الجامعة المستنصرية /كلية العلوم

قسم الفيزياء

Mustansiriyah University

College of science

Physics department

Optics

2023-2024

Lecture (10)

For 3rd year Students

Lecture Title: Optical aberrations and distortions in lenses and mirrors

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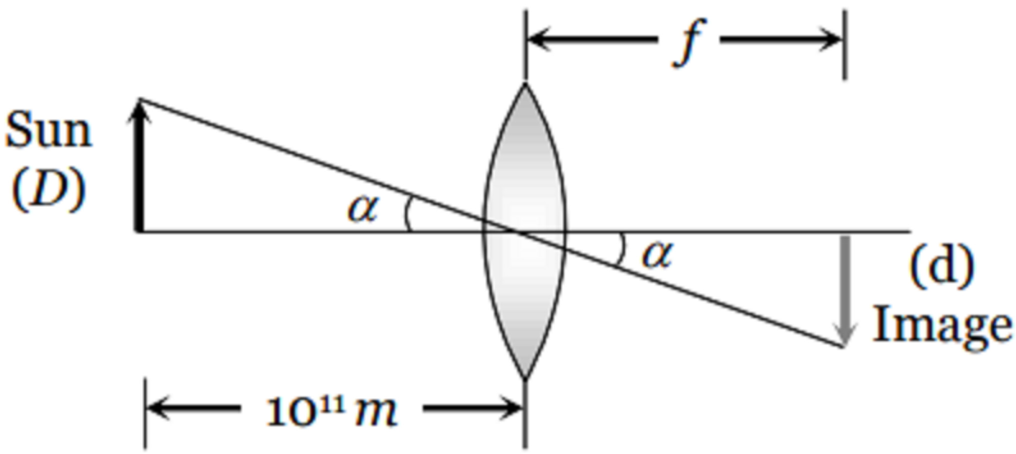
H.w:

1. A convex lens of focal length 10cm produces a real image 5 times the size of the object. What will be the distance of the object from the lens. (u=?cm).

2. The sun's diameter (D) is 1.4×10^{9}m and its distance from the earth is 10^{11}m . find the diameter of its image (d), formed by a convex lens of focal length 2m.

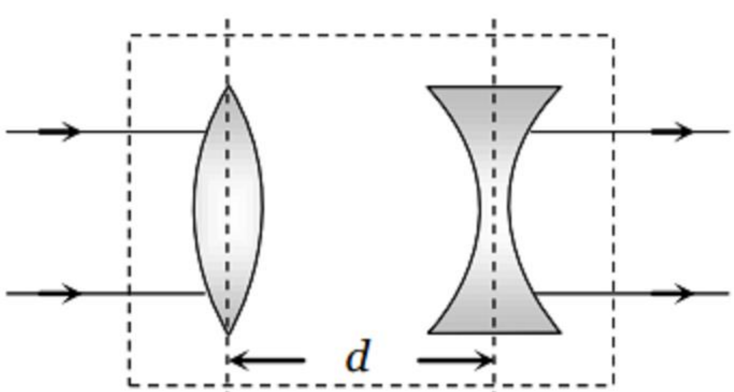


Sol: form the fig:

$$\frac{D}{d} = \frac{u}{v} = \frac{u}{f}$$

$$d = \frac{Dv}{u} = \frac{2 \times 1.4 \times 10^{9}}{10^{9}} = 2.8cm$$

3. A convex lens of local length 30 cm and a concave lens of 10 cm focal length are placed so as to have the same axis. If a parallel beam of light falling on convex lens leaves concave lens as a parallel beam. Find the distance between two lenses:



Aberrations

Aberrations, in the context of optics, refer to imperfections or deviations from ideal optical behavior in lenses and optical systems. These imperfections can lead to distortions, blurring, or other unwanted effects in the formation of images.

Achromatic Aberrations: Image of a white object is colored and blurred because μ (hence f) of lens is different for different colors. This defect is called chromatic aberration.

