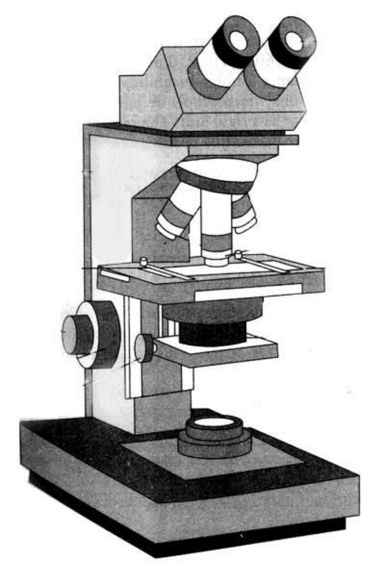
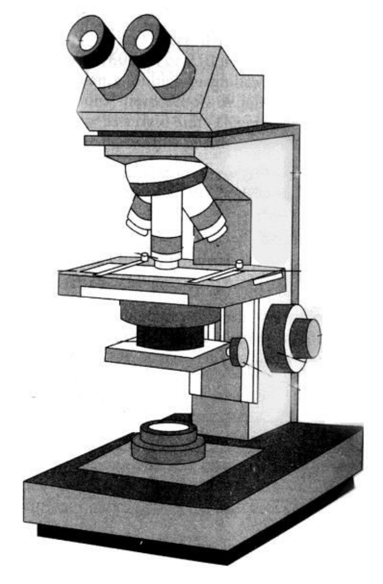


DISTORTION – ABERRATION OF IMAGES IN MICROSCOPES



- **Distortion of an image from the ideal optical image is called aberration.**
- **An ideal optical image satisfies the following three conditions.**
  1. **A point object creates a point image.**
  2. **A plane object perpendicular to the optical axis creates a plane image.**
  3. **A figure on a plane perpendicular to the optical axis creates an image similar to that figure.**

MONOCHROMATIC ABERRATIONS

There are the following 5 types of monochromatic aberration, caused by the shape of the lens (these are called the Seidel aberrations, named after the researcher Seidel)

i. Spherical aberration

ii. Coma

iii. Astigmatism difference

iv. Curvature of field

v. Distortion

CHROMATIC ABERRATIONS

There are the following 2 types of chromatic aberration, caused by the material in the lens.

vi. Longitudinal chromatic aberration

vii. Lateral chromatic aberration

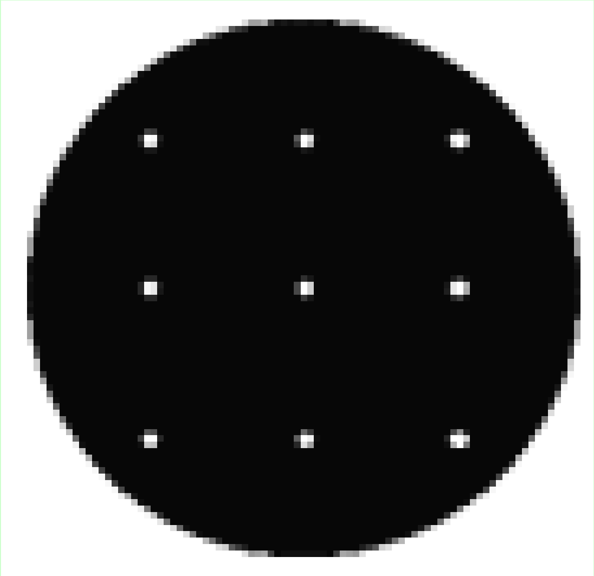
ABERRATIONS

- **An ideal optical image satisfies the following three conditions.**
    1. **A point object creates a point image.**
    2. **A plane object perpendicular to the optical axis creates a plane image.**
    3. **A figure on a plane perpendicular to the optical axis creates an image similar to that figure.**

Types i-iii, vi and vii do not satisfy condition 1) above.

Type iv and v aberrations do not satisfy conditions 2) and 3) respectively.

