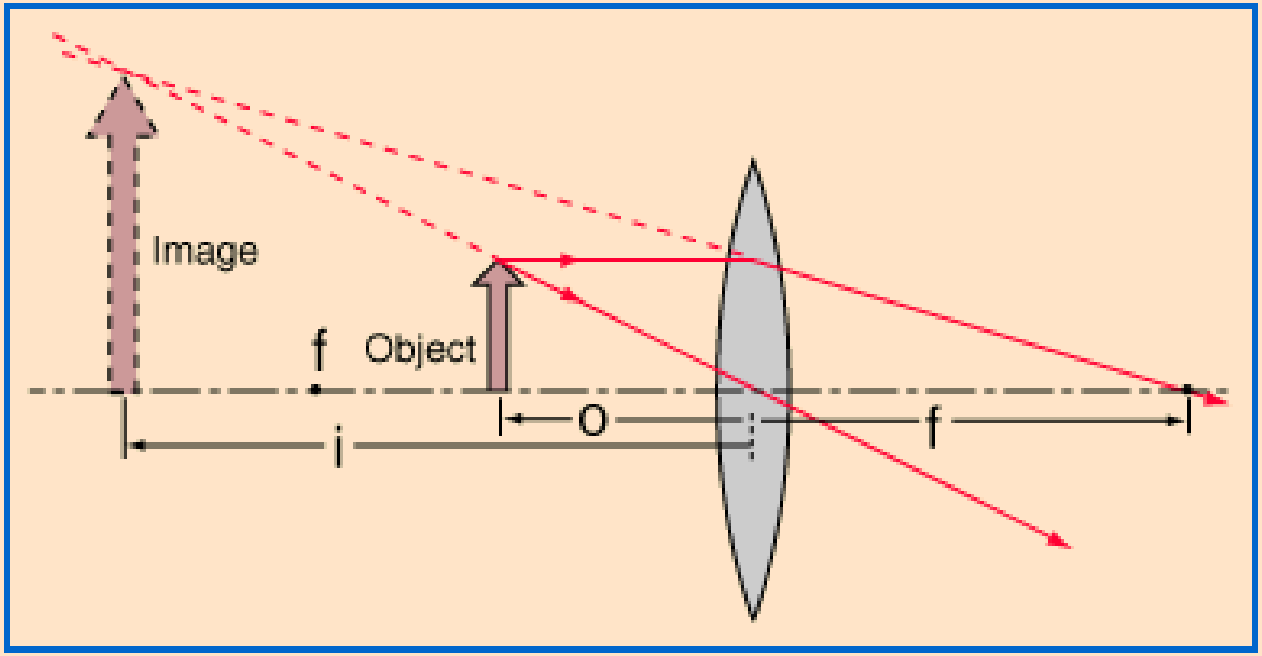
The "three principal rays" which are used for visualizing the image location and size are:

1. A ray from the top of the object proceeding parallel to the centerline perpendicular to the lens. Beyond the lens, it will pass through the principal focal point. For a negative lens, it will proceed from the lens as if it emanated from the focal point on the near side of the lens.
2. A ray through the center of the lens, which will be undeflected. (Actually, it will be jogged downward on the near side of the lens and back up on the exit side of the lens, but the resulting slight offset is neglected for thin lenses.)
3. A ray through the principal focal point on the near side of the lens. It will proceed parallel to the centerline upon exit from the lens. The third ray is not really needed, since the first two locate the image.

Ray Diagrams for Convex Lenses

For an object outside the focal point, a real inverted image will be formed.

