OPTICS
ABERRATIONS IN LENSES

Learning Material

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Power of a Lens and Aberration in Lenses

- **The greater effect of a lens on light rays, the more powerful it is said to be.**
- **The light will also focus into a smaller and more intense spot for a more powerful lens**
- **Power of a lens is its ability to converge (focus) or diverge the incident light rays**

The *power P* of a lens is defined to be the inverse of its focal length. In equation form, this is P=1/f

The **power** *P* of a lens is defined to be the **inverse** of its **focal length**. In equation form, this is P=1/f where *f* is the focal length of the lens, which must be given in meters (and not cm or mm).

The power of a lens *P* has the unit diopters (D), provided that the focal length (f) is given in meters.. Thus, when *f* = 8.00 cm.

To find the power of the lens, we must first convert the focal length to meters; then, we substitute this value into the equation for power. This gives P=1/f=1/0.0800 m=12.5 D

converging lens: a convex lens in which light rays that enter it parallel to its axis converge at a single point on the opposite side

diverging lens: a concave lens in which light rays that enter it parallel to its axis bend away (diverge) from its axis.

focal point: for a converging lens or mirror, the point at which converging light rays cross; for a diverging lens or mirror, the point from which diverging light rays appear to originate.

focal length: distance from the center of a lens or curved mirror to its focal point.

Magnification (m): ratio of image height (h_I) to object height (h_O) or ratio of image distance (v) to object distance (u),

$m = h_I / h_O$ or $m = v/u$

power: inverse of focal length $P = 1/f$

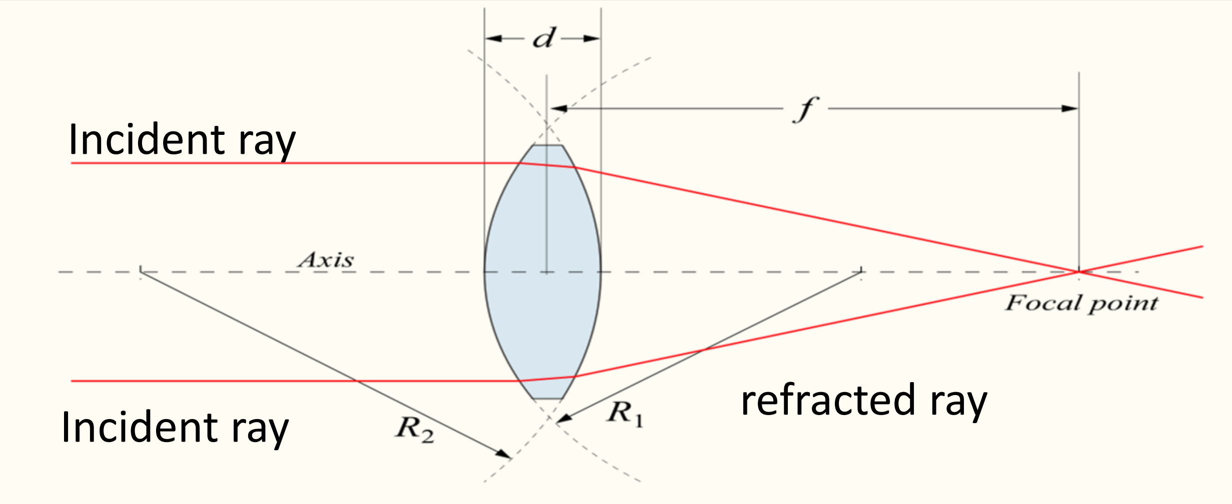
real image: image that can be projected

virtual image: image that cannot be projected

Sign convention for radii of curvature R_1 and R_2.

All the distances above the axis are taken as positive and distances below the axis are taken as negative.

All the distances to the left of a lens are taken as negative and at right are taken as positive



Positive (converging) lens

The focal length of a lens *in air* can be calculated from the **lensmaker's equation**:

lensmaker's equation

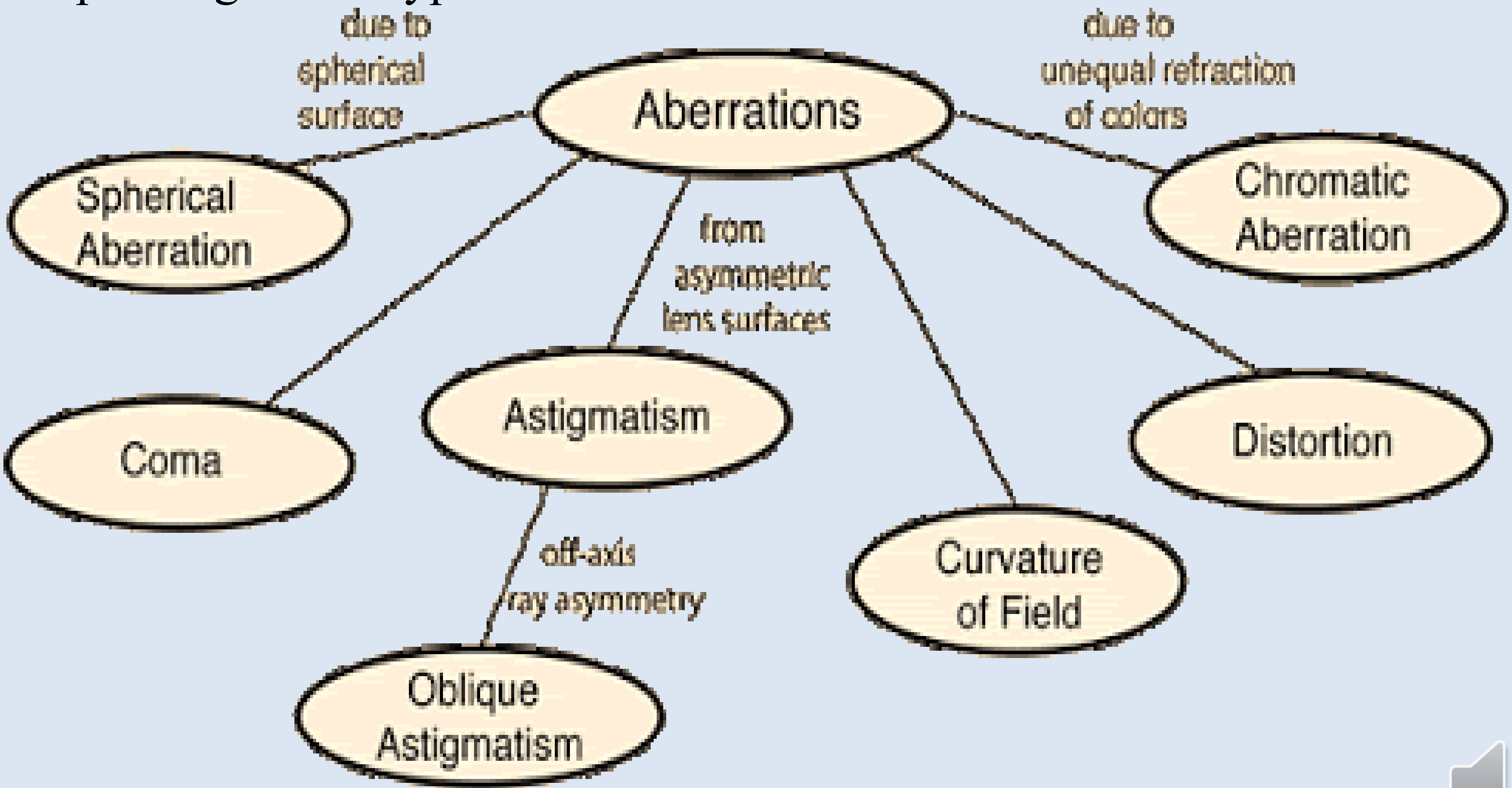
$1/f = (n-1)\,(1/R_1 - 1/R_2)$ where,

f is the focal length of the lens,
n is the refractive index of the lens material,
R_1 *and* R_2 are the radii of curvatures.