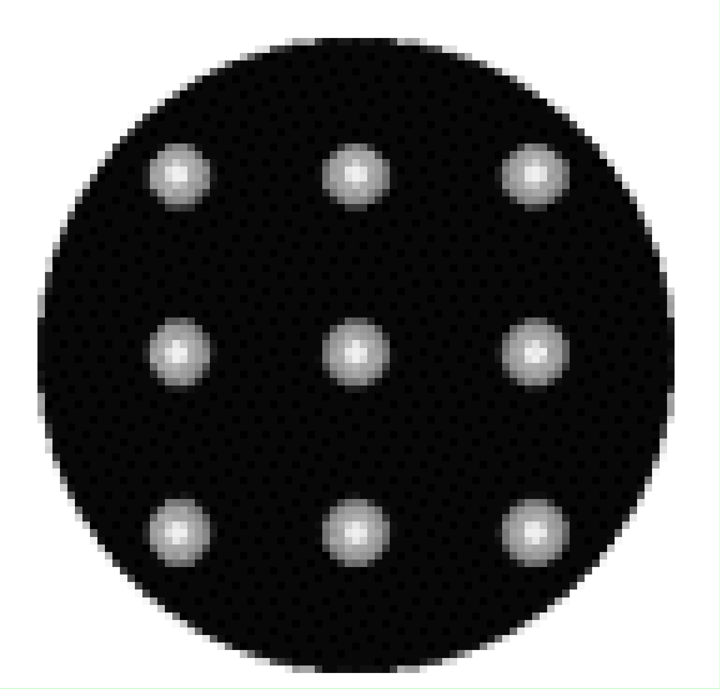
Undistorted ideal optical image



Pin hole specimen image

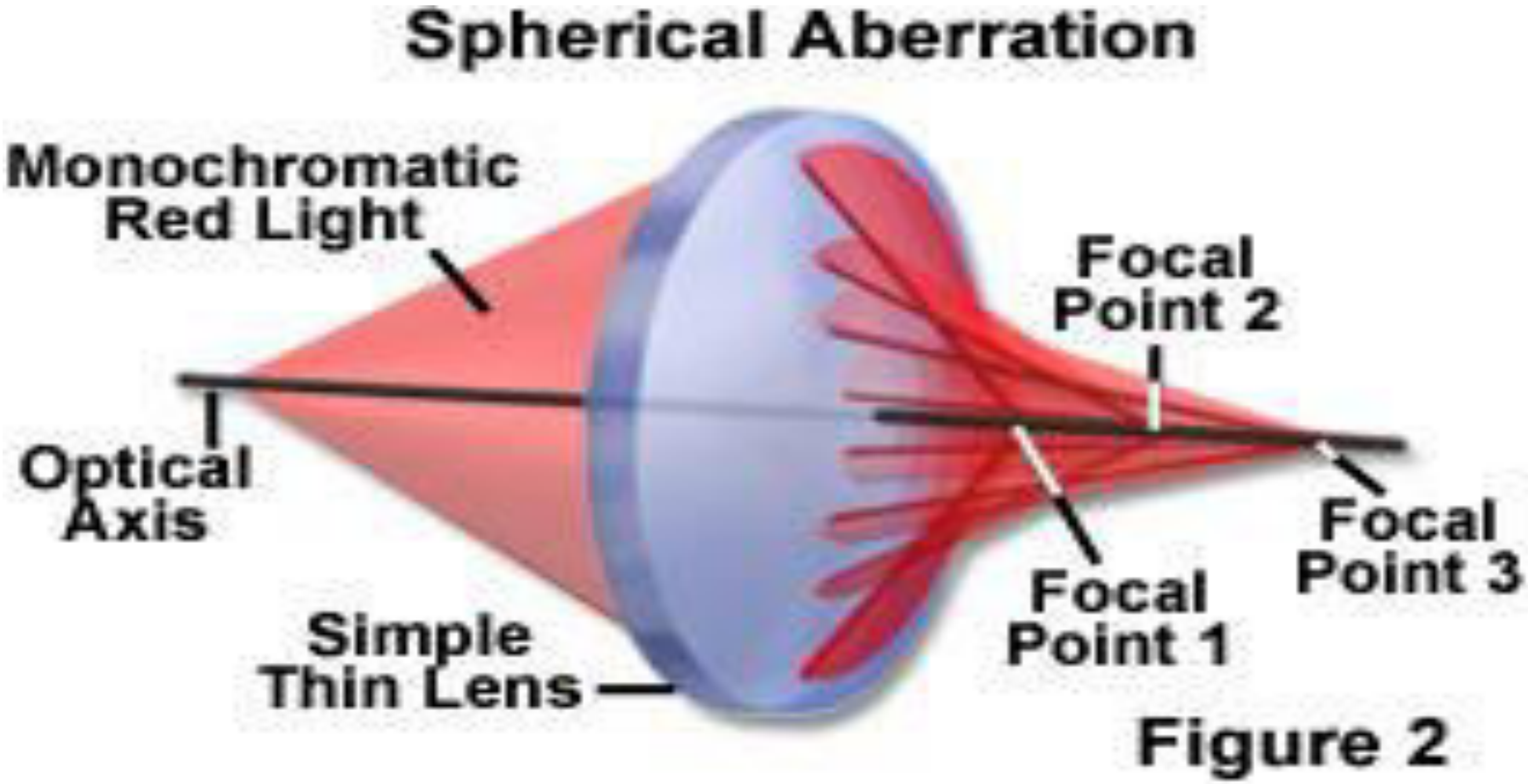
Regardless of whether the light is on the axis or off the axis or regardless of wavelength, light emitted from a point intersects in a point and forms a plane image. Plan Apo and other microscope objectives are near to the optically ideal.

Spherical aberration



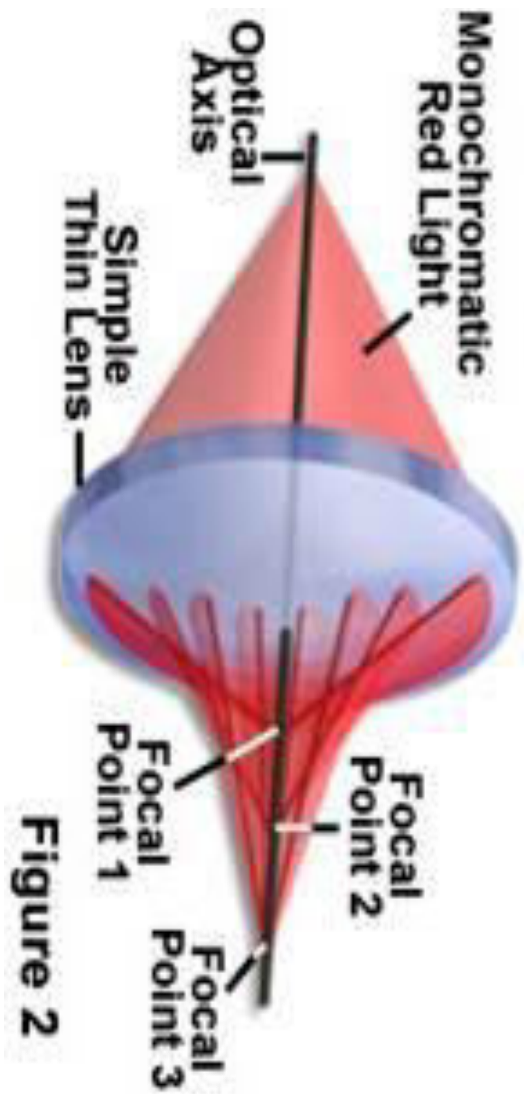
Pin hole specimen image

This aberration is proportional to the NA to the power of 3, and is independent of the width of the field of view. This is the only aberration which still appears at the center of the field of view. It appears as a circular blur, and is the source of all kinds of aberration; the more the NA increases, the more difficult it is to correct. For an objective of a microscope, it is necessary to correct it sufficiently.