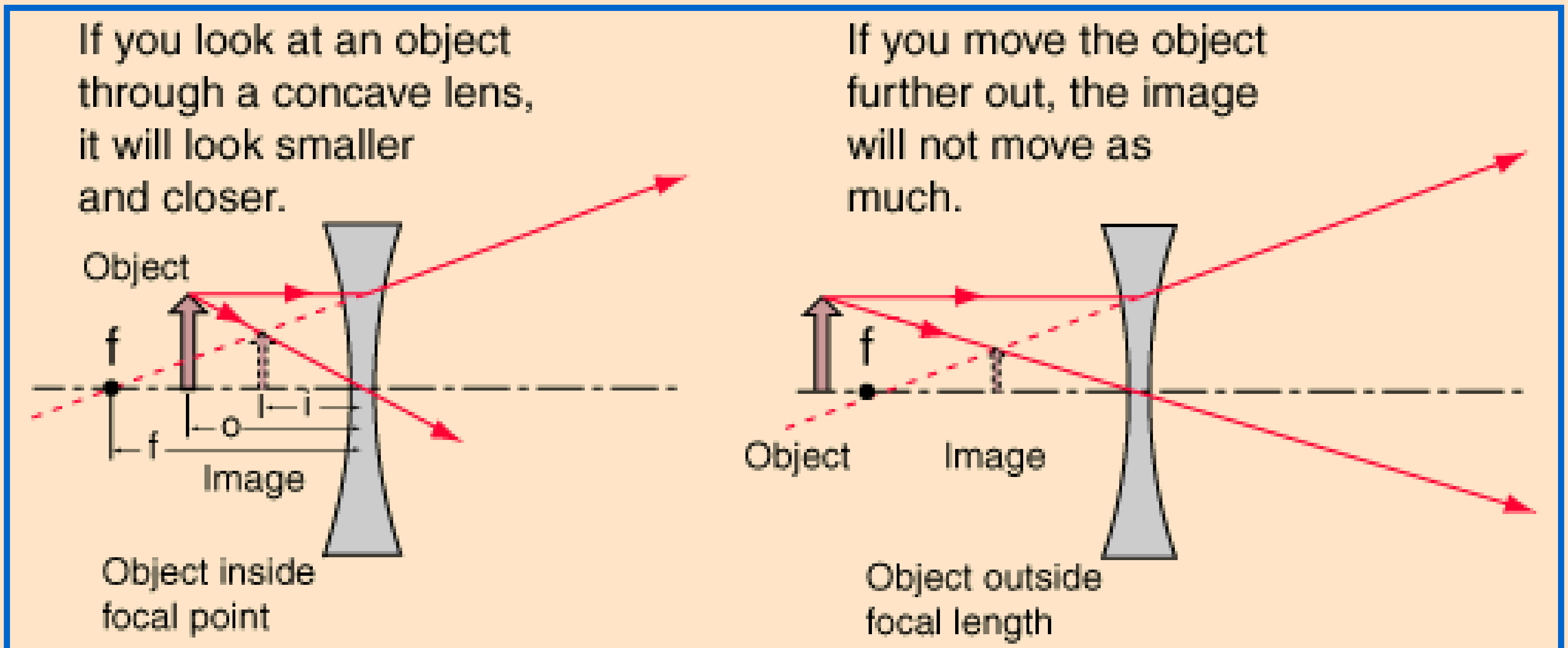




For an object inside the focal point, a virtual erect image will be formed.