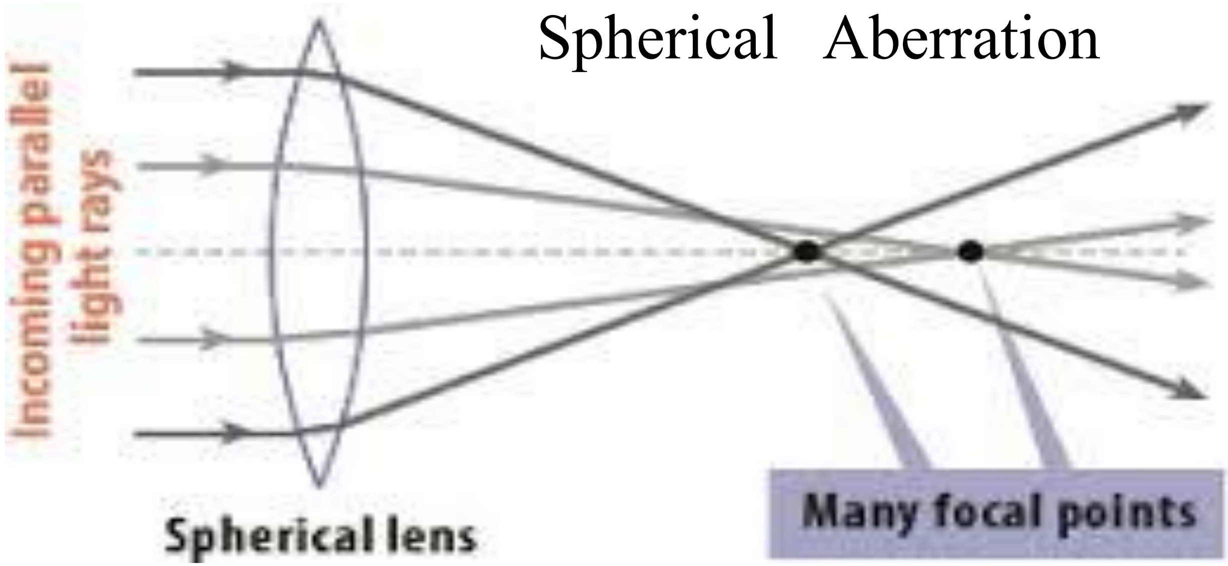
The focal length *f* is positive for converging lenses, and negative for diverging lenses.

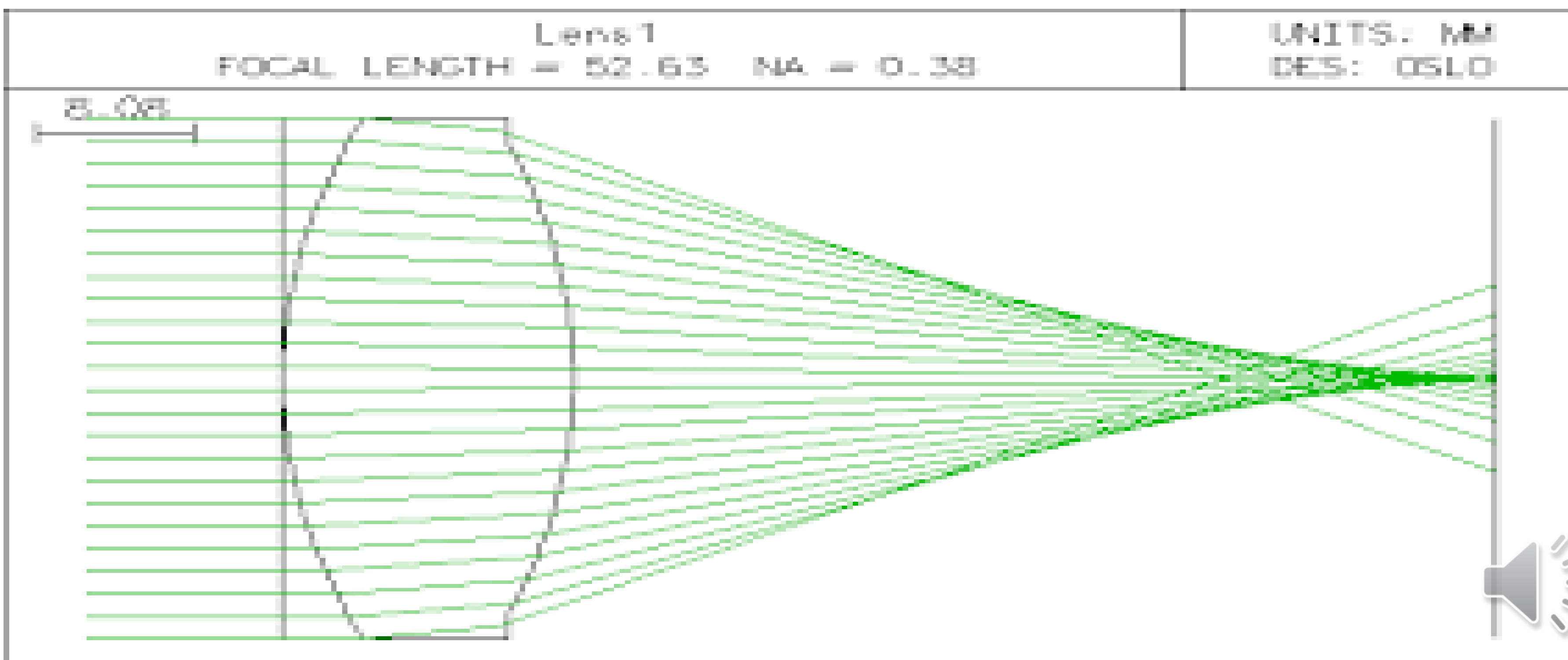
Lenses have **the same focal length** when light travels from the back to the front as when light goes from the front to the back. Other properties of the lens, such as the **aberrations are not the same in both directions.**

In optics, **aberration** is a property of optical systems such as **lenses** that causes light to be spread out over some region of space rather than focused to a point. **Aberrations** cause the image formed by a **lens** to be blurred or distorted, with the nature of the distortion depending on the type of **aberration**.