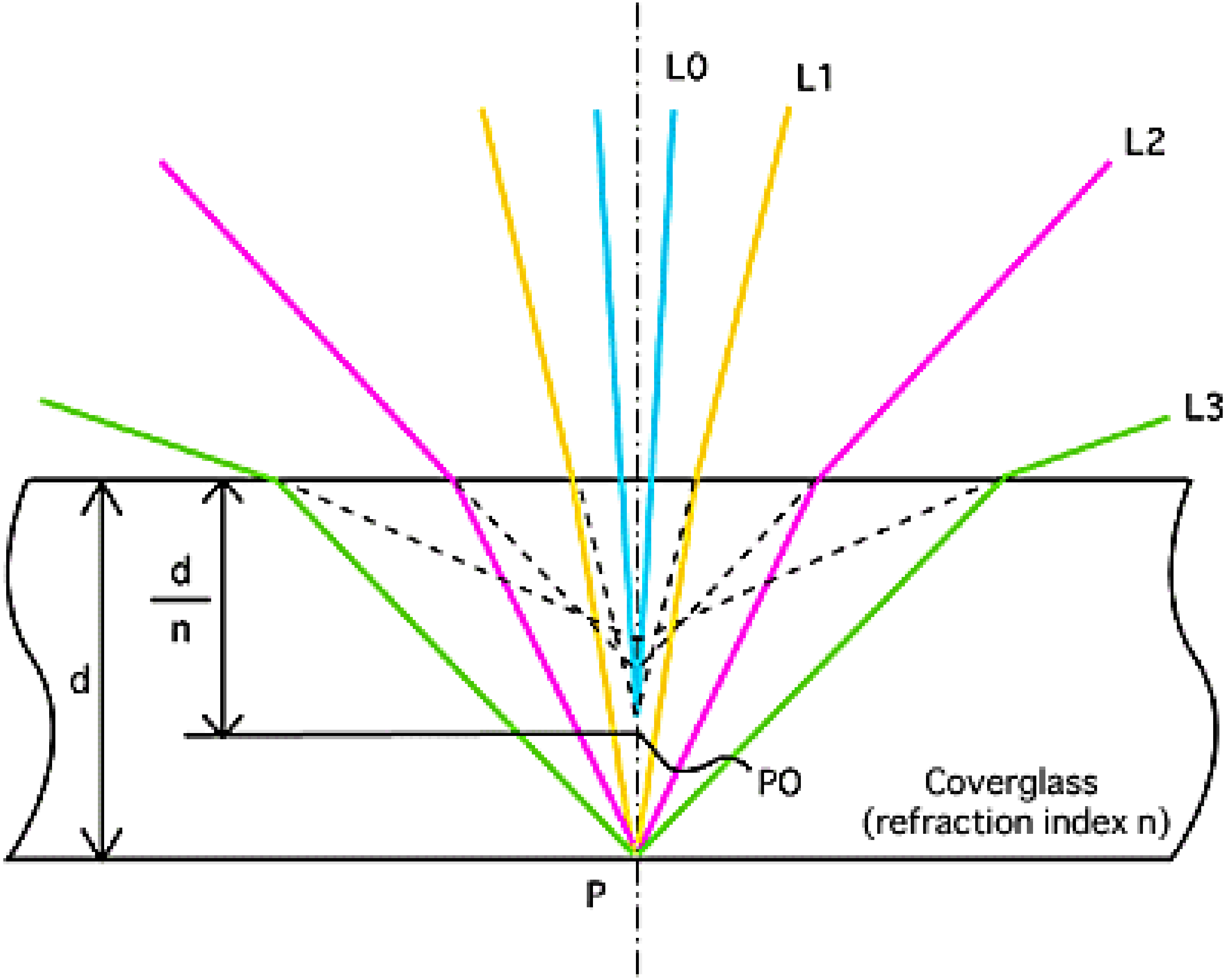
Spherical aberration is the result of using lenses having spherical surfaces. A single lens should have single focal point to get clear image. If a single lens have different focal point, the image is blurred. Due to the spherical nature of the lens the focal point of the light passes through the periphery is different from the focal point of the light passes towards the centre of the spherical lens.

Spherical aberration - Correction



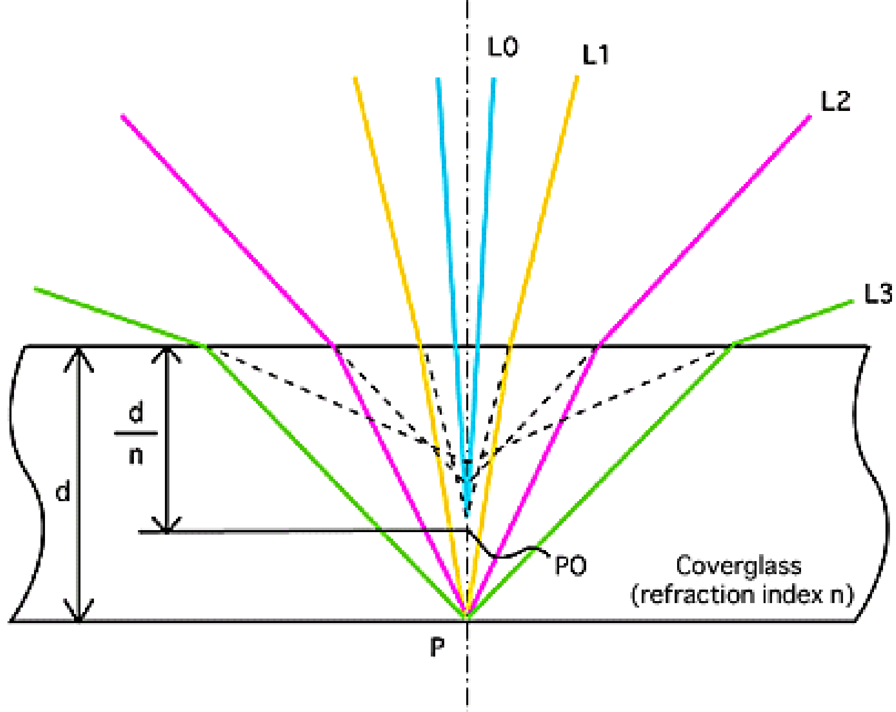
Spherical aberrations are reduced in a number of ways including special lens-grinding techniques, improved glass formulations, and better control of optical pathways.

Spherical aberration by covergalss



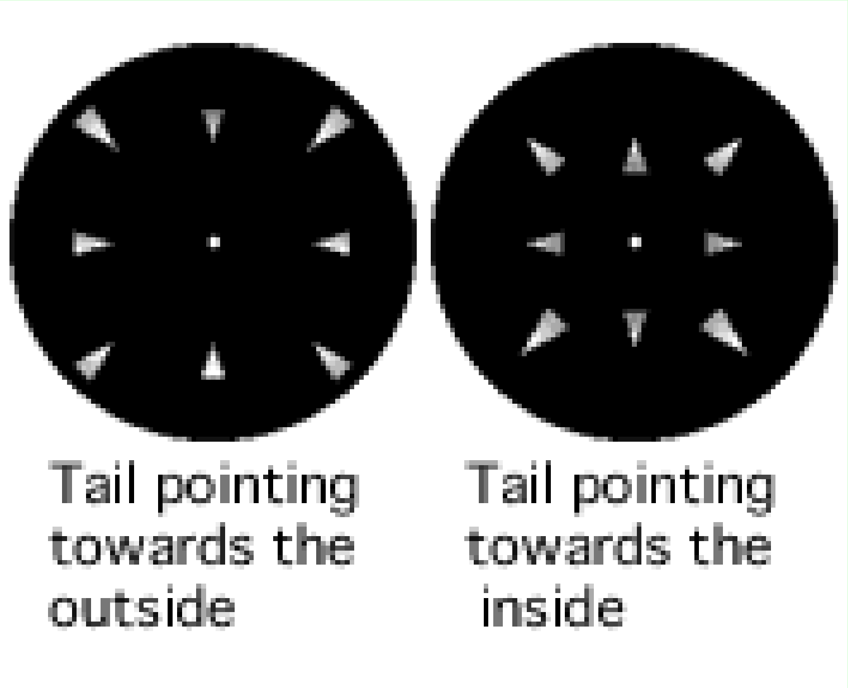
- **Why is it necessary to have an objective designed to meet the standards of the coverglass holding your specimen?**
- **For example, if you were to place a plate of glass over something, it wouldn't normally look very different other than appearing slightly closer. This is because the angle of a single ray of light coming off the object toward the observer's eye (also called numerical aperture in optical terms) is very small. In other words, if the numerical aperture is small a coverglass will not significantly effect how an object appears.**
- **However, if the numerical aperture is large, such as in the case of an objective, then even a thin coverglass will negatively affect image quality. The main cause of this is something called 'spherical aberrations'.**