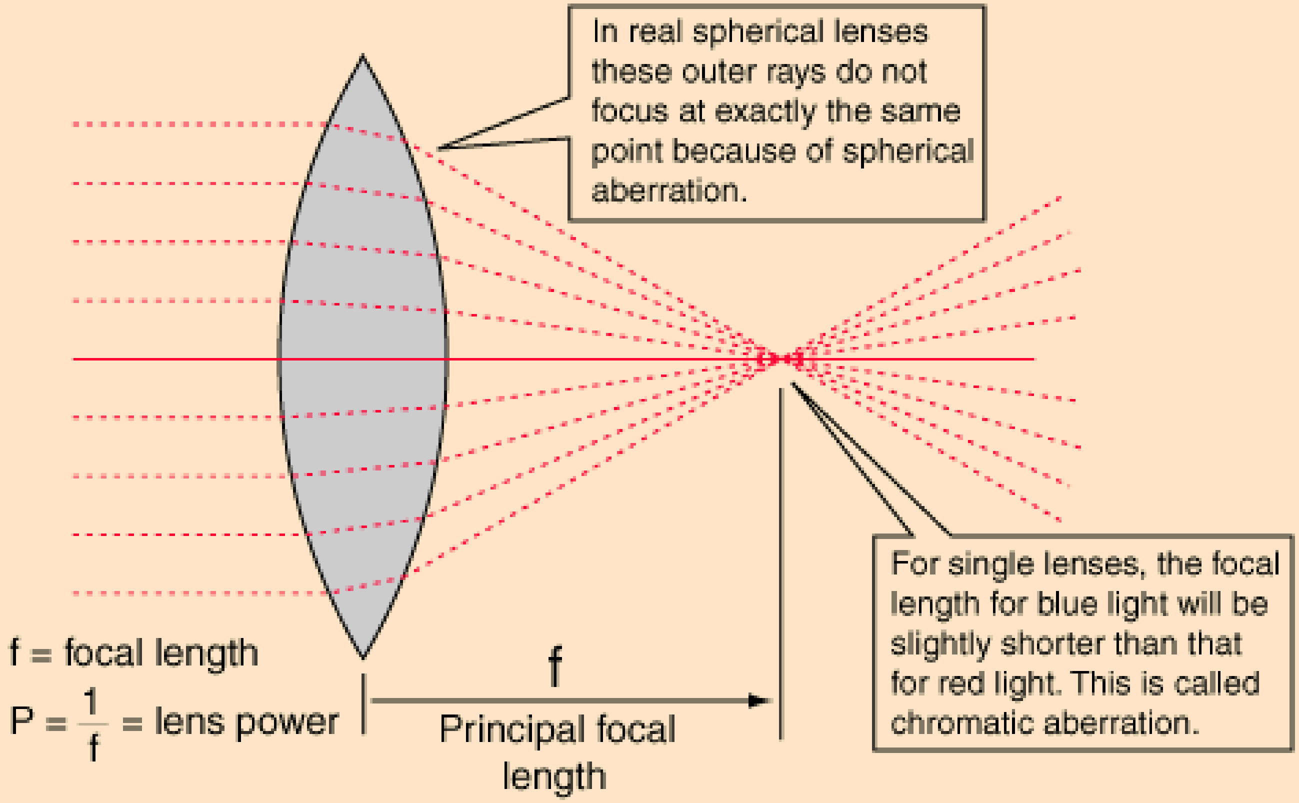
Ray Diagrams for Concave Lenses

The ray diagrams for concave lenses inside and outside the focal point give similar results: an erect virtual image smaller than the object. The image is always formed inside the focal length of the lens.



Focal Length and Lens Strength

The most important characteristic of a lens is its principal focal length, or its inverse which is called the lens strength or lens "power". Optometrists usually prescribe corrective lenses in terms of the lens power in diopters. The lens power is the inverse of the focal length in meters: the physical unit for lens power is 1/meter which is called diopter.

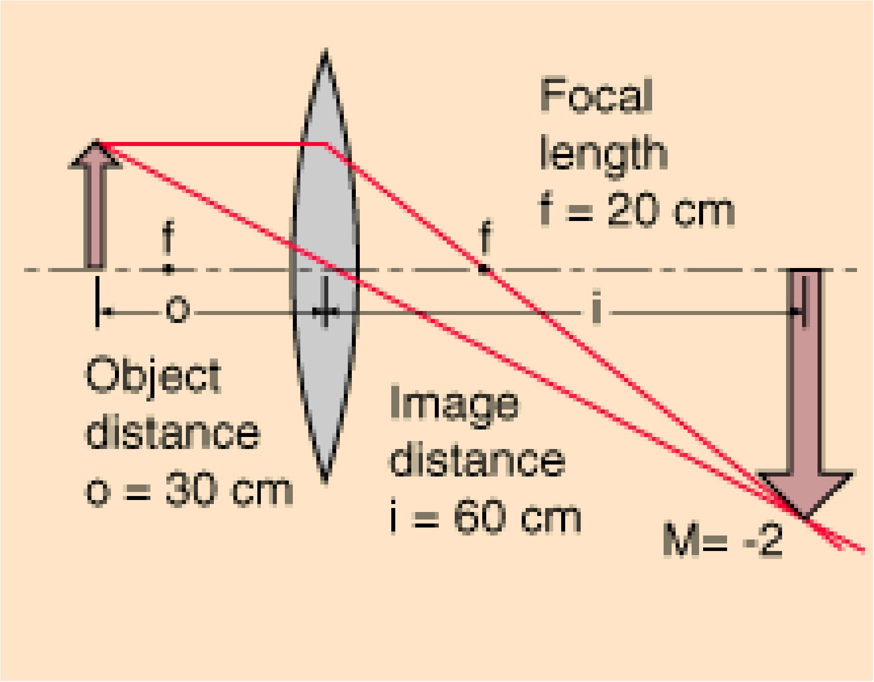


The Thin Lens Equation

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$

$$\frac{1}{\text{object distance}} + \frac{1}{\text{image distance}} = \frac{1}{\text{focal length}}$$

Negative image distance>image is a virtual image on the same side of the lens as the object.