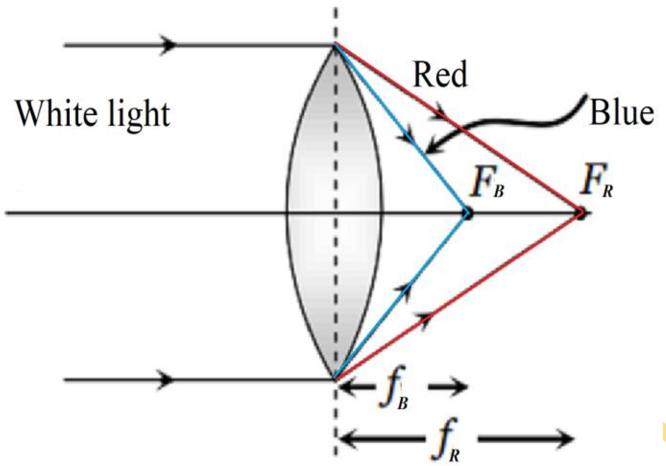


Fig: Chromatic aberration.

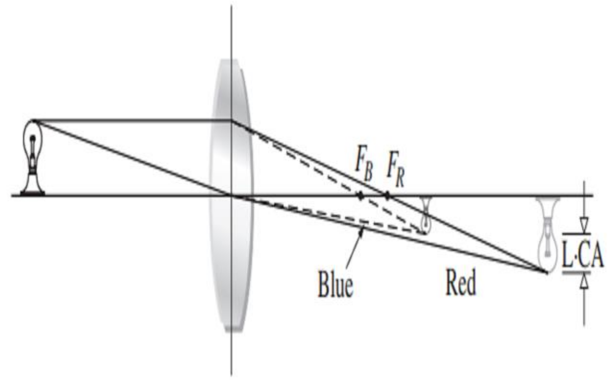


Fig: Lateral chromatic aberration.

$$\mu_B > \mu_R \quad so \quad f_R > f_B$$

Mathematically chromatic aberrations given by:

$$C = f_R - f_B = \omega f_y \quad ,,,(1)$$

Where: ω is the dispersion power of the lens, the equation for the dispersion power (V) in optics is given by:

$$\omega = V = \frac{\mu_B - 1}{\mu_y - \mu_R} \quad ..(2)$$

Where: μ_B is the refractive index for the blue/violet light.

μ_R is the refractive index for the red light.

μ_y is the refractive index for the yellow light.

The dispersion power is a measure of how much a material disperses light into its component colors. It quantifies the extent to which different colors of light are spread out as they pass through a medium.

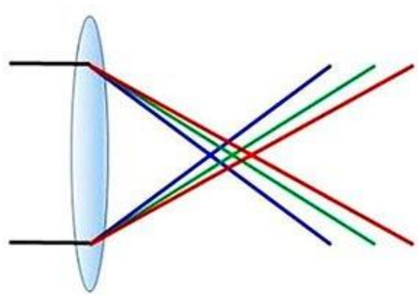
and f_y is the focal length for the mean color:

$$f_y = \sqrt{f_R f_B} \quad \ldots (3)$$

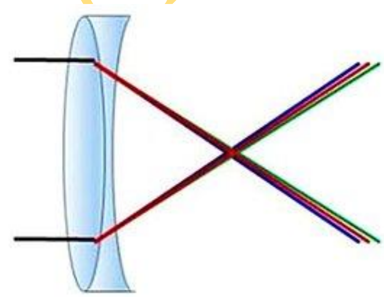
Reducing chromatic aberrations: To remove this defect i.e. for Achromatism we use two or more lenses in contact in place of single lens. Mathematically condition of Achromatism is:

$$\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0 \quad or \quad \frac{f_1}{f_2} = -\frac{\omega_1}{\omega_2} = 0 \; or \; \omega_1 f_2 = -\,\omega_2 f_1 \quad \ldots (4)$$

Note: Component lenses of an achromatic doublet cemented by Canada blasam because it is transparent and has a refractive index almost equal to the refractive of the glass.