- **As shown in Figure 1, when light rays L0-L3 bounce off the object P under a coverglass, they are each refracted within the coverglass before entering the objective. From the perspective of the objective, it will appear as though each of these light rays is coming from a different point. Even L0, with the smallest numerical aperture, appears as though it is coming from a point other than P. This is why objects with glass over them appear closer to the naked eye, with the depth of P0 equivalent to thickness (d) divided by refraction index (n). Deviations from this position become spherical aberrations.**



- **When the numerical aperture is relatively small, such as light ray L1, the deviation from the P0 point is small. However, as the numerical aperture increases, spherical aberrations increase as well. This is why aberration design with coverglass spherical aberrations in mind is necessary when designing biological objectives with larger numerical apertures.**

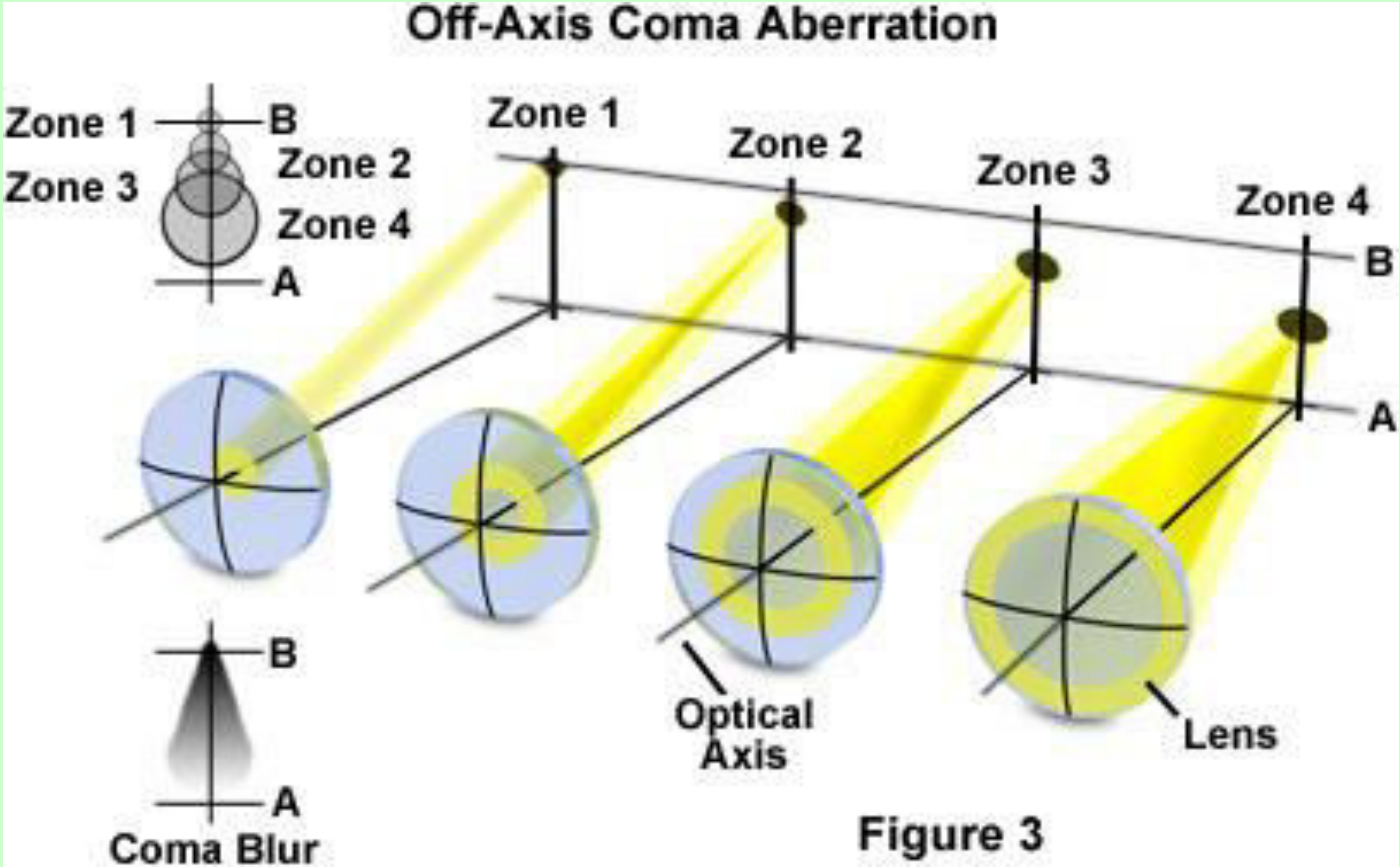
COMA



Coma is generally encountered with off-axis light rays and is most severe when the microscope is out of proper alignment. The aberration is named for its strong resemblance to the shape of a comet tail.

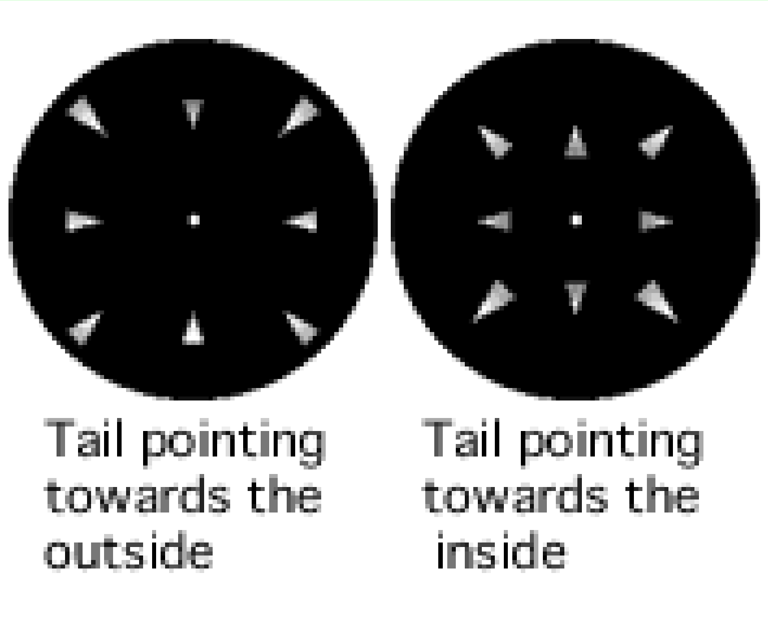
For example, on a bright, sunny day, when a magnifying glass is used to focus an image of the sun on the sidewalk, coma aberration can be seen in the image when the magnifying glass is tilted with respect to the principal rays from the sun.