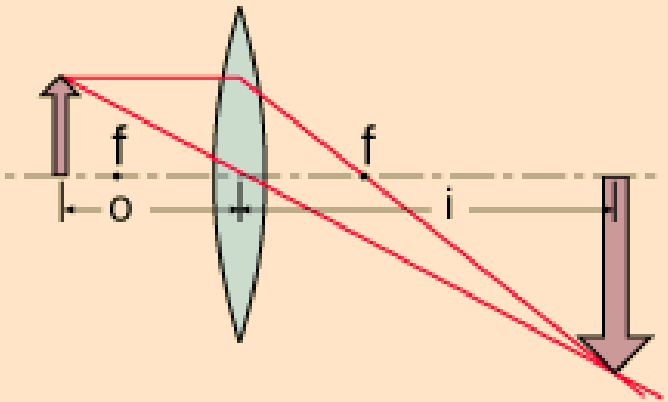
- Negative focal length> diverging lens rather than the converging lens in the illustration

- Lens equation> used to calculate the image distance for either real or virtual images and for either positive on negative lenses

- linear magnification relationship> predict the size of the image

Magnification:Transverse &Angular

The linear magnification or transverse magnification is the ratio of the image size to the object size. If the image and object are in the same medium it is just the image distance divided by the object distance.



$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$ Lens equation

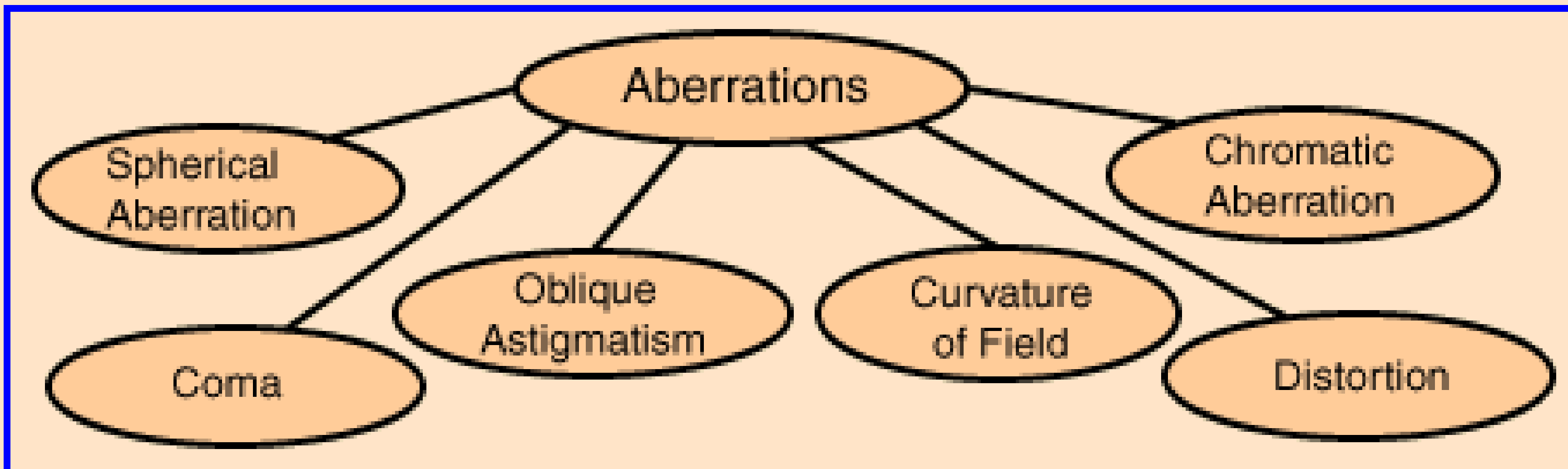
Linear magnification:

$$M = \frac{-i}{o} = \frac{h'}{h}$$

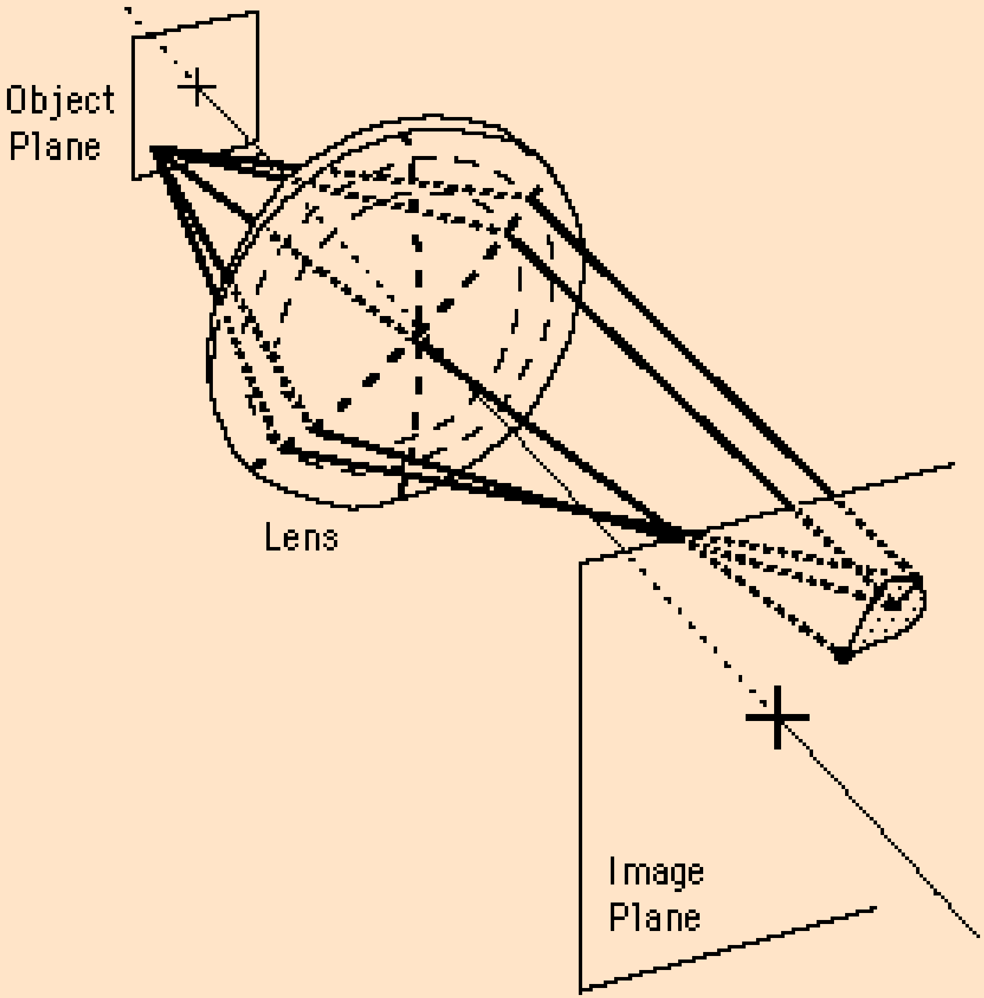
Using the Gaussian form of the lens equation, a negative sign is used on the linear magnification equation as a reminder that all real images are inverted. If the image is virtual, the image distance will be negative, and the magnification will therefore be positive for the erect image.

Aberrations

In an ideal optical system, all rays of light from a point in the object plane would converge to the same point in the image plane, forming a clear image. The influences which cause different rays to converge to different points are called aberrations.

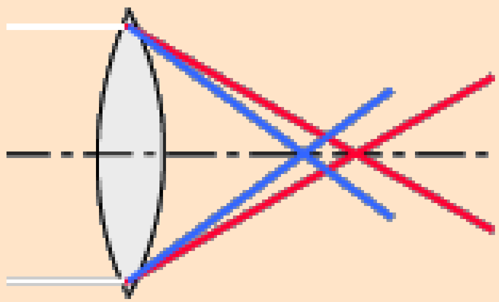


Coma

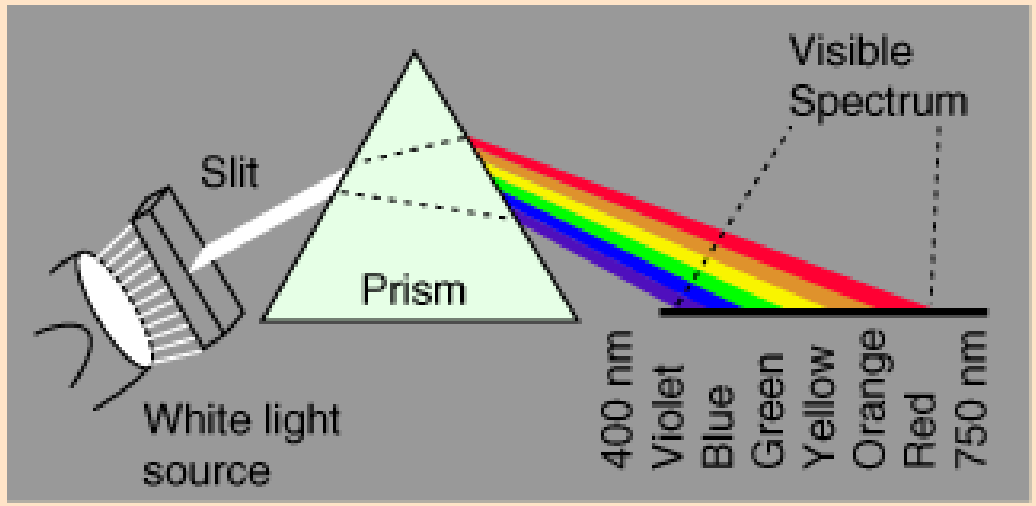


Coma is an aberration which causes rays from an off-axis point of light in the object plane to create a trailing "comet-like" blur directed away from the optic axis. A lens with considerable coma may produce a sharp image in the center of the field, but become increasingly blurred toward the edges. For a single lens, coma can be partially corrected by bending the lens. More complete correction can be achieved by using a combination of lenses symmetric about a central stop.