Chromatic aberration in a single lens



Achromatic doublet

Fig: Achromatic aberration

Achromatic lenses are used to correct chromatic aberration in optical systems. Chromatic aberration is the phenomenon where light of different wavelengths (colors) is bent by different amounts as it passes through a lens, resulting in a blurred image. Achromatic lenses are designed to minimize this effect by combining two or more elements made of different types of glass. This allows them to bring all colors of light to a common focal point, resulting in a sharper image. They are commonly used in telescopes, cameras, binoculars, and other optical instruments.

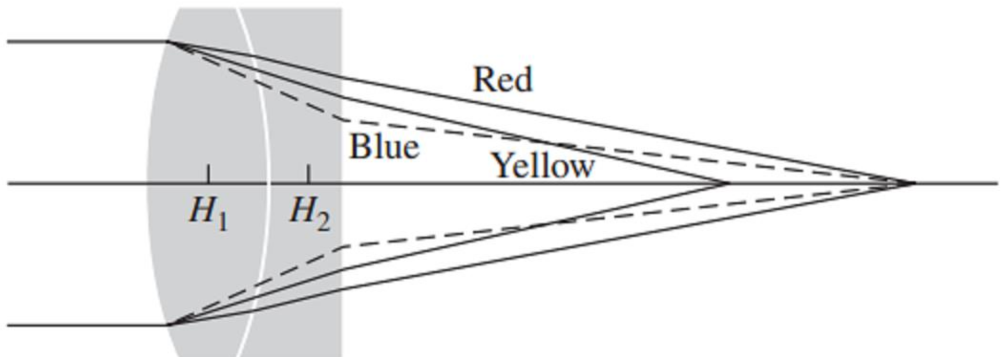


Fig: An achromatic doublet. The paths of the rays are much exaggerated.

Note: ***Mirrors do not exhibit chromatic aberrations*** because they rely on reflection rather than refraction to form images. Chromatic aberration occurs due to the dispersion of light, where different colors are refracted by different amounts as they pass through a lens or other optical element. This dispersion results in the separation of colors and can lead to color fringing in the formed images. Mirrors, being reflective surfaces, do not involve the refraction of light. Instead, they reflect light, preserving its original color composition without causing dispersion. Therefore, mirrors are free from chromatic aberrations, making them advantageous in optical systems where the elimination of color distortions is crucial.

Problem1: The focal length of a convex lens made of flint glass is 15cm. To remove its chromatic aberration, it is placed in contact with a concave lens made of crown glass. Find the focal length of the concave lens. The ratio of dispersive powers of flint glass lens ω_1 to the crown glass lens ω_2 is 1.5.

Sol:

The Focal length of a convex lens made of flint glass f_1=15 cm. Ratio of dispersive powers of flint glass to crown glass is ($\frac{\omega_1}{\omega_2} = 1.5$), to find : The focal length of the concave lens (f_2)

For achromatic combination,

$$\frac{f_1}{f_2} = -\frac{\omega_1}{\omega_2}$$

$$\frac{15}{f_2} = -1.5$$

$$f_2 = -10cm$$

negative sign indicates that the lens used is concave lens.

Notes:

- In chromatic aberration of lens: the image of white object is colored and blurred
- Mirror will not produce chromatic aberration.

Spherical Aberration:

Spherical aberration is an optical phenomenon that occurs when light rays passing through different parts of a lens or mirror focus at different points, creating blurred or distorted images. This defect arises because spherical surfaces, such as those in lenses or mirrors, do not bring parallel rays to a single, well-defined focal point. Instead, the outer rays tend to focus closer to the lens or mirror than the inner rays, resulting in image imperfections. Spherical aberration can be minimized or corrected through the use of specialized lens shapes or additional optical elements.