COMA


Off-Axis Coma Aberration
Zone 1
B
Zone 2
Zone 3
Zone 4
A
Zone 1
Zone 2
Zone 3
Zone 4
B
A
B
A
Coma Blur
Optical Axis
Lens
Figure 3

Coma

The center of the field of view is sharp, but as you approach the edge of the field of view the comet-shaped blur gets larger.



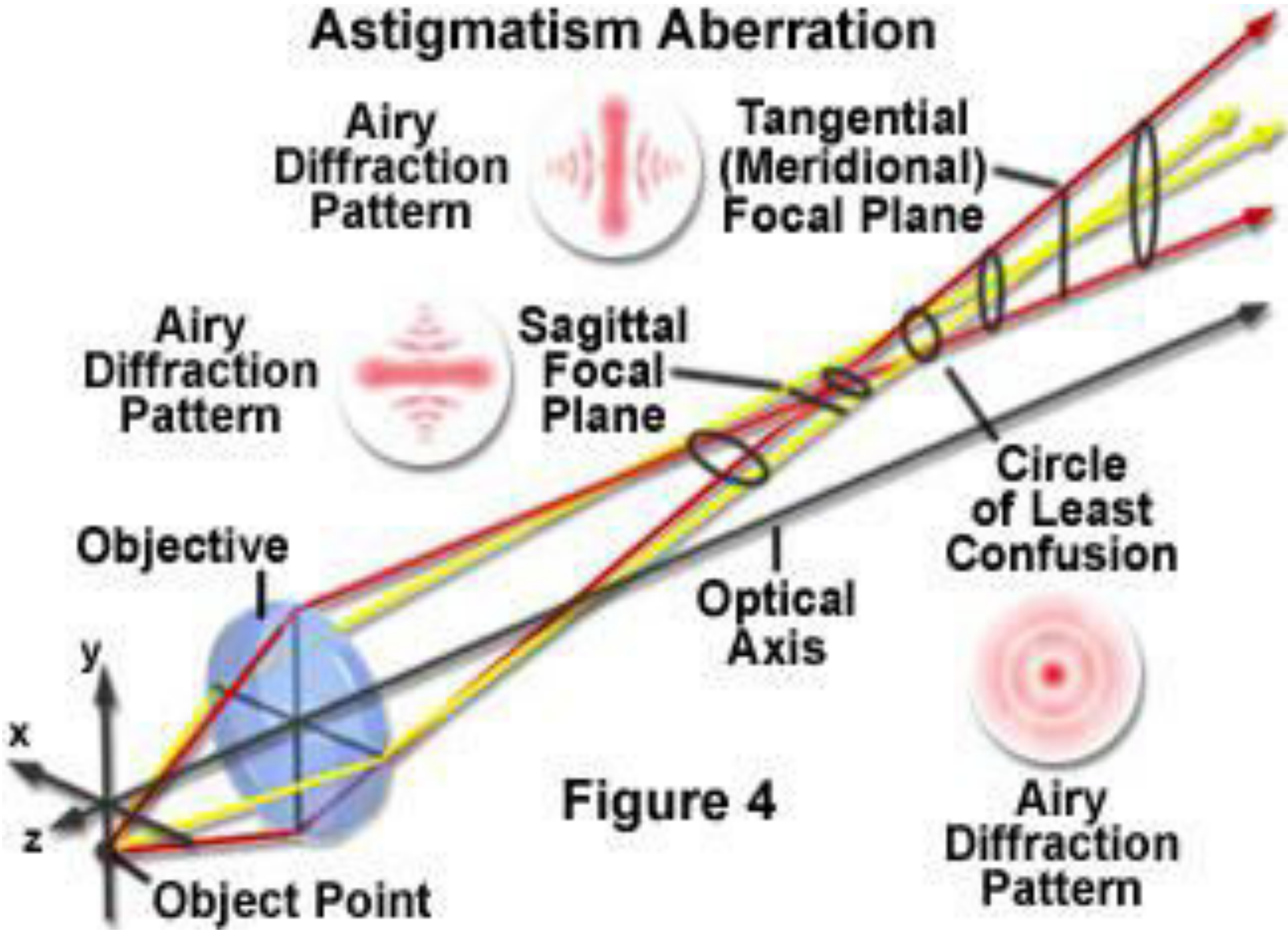
Pin hole specimen image

This aberration is proportional to the square of the NA and linearly proportional to width of the field of view. It is noticeable even in a narrow field of view, so it is necessary for the objective of a microscope to minimize this as much as possible.

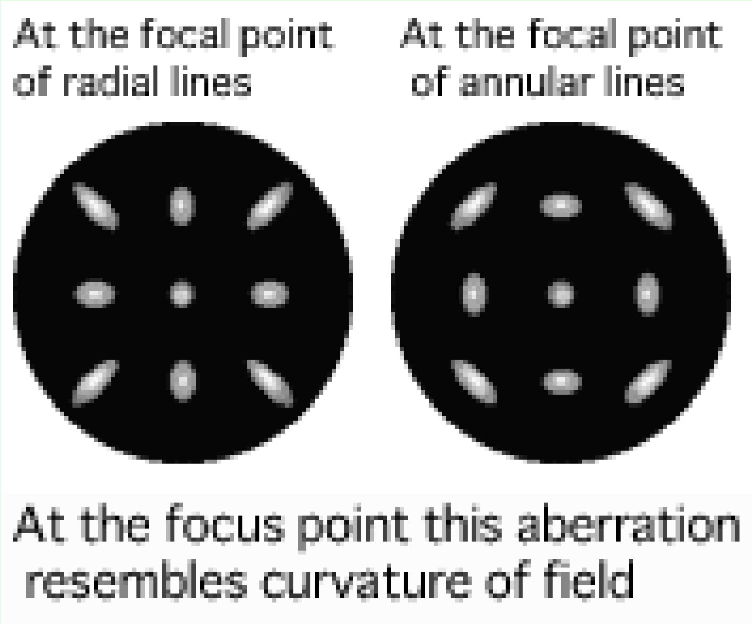
ASTIGMATISM

The aberration is manifested by the off-axis image of a specimen point appearing as a line or ellipse instead of a discrete point. Depending on the angle of the off-axis light rays entering the lens, the line image may be oriented in either of two different directions (see Figure), tangentially (meridionally) or sagitally (equatorially). The intensity ratio of the unit image will diminish, with definition, detail, and contrast being lost as the distance from the center is increased.

Astigmatism aberration is similar to coma; however, this artifact is not as sensitive to aperture size and depends more strongly on the oblique angle of the light beam.