Dispersion



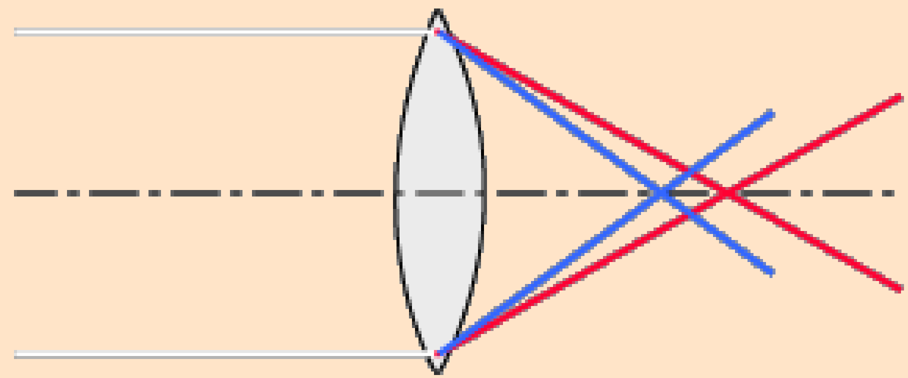
Chromatic aberration arising from dispersion.

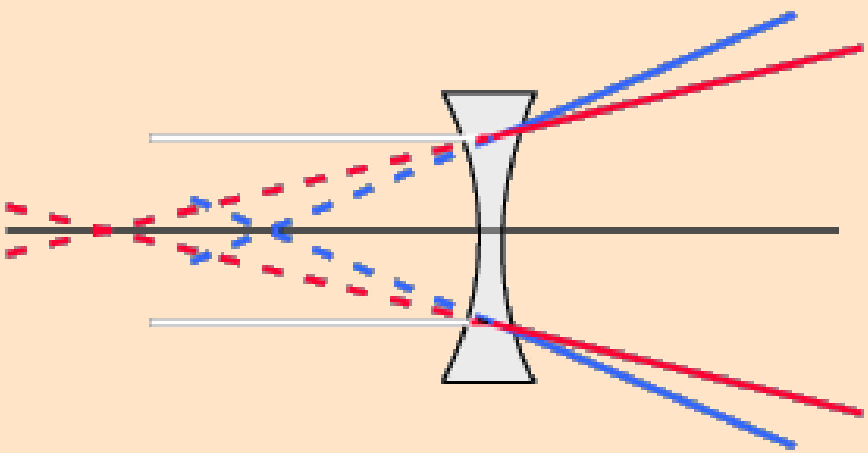


Separation of colors by a prism is an example of dispersion.

Chromatic Aberration

A lens will not focus different colors in exactly the same place because the focal length depends on refraction and the index of refraction for blue light (short wavelengths) is larger than that of red light (long wavelengths). The amount of chromatic aberration depends on the dispersion of the glass.

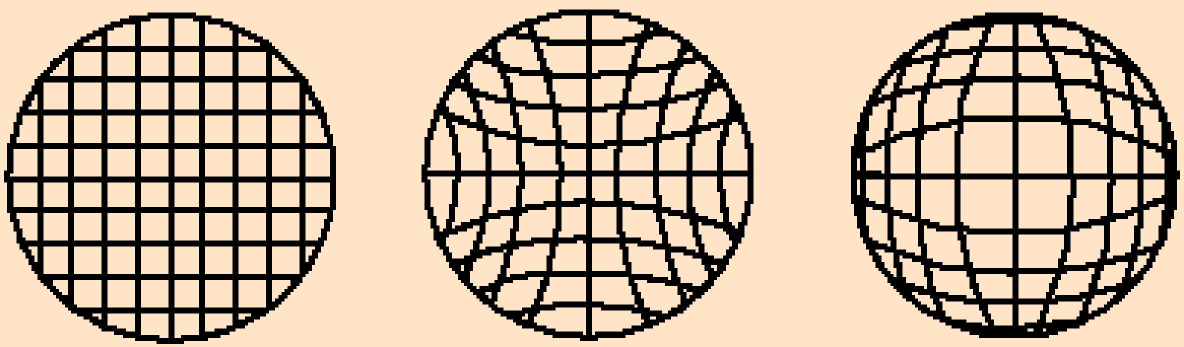




One way to minimize this aberration is to use glasses of different dispersion in a doublet or other combination.