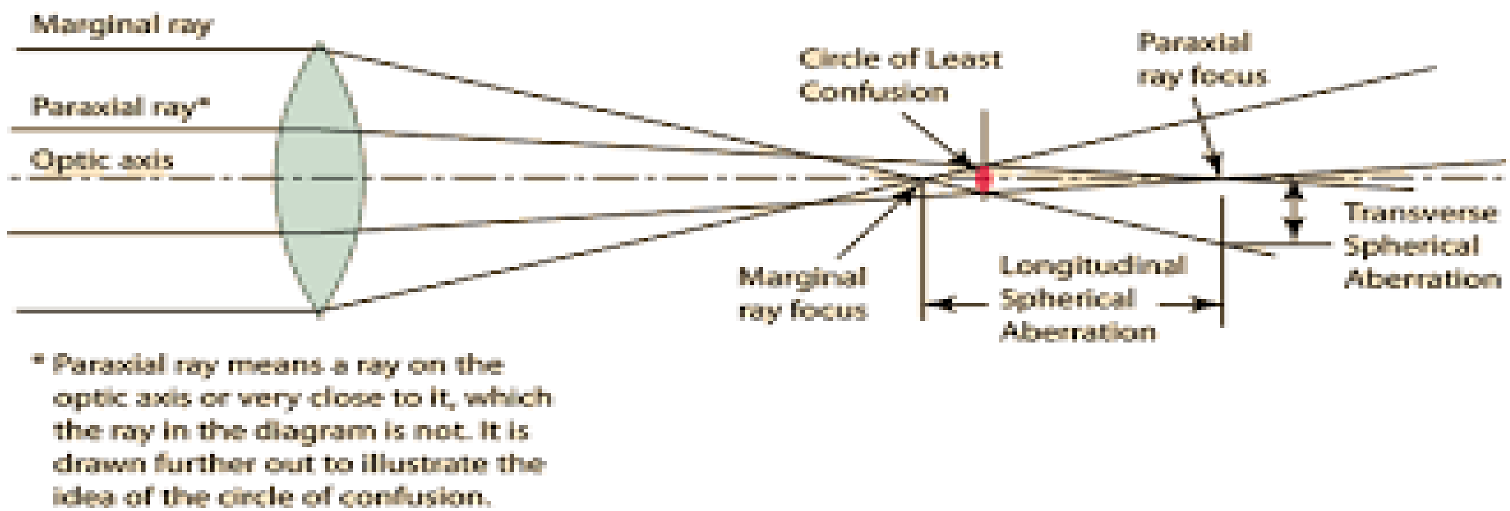


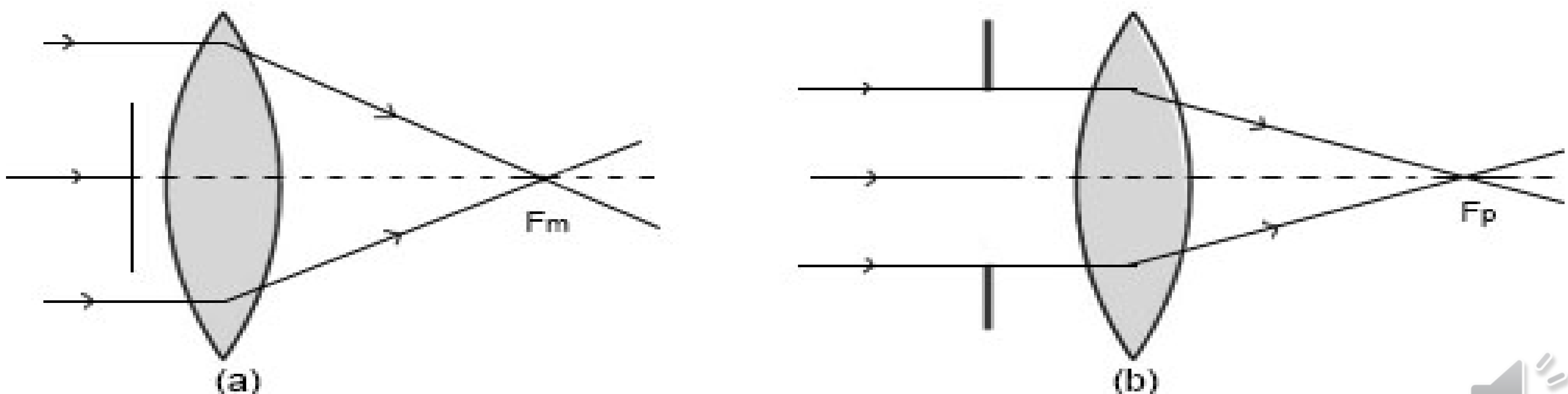
Spherical Aberration



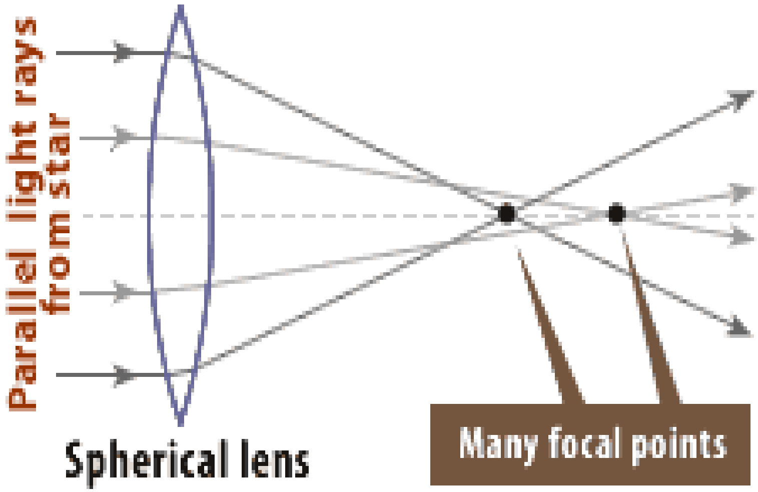


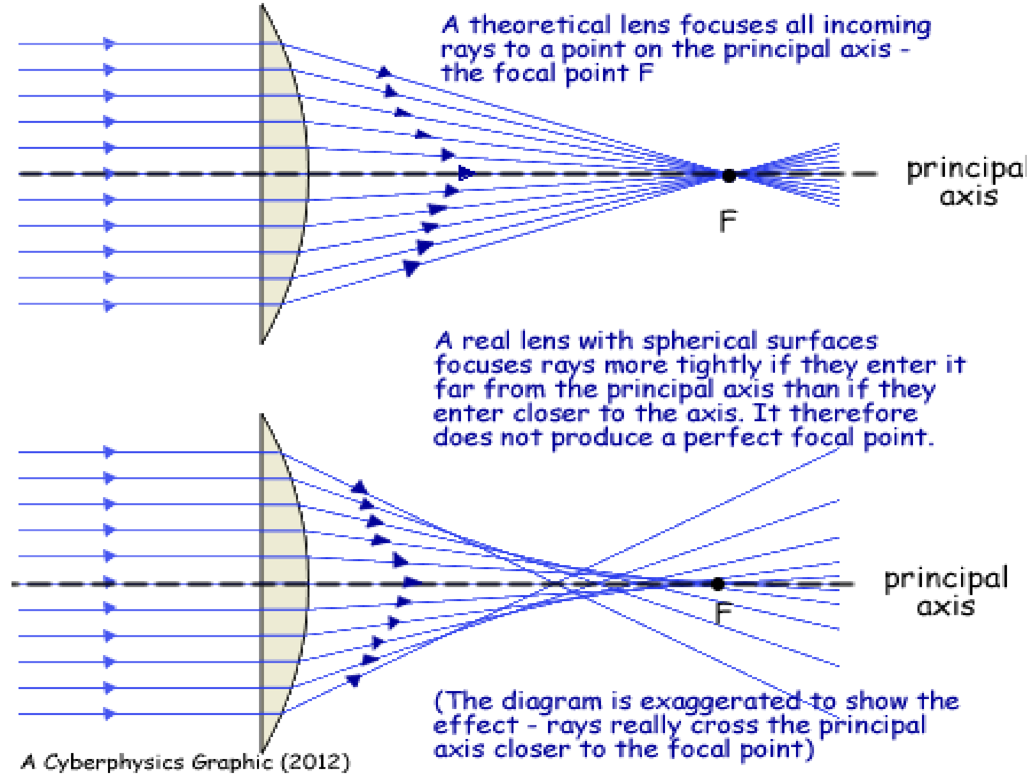
The simplest method of reducing **spherical aberration** is to place an aperture, hole or "stop", in front of or after the lens. The aperture blocks out rays that blur the image.





Reduction of spherical aberration by using stops in different positions.