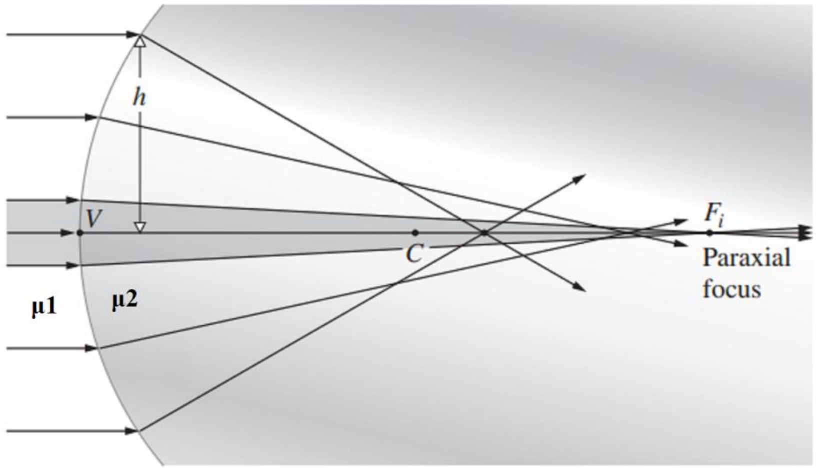


Fig: Spherical aberration resulting from refraction at a single interface.

Inability of a lens to form the point image of a point object on the axis is called Spherical aberration. In this defect all the rays passing through a lens are not focused at a single point and the image of a point object on the axis is blurred.

A series of positive lenses of the same diameter and paraxial focal length but of different shape is presented in Fig. below. The alteration of shape represented in this series is known as bending the lens. Each lens is labeled by a number q called its shape factor defined by the formula:

$$q = \frac{R2 + R1}{R2 - R1} \quad \dots (5)$$

As an example, if the two radii of a converging meniscus lens are R1=-15cm and R2 = - 5 cm, it has a shape factor

$$q = \frac{-5 - 15}{-5 + 15} = -2$$

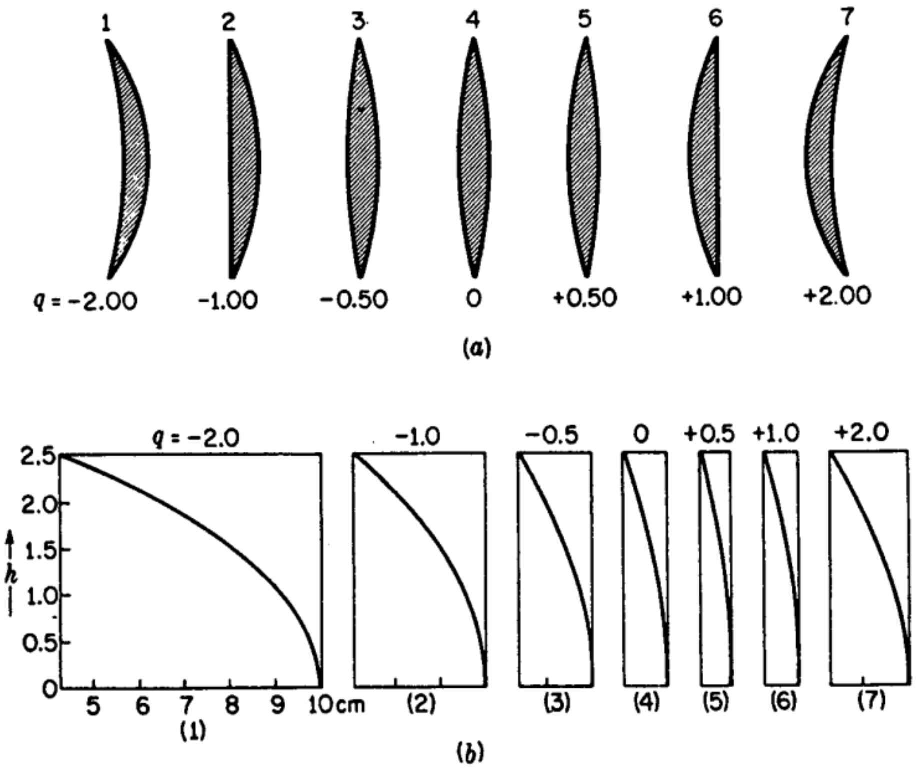


Fig: (a) Lenses of different shapes but with the same power or focal length. The difference is one of bending. (b) Focal length versus ray height h for these lenses