Distortion

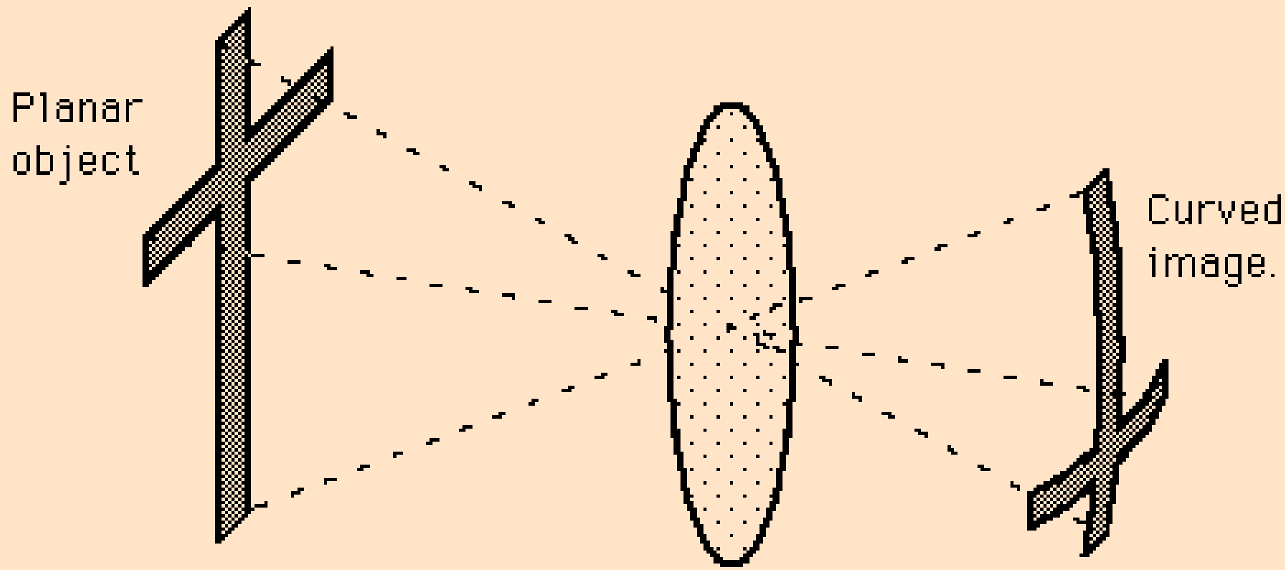
Other than distortions from lens imperfections, certain distortions occur from the geometry of the lens. The barrel and pincushion distortions below can be readily seen in the image formed by a thick double convex glass lens. They are the reason for a practical limitation in the magnification achievable from a simple magnifier. These distortions are mimimized by using symmetric doublets such as the orthoscopic doublet and eyepieces such as the Ramsden eyepiece.