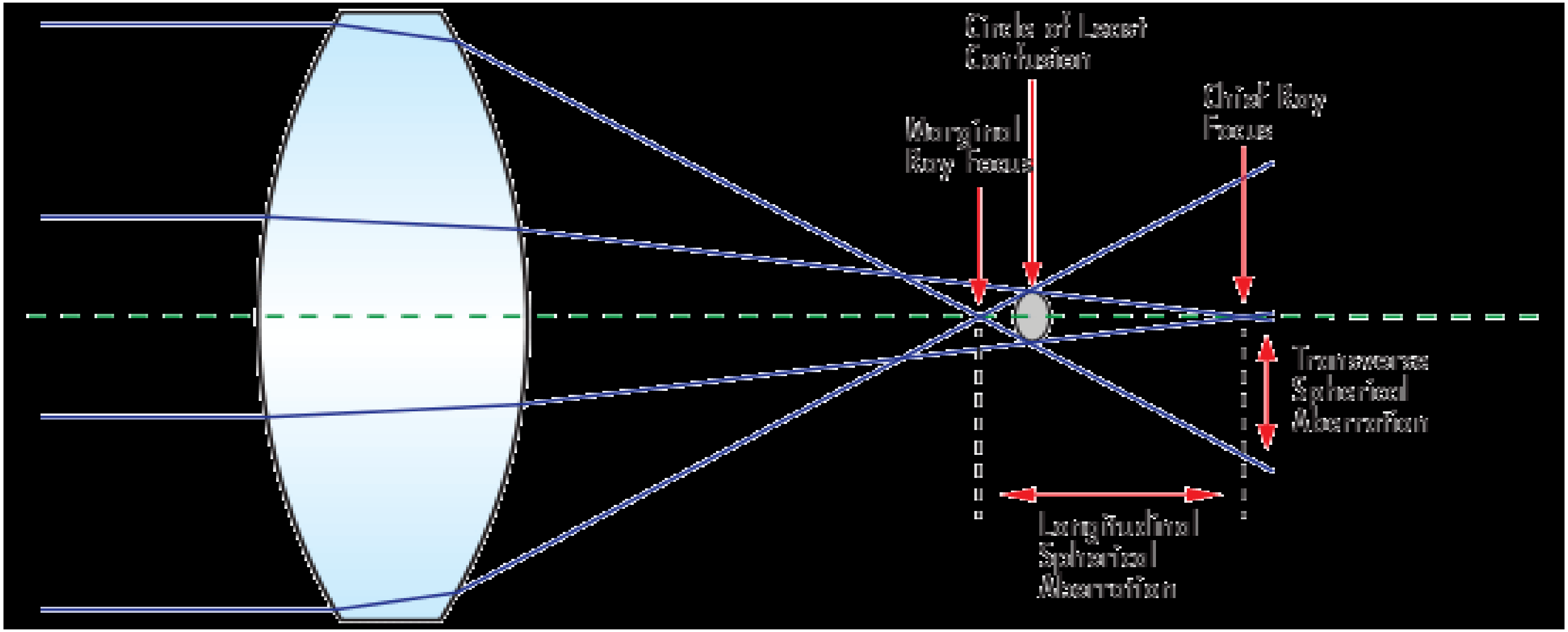


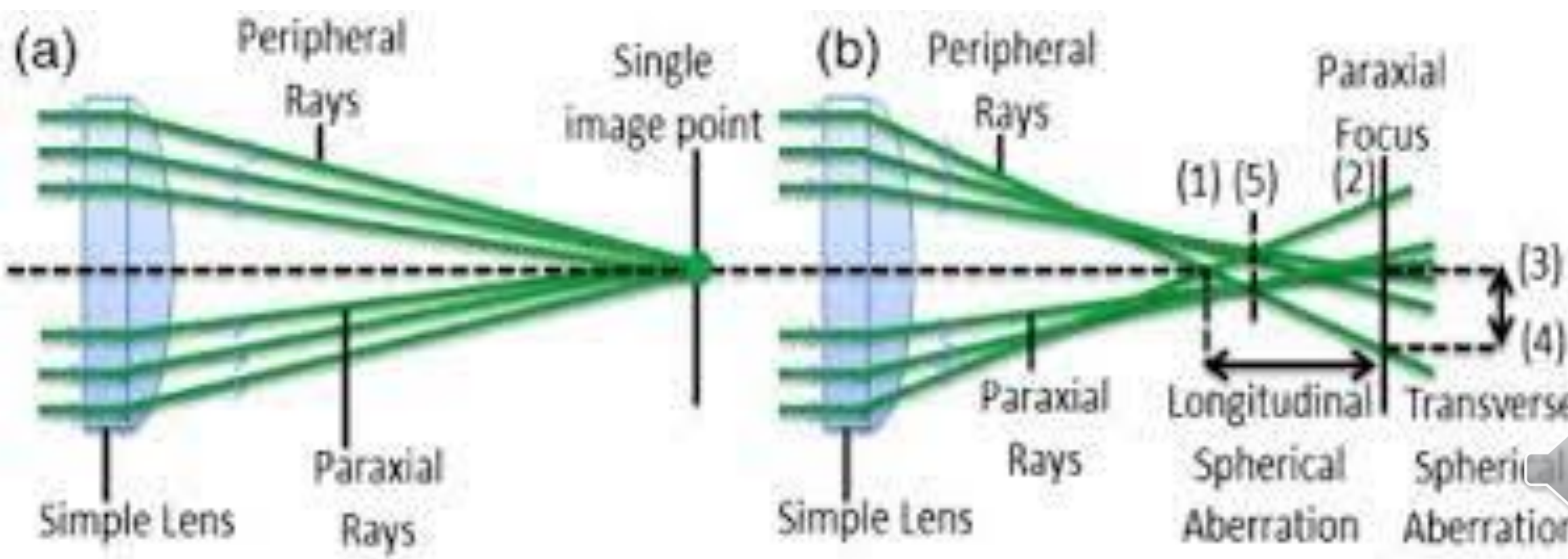


An aberration is a term that describes anything that deviates from the normal.

In optics there are two forms of this that you should be aware of:

Spherical aberration, which occurs when light rays strike a lens or mirror near its edge.


Circle of Least Confusion
Chief Ray Focus
Marginal Ray Focus
Transverse Spherical Aberration
Longitudinal Spherical Aberration

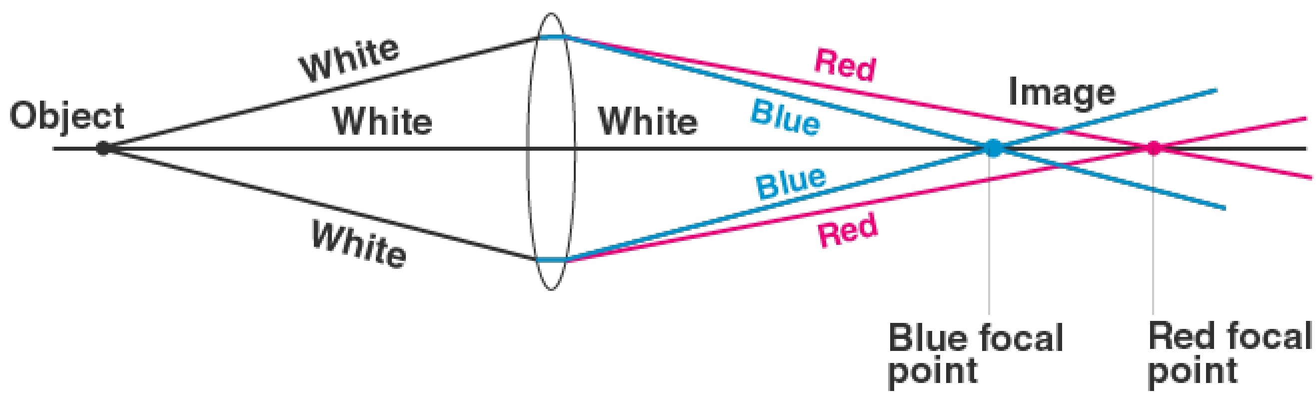

(a)
Peripheral Rays
Single image point
Simple Lens
Paraxial Rays
(b)
Peripheral Rays
Paraxial Focus
(1) (5)
(2)
(3)
(4)
Paraxial Rays
Simple Lens
Longitudinal Spherical Aberration
Transverse Spheri Aberration

Methods of removal spherical aberration

1. Using plano-convex lenses
2. Using two convex lenses in contact
3. Using two convex lenses separated by a distance
4. Using stops or wooden blocks to cut (stop) either marginal rays or paraxial rays
5. Using specially prepared lens with radii of curvature in the ratio R1/R2 = -1/6.
   this lens is called crossed lens
6. Using a combination of convex and concave lenses

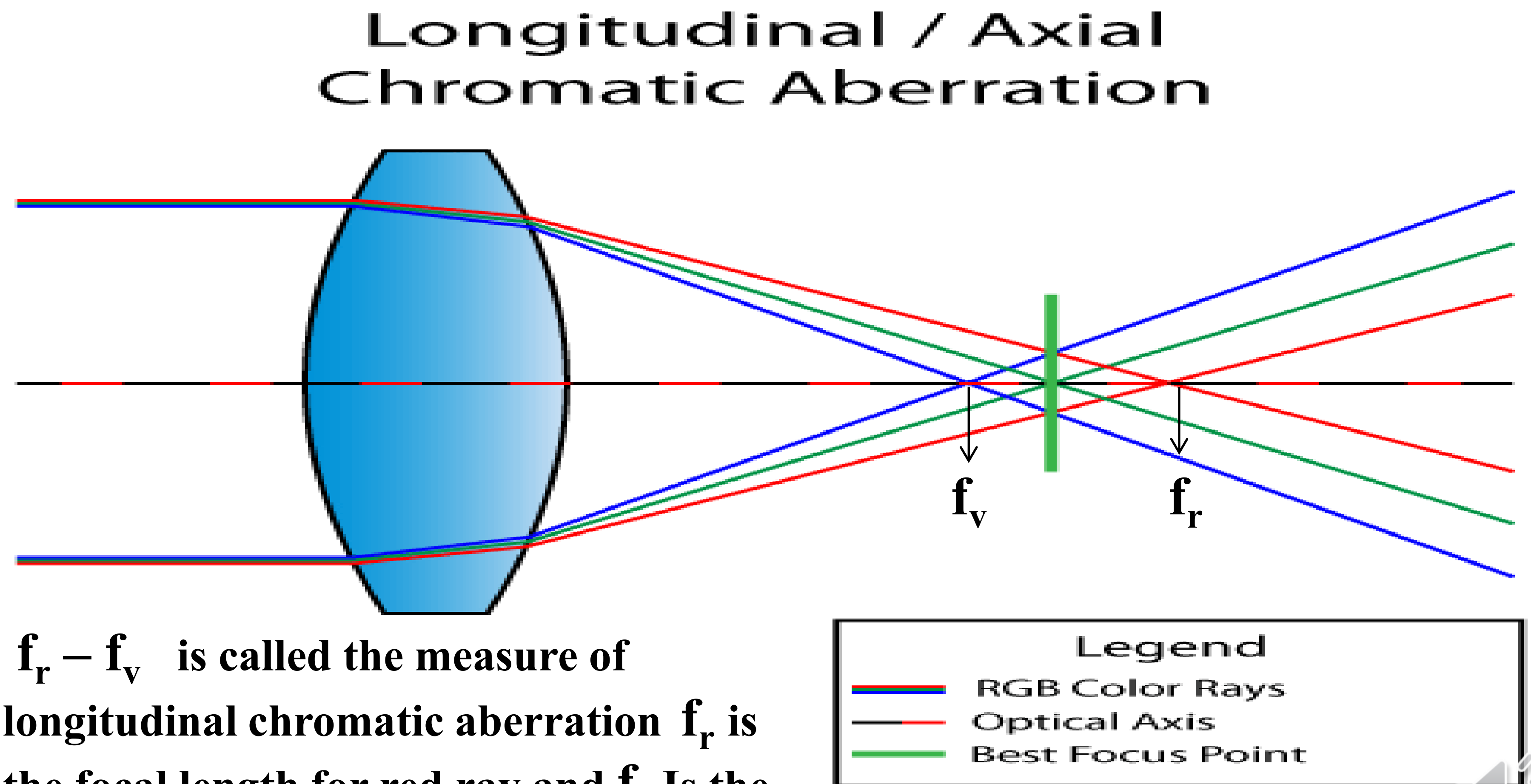
Chromatic Aberration

Chromatic aberration is the inability of a lens to focus all the composite white light is composed of seven colours of white light at a point. There are two types of chromatic aberration 1. Longitudinal chromatic aberration and 2. Lateral chromatic aberration. The following diagram shows the longitudinal chromatic aberration