Notes:

- Marginal rays : The rays farthest from the principal axis.
  Paraxial rays : The rays close to the principal axis.
- Spherical aberration can be reduced by either ***stopping paraxial*** rays or ***marginal rays***, which can be done by using a circular annular mask over the lens.
- Parabolic mirrors are free from spherical aberration

Spherical aberrations reductions:

A simple method to reduce spherical aberration is to using:

1. Stops before and in front of the lens. (but this method reduces the intensity of the image as most of the light is cut off).
2. A plano-convex lens.
3. Lenses separated by distance d = F – F'.
4. crossed lens.

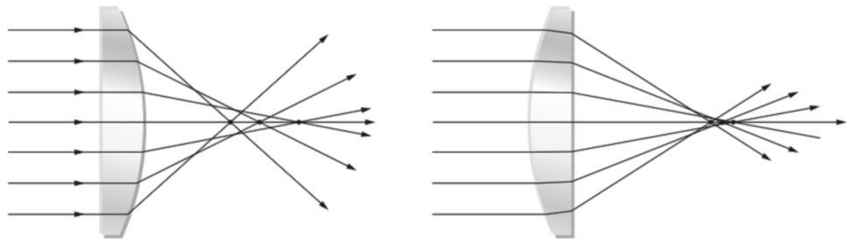


Fig: Reduced spherical aberrations

Coma aberrations:

When the point object is placed away from the principle axis and the image is received on a screen perpendicular to the axis, the shape of the image is like a comet. This defect is called Coma. It refers to spreading of a point object in a plane ⊥ to principle axis.

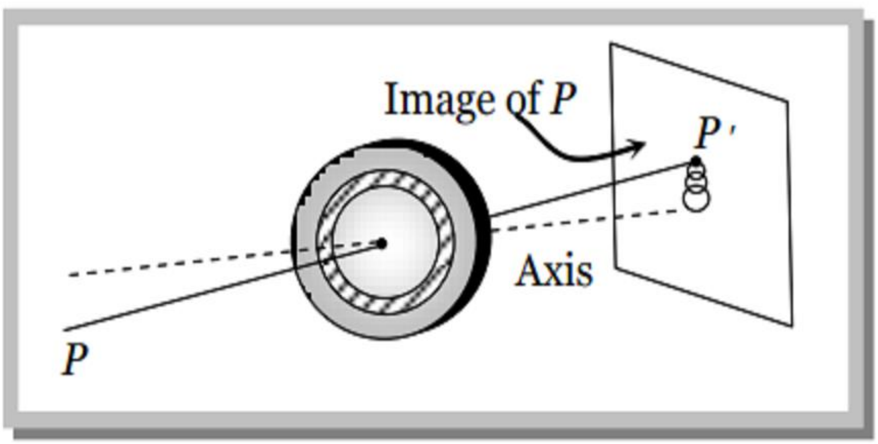


Fig: coma aberration

Reducing coma aberrations: It can be reduced by properly designing radii of curvature of the lens surfaces. It can also be reduced by appropriate stops placed at appropriate distances from the lens.

Curvature field aberrations:

Curvature field distortion refers to the optical aberration that causes a change in the magnification across the field of view, resulting in a distortion of the image. This distortion is characterized by a curvature or bending of straight lines, making them appear curved or distorted, especially towards the edges of the image. Curvature field distortion is one of the factors that optical designers strive to minimize in lens systems to ensure accurate and undistorted imaging.

For a point object placed off the axis, the image is spread both along and perpendicular to the principal axis. The best image is, in general, obtained not on a plane but on a curved surface. This defect is known as Curvature.