Astigmatism Aberration
Airy Diffraction Pattern
Tangential (Meridional) Focal Plane
Airy Diffraction Pattern
Sagittal Focal Plane
Circle of Least Confusion
Objective
Optical Axis
y
x
z
Figure 4
Airy Diffraction Pattern
Object Point

Astigmatic difference

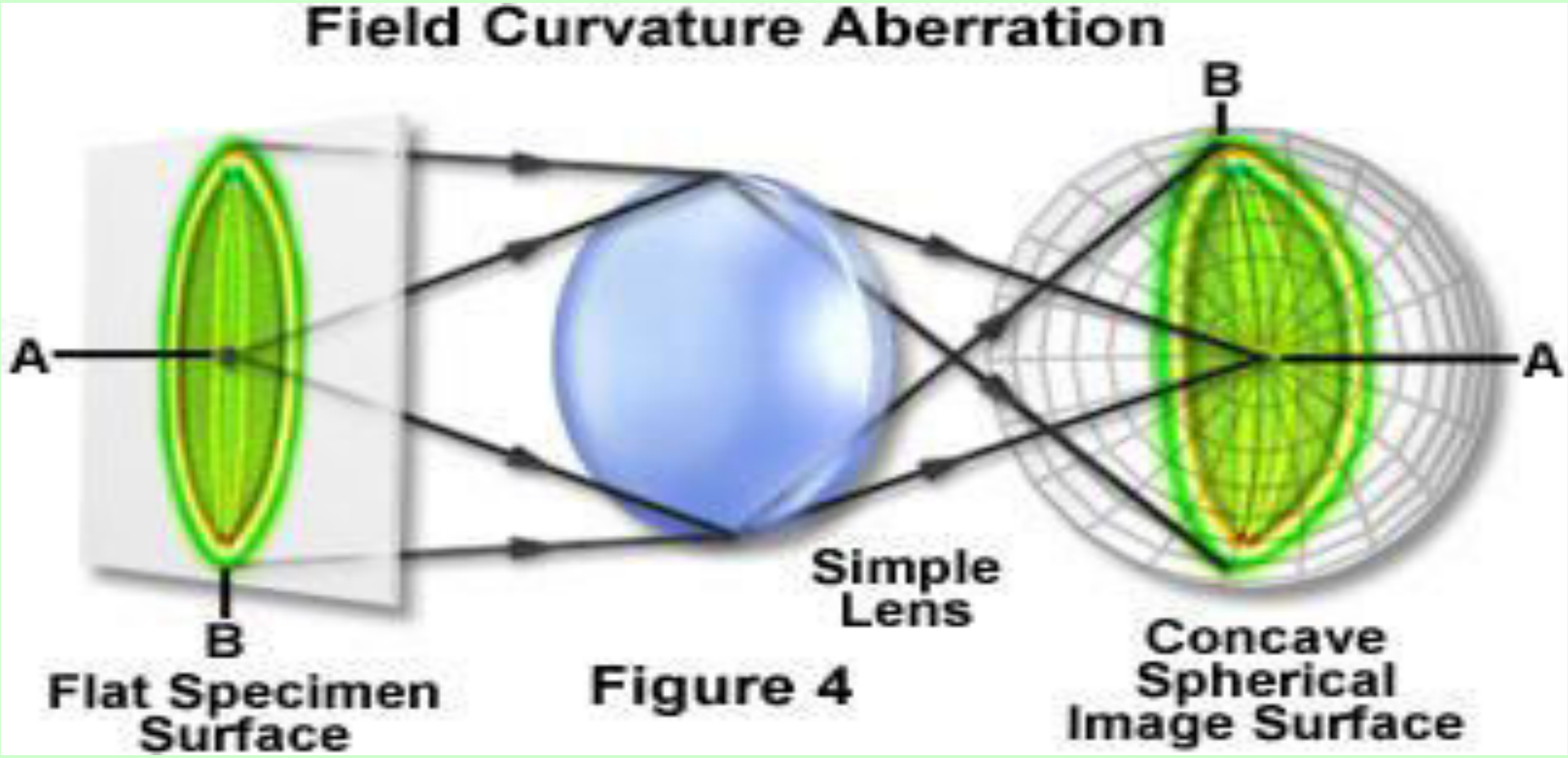


Pin hole specimen image

- **If the focus is moved then the image becomes a long horizontal, a circle, and a long vertical. At the focus point this aberration is similar to curvature of field.**
- **This aberration is linearly proportional to the NA and proportional to the square of the width of the field of view. When a sharp image is required to the edge of the field of view then it is necessary to correct the Plan objective or wide field eyepiece. In this aberration, for one off-axis object point there are two image points, so an image that should be a point becomes two lines at right angles to each other.**

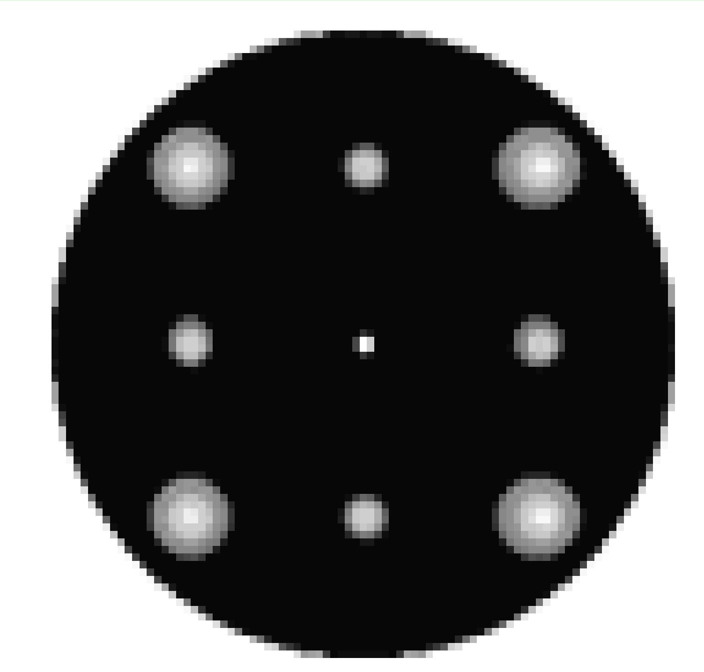
ASTIGMATISM- REASONS

Astigmatism is often the result of asymmetric lens curvature due to mistakes in manufacture or improper mounting of a lens in its frame or orientation within the objective barrel.