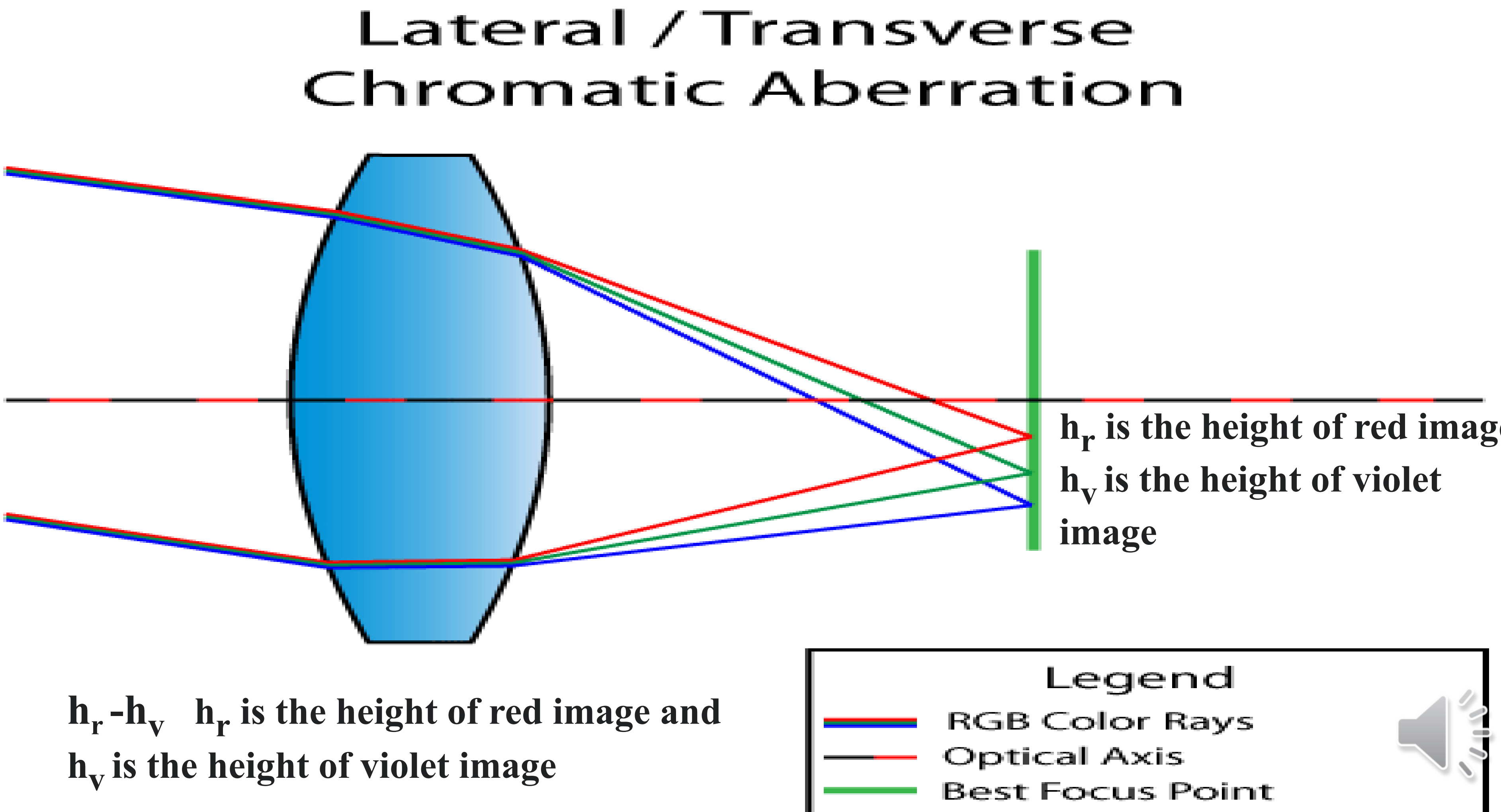
Chromatic Aberration

Longitudinal Chromatic Aberration occurs when different wavelengths of color do not converge at the same point after passing through a lens, as illustrated below:

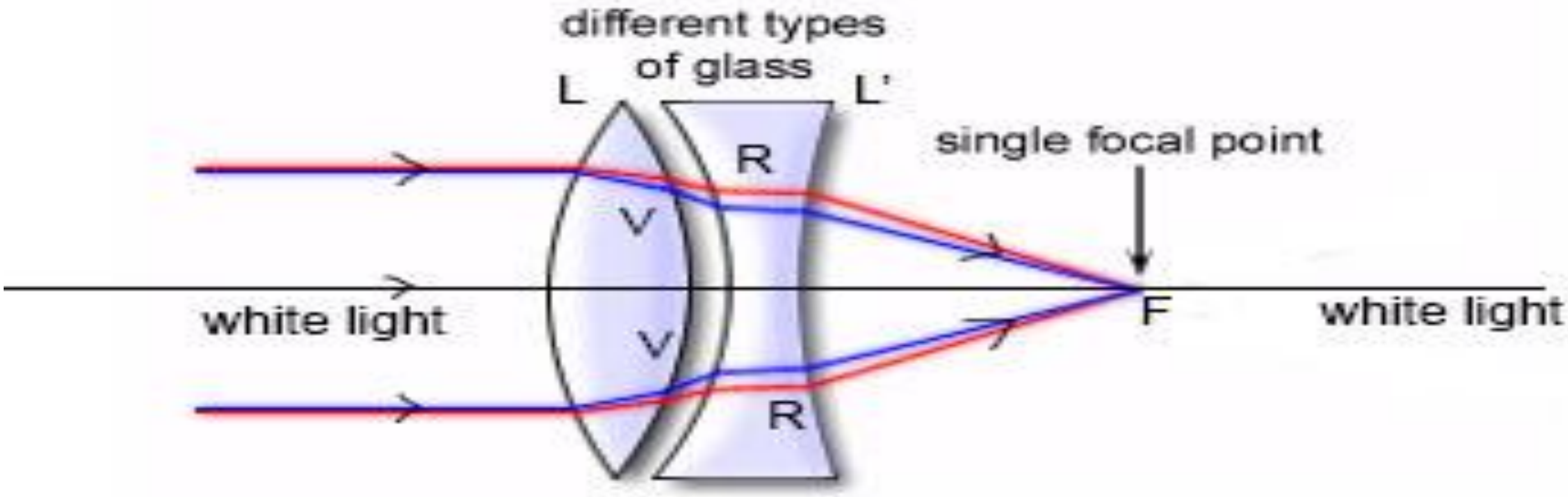


$f_r - f_v$ is called the measure of longitudinal chromatic aberration f_r is the focal length for red ray and f_v Is the focal length of violet ray

It is measured by the difference in focal lengths between red and violet colours.