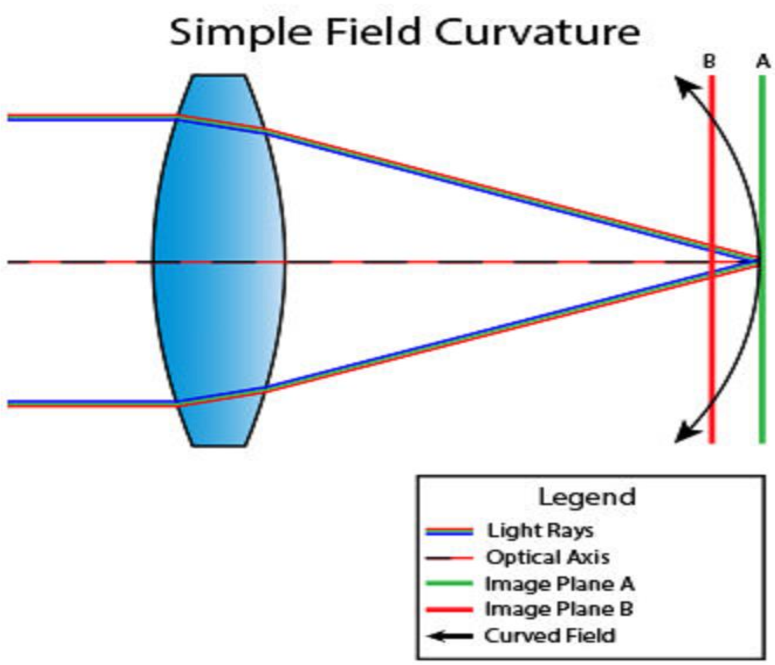


Fig: Curvature field aberrations

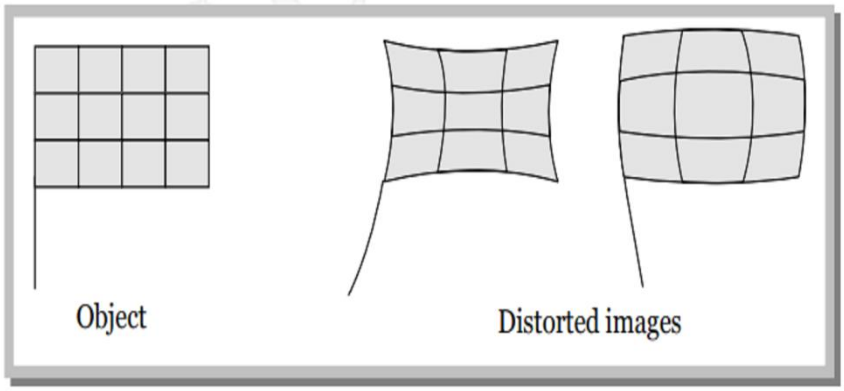
Astigmatism:

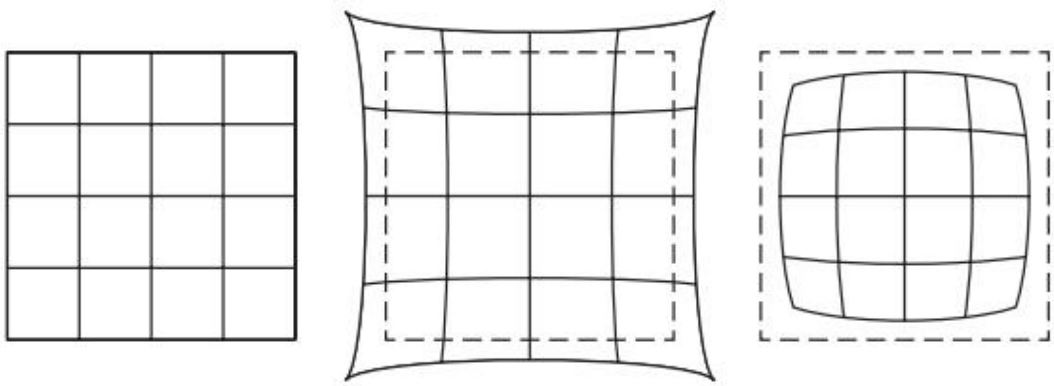
Astigmatism is an optical aberration that causes distorted or blurred images due to uneven curvature in optical surfaces. It results from variations in the focal lengths of different meridians, affecting the clarity of both near and far objects. Corrective lenses or optical adjustments are employed to counteract astigmatism and provide clear, focused vision.