- **When light is focused through a curved lens, the image plane produced by that lens will be curved.**
- **The optical correction for field curvature requires the addition of several new lenses to the design, termed plan or plano lenses.**

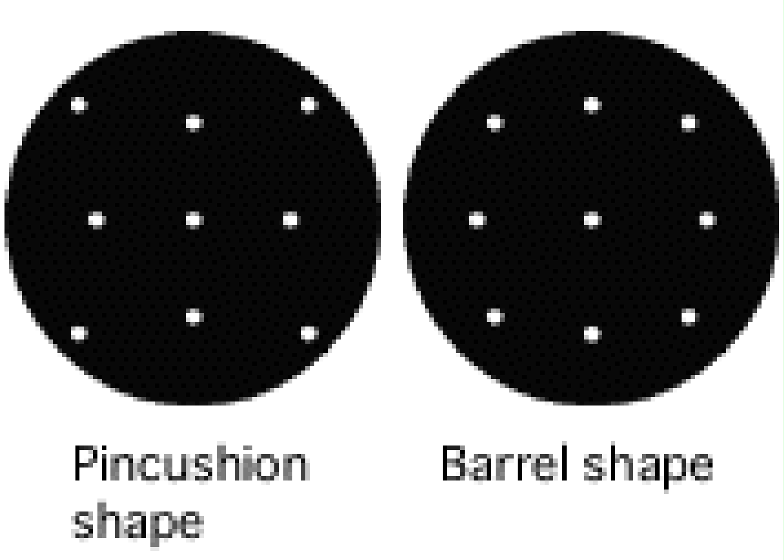
Curvature of field



Pin hole specimen image

- This is a circular blur, and at the center of the field of view and at the edges the focal point is moved. Even when the focal point is moved the blur remains circular. Likewise astigmatism, this aberration must be corrected with a Plan objective or a wide field eyepiece.
- This aberration is linearly proportional to the NA and to the square of the width of the field of view, and it becomes very noticeable when the field of view widens.

Distortion



Pin hole specimen image

- **This aberration is independent of NA, and is proportional to the width of the field of view to the power of 3. This is the only aberration where there is no blur, and even if you reduce the NA the aberration still remains. Distorted rectangular shapes are formed. In the case of the objective of a microscope or a wide field eyepiece the pincushion shaped distortion is most common. In the case of an objective, the angle of view is small, so it is not often a problem. However, for a wide field eyepiece it is necessary to correct it sufficiently.**

GEOMETRICAL DISTORTION

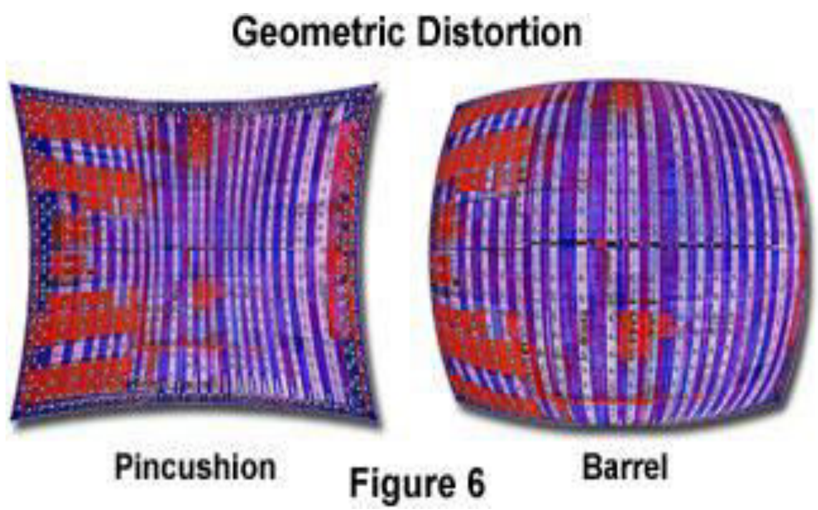


Figure 6

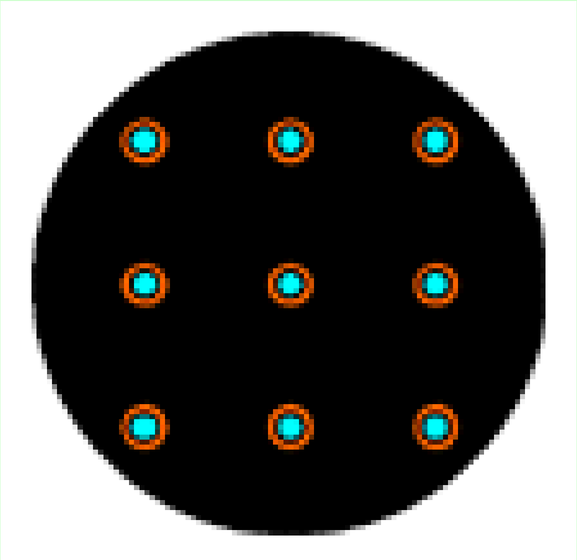
- Image distortion is an aberration commonly observed in stereo microscopy, and is manifested by changes in the shape of an image rather than the sharpness or color spectrum.

The two most prevalent types of geometrical distortion, positive and negative (often termed pincushion and barrel, respectively). When images suffer from distortion, the true geometry of a specimen is no longer maintained in the image. Figure 6 illustrates examples of rather significant pincushion and barrel distortion in the image.

GEOMETRICAL DISTORTION

- Distortion is often found in optical designs utilizing compound lens systems (telephoto, fisheye, and zoom) containing meniscus, concave, hemispherical, and thick convex lenses. Complex lens systems, such as the zoom design, can have rather pronounced distortion, which may vary with focal length, producing pincushion distortion at long focal lengths and barrel distortion at short focal lengths.
- For this reason, stereoscopic zoom microscopes classically have a significant amount of distortion present and microscope manufacturers have expended considerable effort in alleviating this aberration.

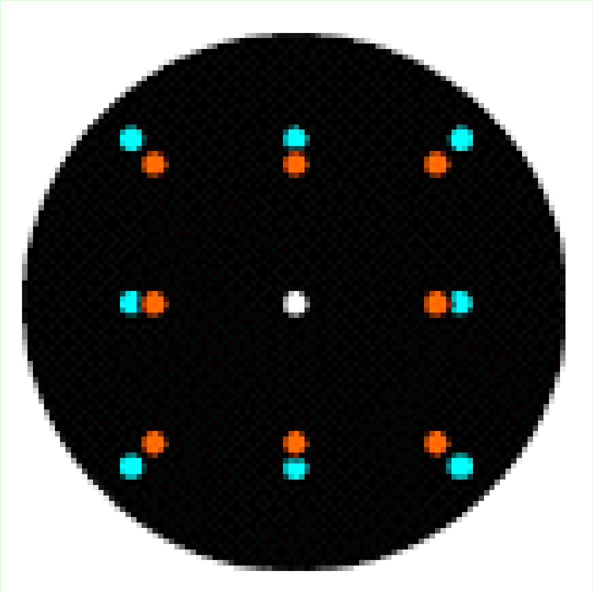
Longitudinal chromatic aberration



Pin hole specimen image

- This aberration is linearly proportional to the NA and independent of the width of the field of view. It is necessary to correct for this in an objective. Depending upon the amount of correction it classifies into Achromat and Apochromat, etc. The focal point varies depending upon the color, so the aberration appears as a dispersion of color regardless of whether the point is on or off the axis. In confocal optical systems this aberration is noticeable, so it is necessary to use an Apochromat objective.