$h_r - h_v$ h_r is the height of red image and h_v is the height of violet image

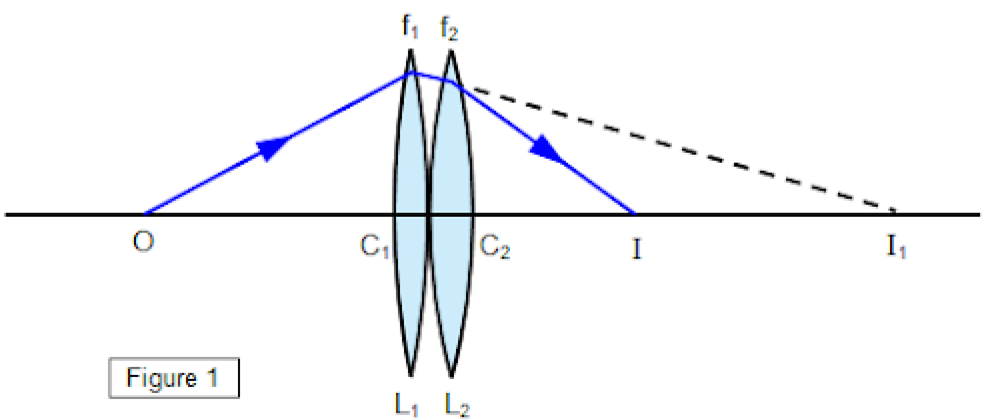


Achromatic Combination of Lenses

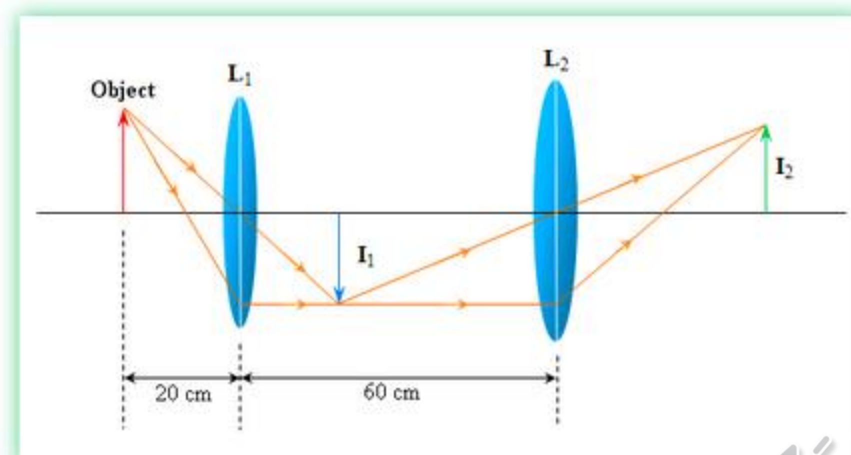
Achromatic combination of lenses is combination of one convex lens and one concave lens combined to remove chromatic aberration. This combination is called achromatic doublet. Deviation produced by convex lens and concave lens for different wavelengths (colours) are complement of each so they cancel each.

Methods of removal of chromatic aberration

1. By using achromatic doublet (see next slide)
2. Using two lenses in contact
3. Using two lenses separated by a distance
4. Using combination of plano-convex lenses