Reduced Astigmatism and the curvature field: may be reduced by using proper stops placed at proper locations along the axis.

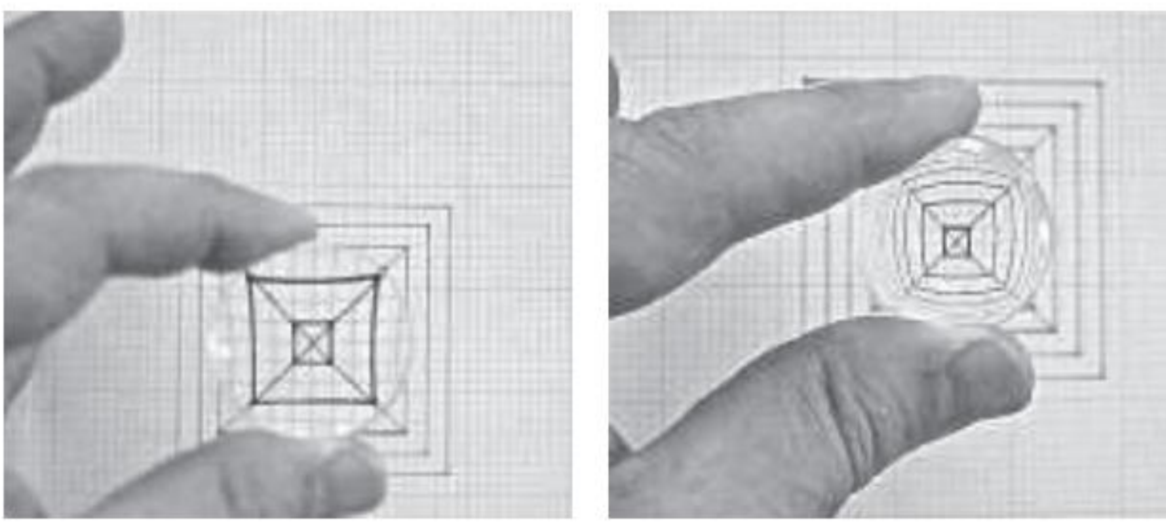
Distortions:

When extended objects are imaged, different portions of the object are in general at different distances from the axis. The magnification is not the same for all portions of the extended object. As a result a line object is not imaged into a line but into a curve





(a) (b) (c)



(d) (e)

Fig:(a) Undistorted object. (b) When the magnification on the optical axis is less than the off-axis magnification, **pincushion distortion** results. (c) When it is greater on axis than off, barrel distortion results. (d) Pincushion distortion in a single thin lens. (e) Barrel distortion in a single thin lens.

Distortions in optical systems can manifest in several types:

1. Barrel Distortion: Causes a bulging effect toward the edges, common in wide-angle lenses.

2. Pincushion Distortion: Results in a pinched appearance toward the center, often seen in telephoto lenses.

3. Mustache Distortion: Combines elements of both barrel and pincushion distortions, creating a wavy or complex pattern.

References

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2. Francis A. Jenkins , and Harvey E.White, " Fundamental of optics" Fourth Edition, McGraw-Hill Higher Education 1981.
3. N. Subrahmanyam, and Brij Lal ,"A textbook of optics ", S. CHAND & Company LTD. (AN ISO 9001: 2000 company) RAM NAGAR, New Delhui-110 055, 2000.