Lateral chromatic aberration



Pin hole specimen image

- As the image magnification for each color is different, a bias of color appears off the axis. An objective tends to distort blue light in the radial direction because of its construction. This aberration is independent of the NA, and linearly proportional to the width of the field of view. In the Nikon CFI60 optical system, this aberration is corrected independently in the objective.

CHROMATIC ABERRATION

- Chromatic aberration artifacts are compounded by the difference in image magnification that occurs as a result of the varying focal planes for each color group, an effect termed chromatic difference of magnification.

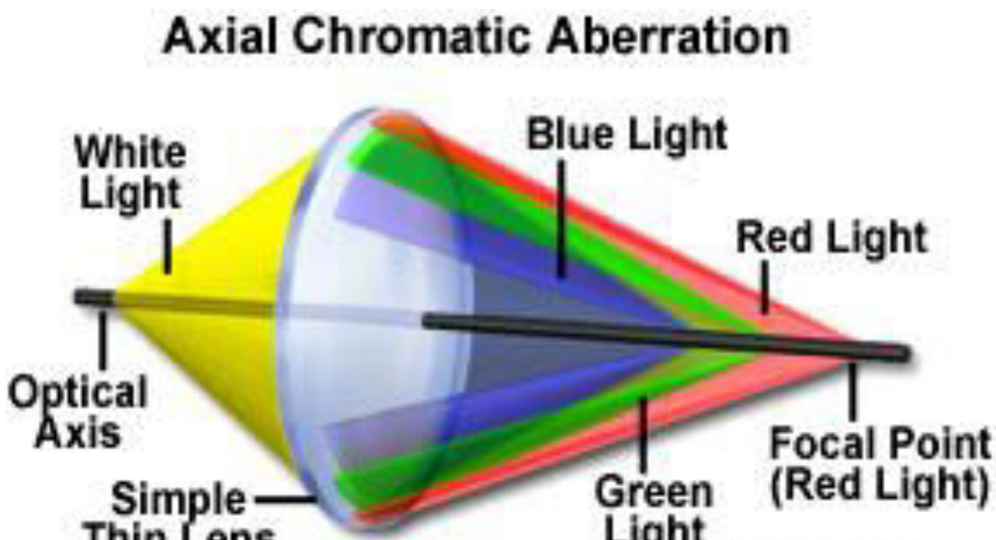
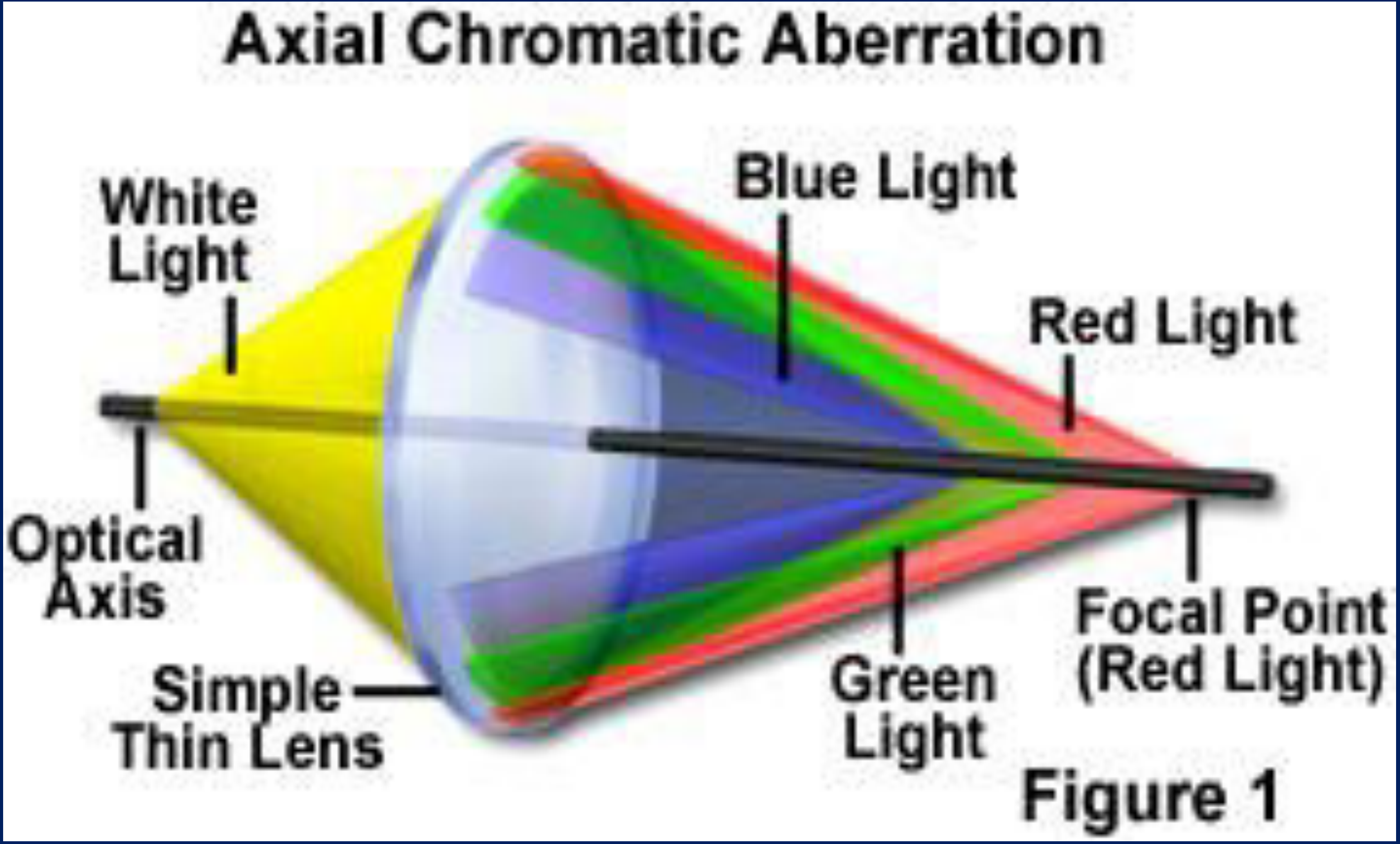


Figure 1

CHROMATIC ABERRATION



CHROMATIC ABERRATION

Aberrations of this type can be significantly reduced, or eliminated, by making compound lenses that are composed of individual elements having different color-dispersing properties. For example, crown glass has dispersive properties that enable it to be paired in a lens doublet with a flint glass element to produce an achromatic doublet lens system that focuses blue and red wavelengths in the same image plane. Additional refinement of an optical system with even more sophisticated glass formulas and shapes can reduce chromatic aberration even further.