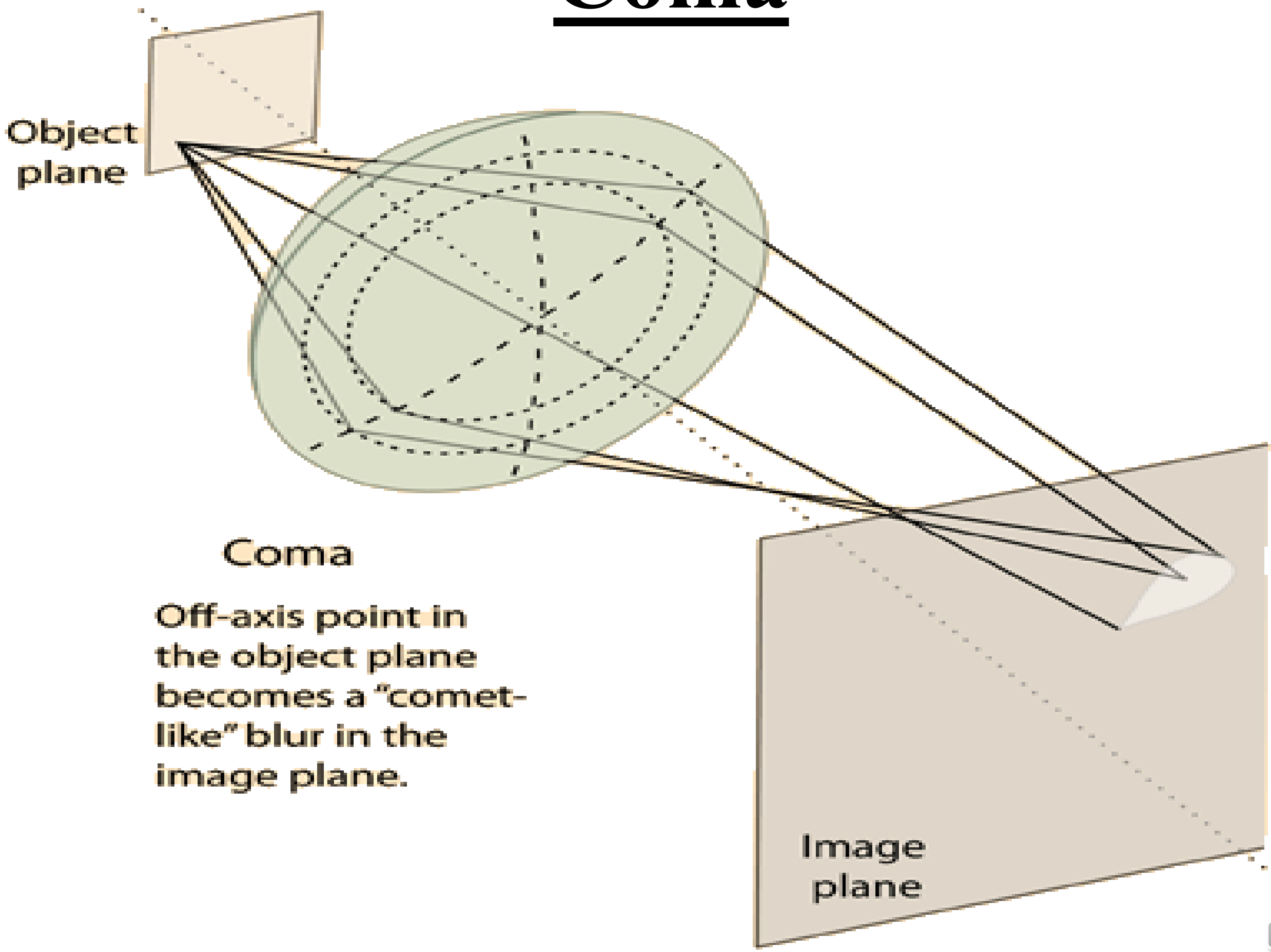


two lenses in contact



two lenses separated by a distance

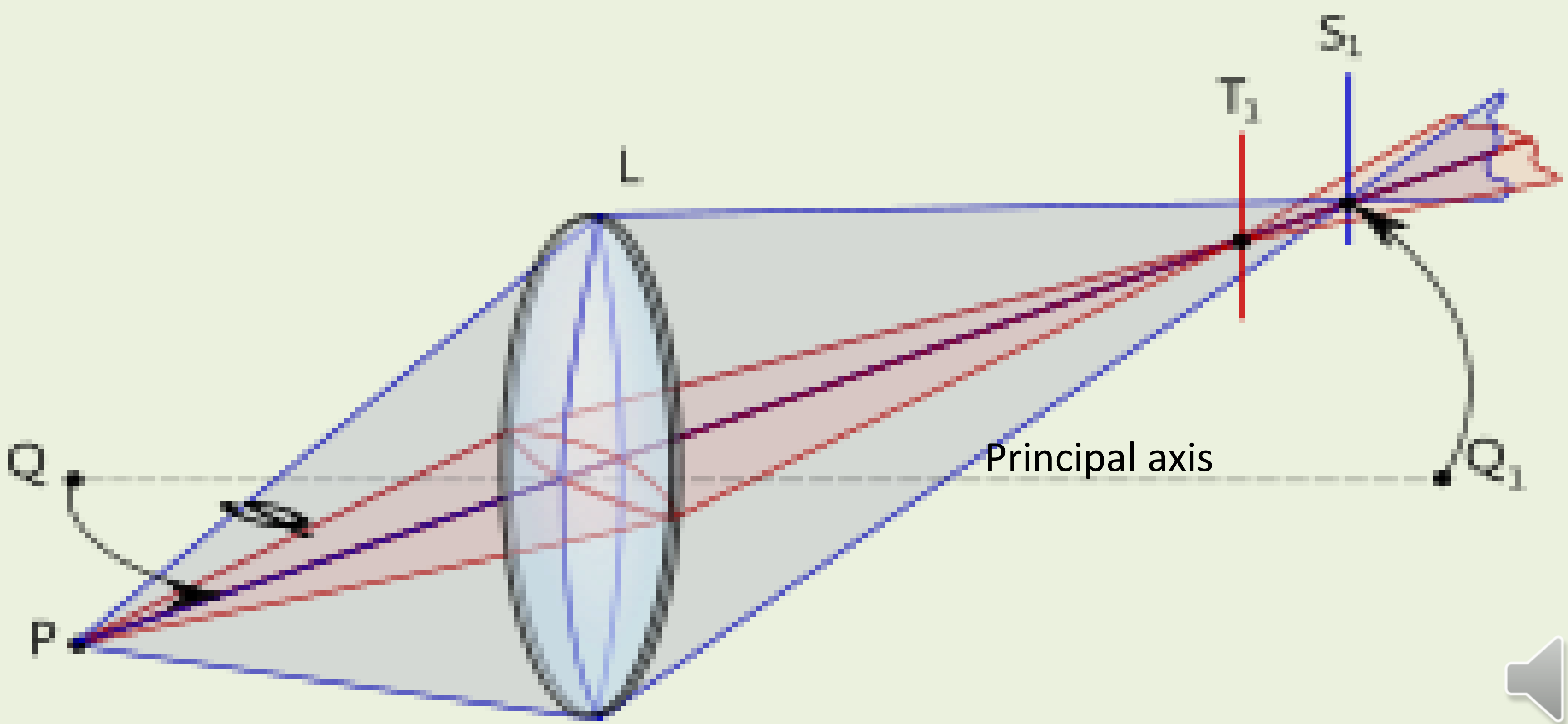
Coma

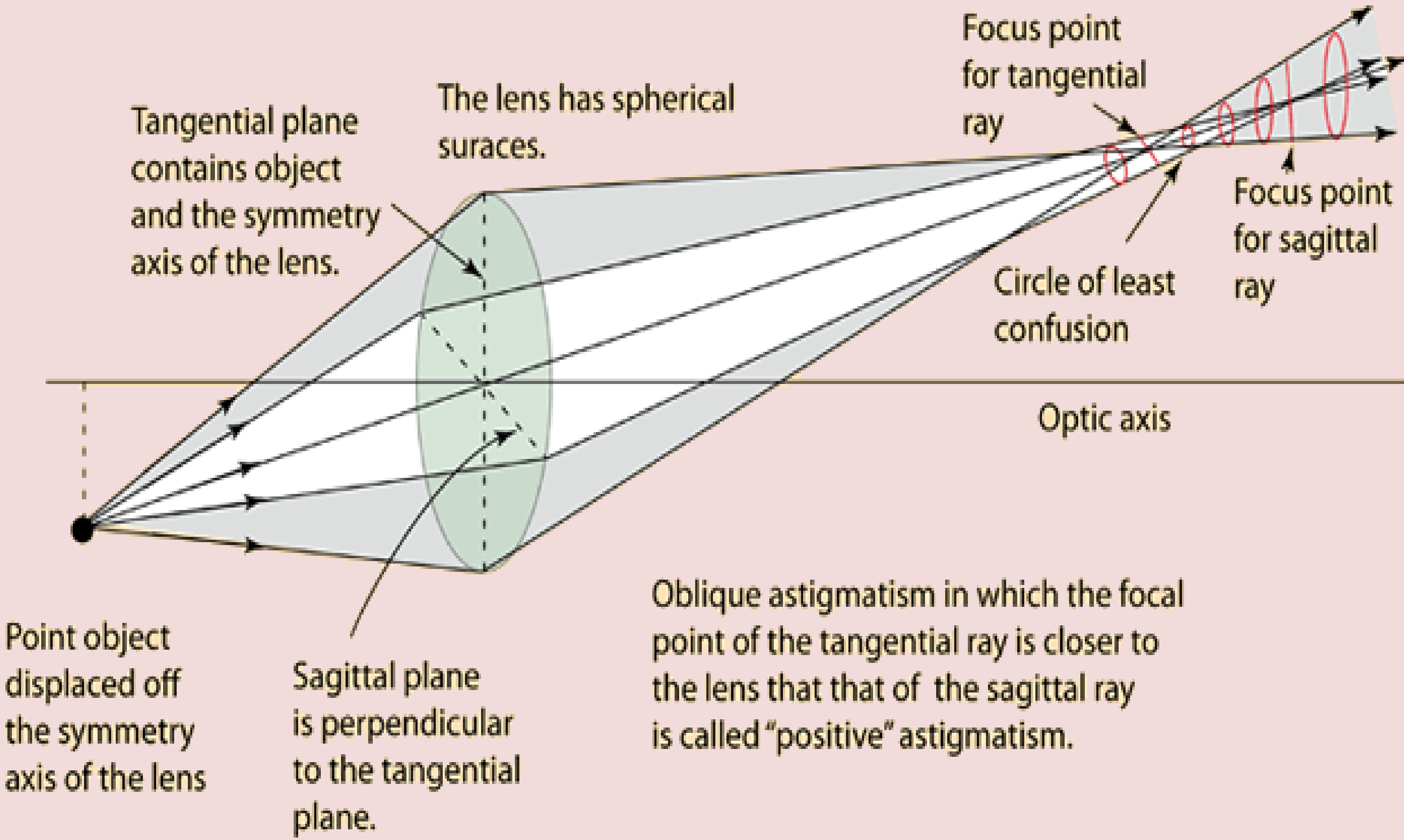

Object plane
Coma
Off-axis point in the object plane becomes a "comet-like" blur in the image plane.
Image plane

Removal of Coma:

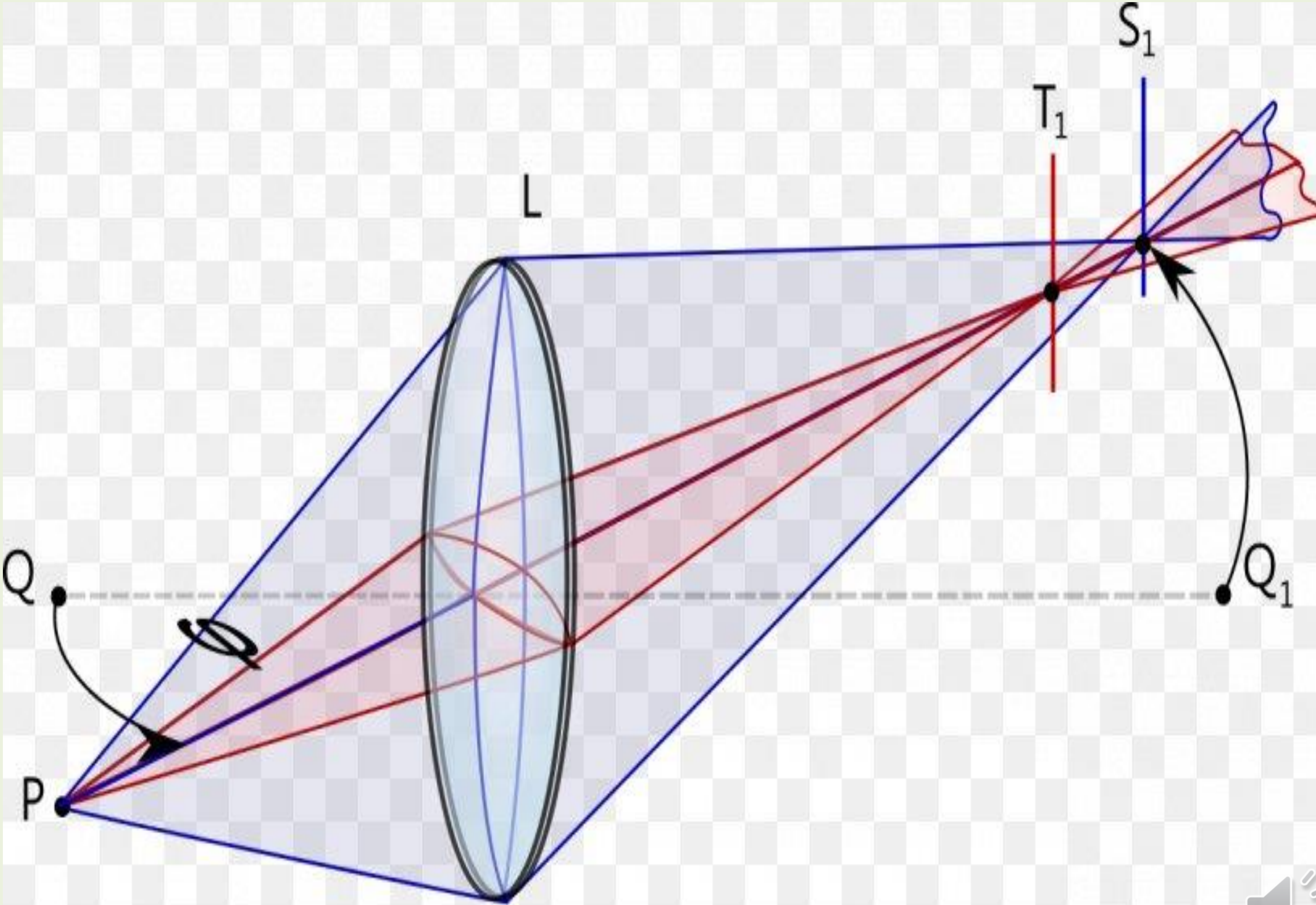
- Coma is an aberration which causes rays from an off-axis point of light in the object plane to create a trailing "comet-like" blur directed away from the optic axis (for positive coma).
- A lens with considerable coma may produce a sharp image in the center of the field, but become increasingly blurred 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.
- Coma is shape-dependent, so a lens shape can be found with zero coma for a given object distance. That lens would not be optimum for other object distances.
- Coma can be removed using stops
- It can be removed by using plano-convex lenses