Undistorted Image | Pincushion Distortion | Barrel Distortion

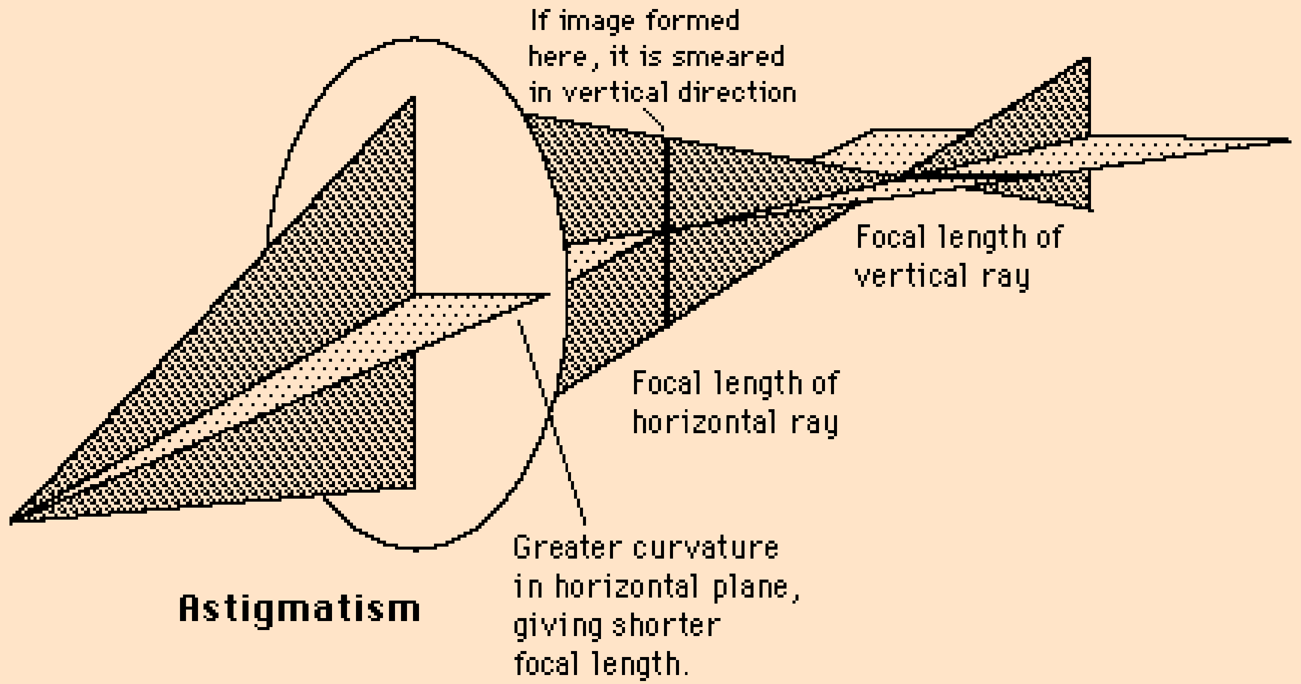
Curvature of Field

Curvature of field causes an planar object to project a curved (nonplanar) image. It can be thought of as arising from a "power error" for rays at a large angle. Those rays see then lens as having an effectively smaller diameter and an effectively higher power, forming the image of the off axis points closer to the lens.



Astigmatism

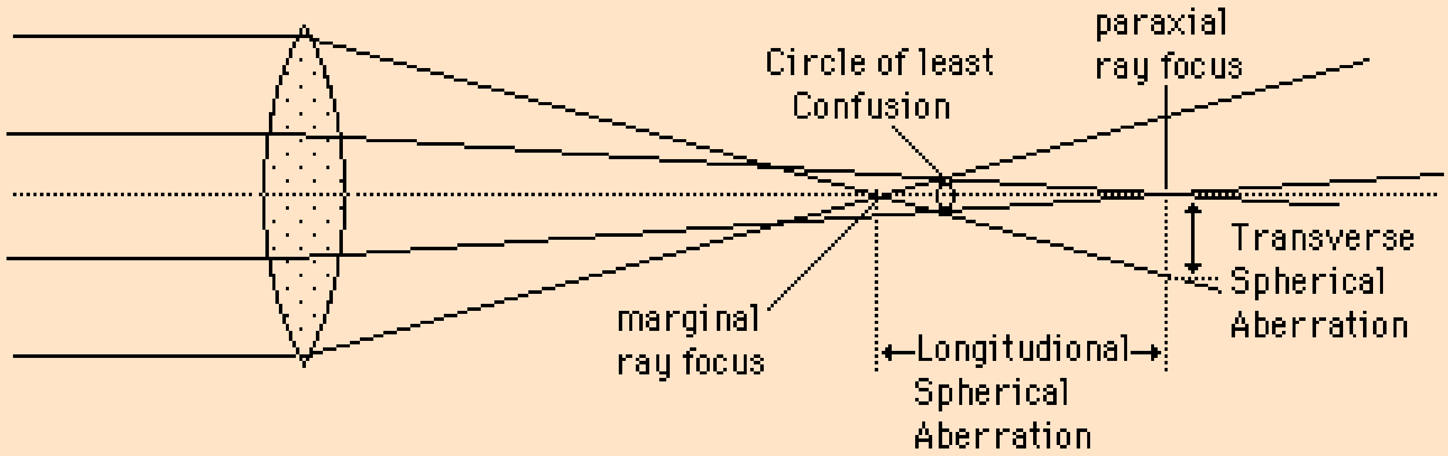
The kind of astigmatism commonly encountered as a vision defect is a result of different lens curvatures in different planes.



A more general type of astigmatism, which occurs for off-axis rays through any spherically ground lens, is called oblique astigmatism.

Spherical Aberration

For lenses made with spherical surfaces, rays which are parallel to the optic axis but at different distances from the optic axis fail to converge to the same point. For a single lens, spherical aberration can be minimized by bending the lens into its best form. For multiple lenses, spherical aberrations can be canceled by overcorrecting some elements. The use of symmetric doublets greatly reduces spherical aberration.



And that's the fun part …