An optical system with astigmatism is one where rays that propagate in two perpendicular planes have different foci. If an optical system with astigmatism is used to form an image of a cross, the vertical and horizontal lines will be in sharp focus at two different distances.





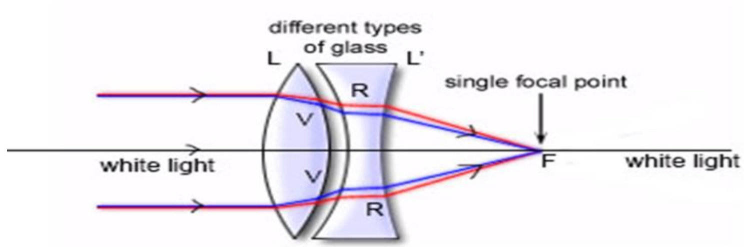
Oblique astigmatism in which the focal point of the tangential ray is closer to the lens that that of the sagittal ray is called "positive" astigmatism.



S_1
T_1
L
Q
Q_1
P

Removal of Astigmatism

1. Using stops or blocks
2. Using a convex concave lenses combination

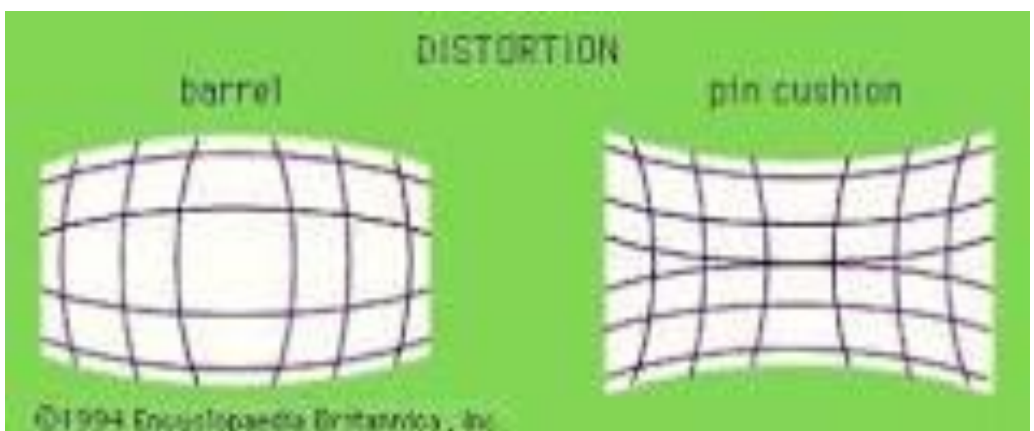


Achromatic Combination of Lenses

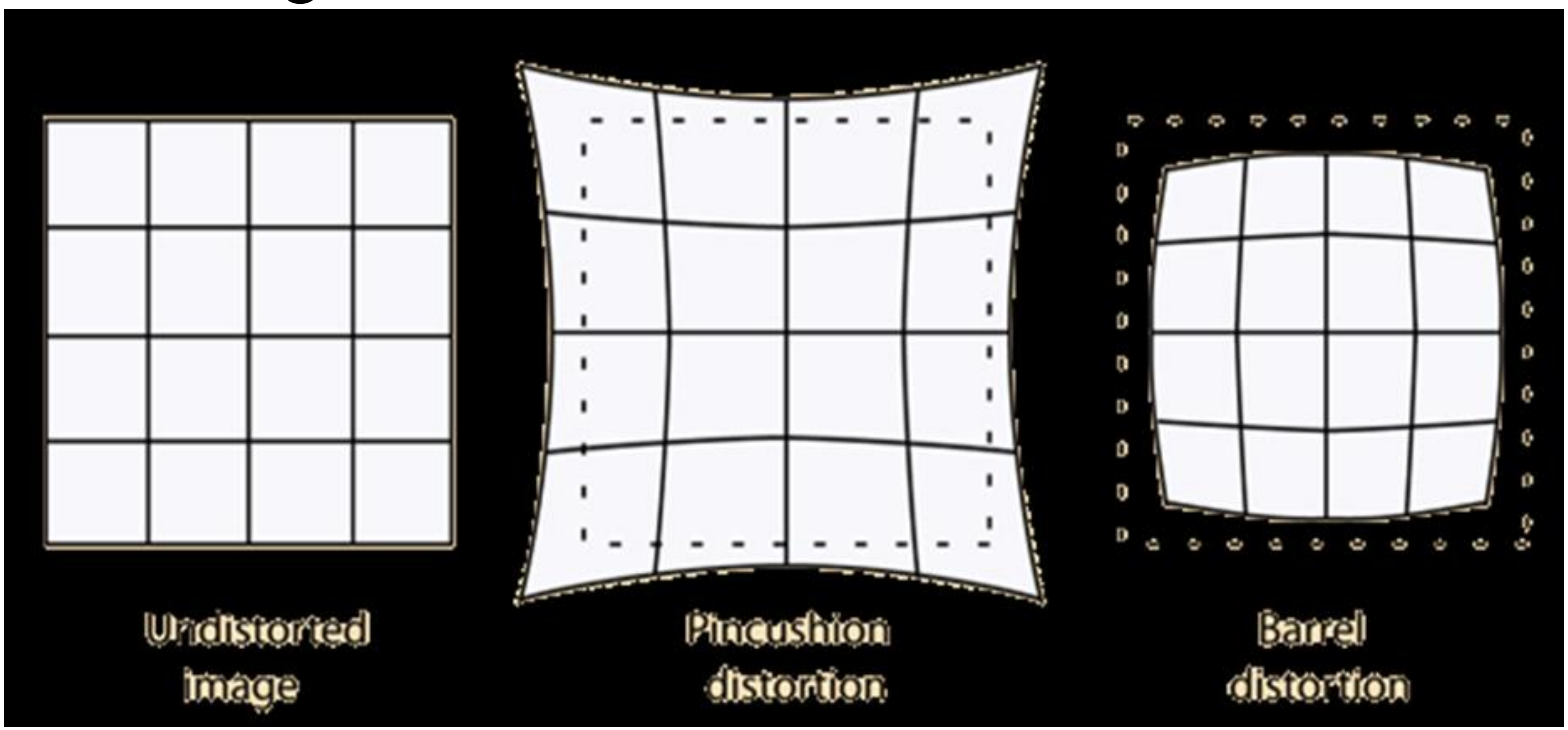
3. Using plano-convex lenses separated by a distance

Distortion

- **Distortion** produces curved images from straight lines in the object. The type and degree of **distortion** visible is intimately related to the possible spherical aberration in the magnifier and is usually most severe in high-powered **lenses**.
- Barrel distortion (fig 1 below) is caused when the stop appears before the lens. Pincushion (fig 2) is when the stop appears after the lens.
- A method used to remove distortion is using both the lenses which have pincushion and barrel distortion together. A stop is usually put in between the lenses.



- Distortions occur due to lens imperfections and 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.



Normal image pincushion distortion Barrel distortion

Why distortion occurs

- Distortion occurs when the linear magnification is a function of the off-axis distance. The linear magnification is a function of the focal length, so if the focal length is different for different areas of the lens, the magnification will change.
- If there is a positive change in the magnification with distance, then the image will be distorted outward with the most distant parts of the image displaced the most. This is typically called "pincushion distortion". Negative distortion decreases the magnification with the most distant points being the most affected. This is called "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.