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S.Y. B.Sc. Physics Sem IV. (CBCS pattern)

Paper II- PHY 242 Optics

Unit-2 Lens Aberrations

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Chapter # 2

Lens Aberrations:

The deviations of the actual image produced by a lens from the ideal image predicted by simple theory of image formation are called aberrations.

* Types of Aberrations:

There are two types of aberrations (a) monochromatic and (b) chromatic aberration.

✓ Monochromatic aberration:

These are the aberrations produced by non-paraxial rays and these aberrations are also called as Seidel aberrations. These were discovered by him in 1955 and are called Seidel monochromatic aberrations.

They are further classified as....

i. Spherical aberrations.
ii. Coma
iii. Astigmatism
iv. Curvature of field
v. Distortion.

✓ Chromatic aberration:

We know that, $\frac{1}{f} = (\mu_o - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

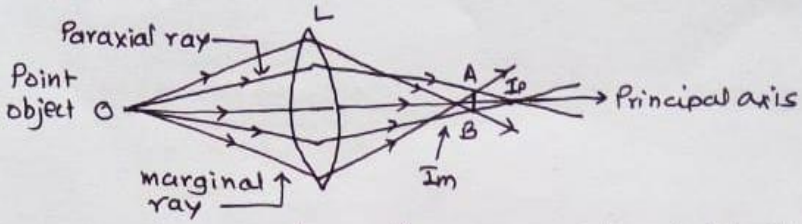
where, R_1 & R_2 are radii of curvature of a lens, μ is refractive index of material of the lens and f is the focal length of a thin lens.

For a lens, $\mu_V > \mu_R$ i.e. focal length decreases from red to violet end of the spectrum.

A large number of coloured images of different sizes situated at different positions due to a white object are seen. Hence the image is blurred. This defect of the image is called chromatic aberration.

* Types of monochromatic Aberrations and their Reductions:

(1) Spherical aberration:



Marginal rays after refraction come to a point at Im.
Paraxial rays after refraction come to a point at Ip.
As different rays are focussed at different points, the lens does not form a point image of an axial point object.

The distance between Im & Ip is called axial or longitudinal spherical aberration.

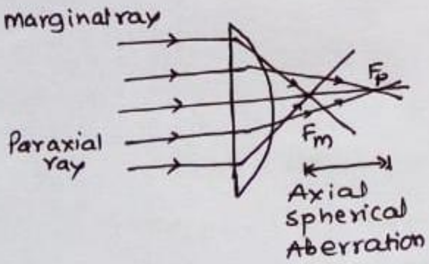
The circular patch of diameter AB is called the circle of least confusion.

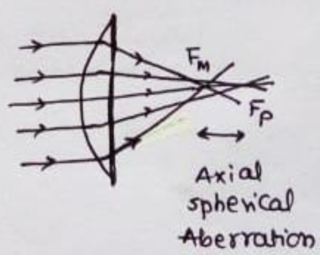
This aberration arises due to large aperture of the lens.

* Reduction of spherical aberration:

(i) By reducing the lens aperture

(ii) By using plano convex lens.





When the curved surface of the plano convex lens faces the incident light, the spherical aberration is minimum.

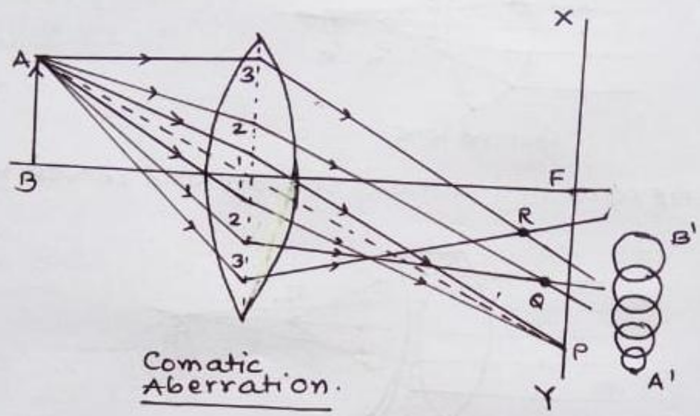
(iii) By using crossed lens.

$$\frac{R_1}{R_2} = \frac{\mu(2\mu-1)-4}{\mu(2\mu+1)}$$

If this equation is satisfied by a lens with radii of curvature R_1 & R_2, spherical aberration is reduced.

* Coma:

If a point object is situated off the principal axis, the lens forms a comet like image in place of point image. This defect in the image is called coma.



Comatic Aberration.

Rays coming from different zones (1-1, 2-2, 3-3 ...) form different circles on the screen XY. All these circles overlap, resulting in image having the appearance of a comet. The intensity of this comet is greater at point P and decreases as it approaches to F.

Reduction in coma:

(i) It can be reduced by using a lens of refractive index $\mu = 1.5$ and $\frac{R_1}{R_2} = -\frac{1}{9}$

(ii) It can be minimized by using a stop or a diaphragm.

(iii) It can be eliminated, if each zone of the lens satisfies the Abbe's sine condition.

$$\mu_1 y_1 \sin\theta_1 = \mu_2 y_2 \sin\theta_2$$

μ_1, y_1 & θ_1 refer to RI, height of object & slope angle of incident ray

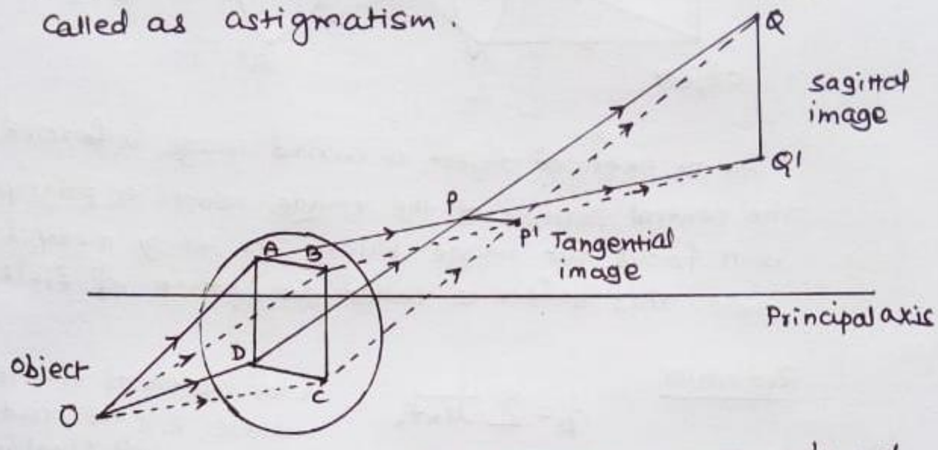
μ_2, y_2 & $\theta_2 \rightarrow$ RI, height of image & slope angle of emergent ray.

Lateral magnification of image, $\frac{y_2}{y_1} = \frac{\mu_1 \sin\theta_1}{\mu_2 \sin\theta_2}$

If $\frac{y_2}{y_1}$ is same for all rays irrespective of θ_1 & θ_2, the coma may be eliminated.

*(3) Astigmatism:

When a point object is situated far off the principal axis, its image consists of two mutually perpendicular lines seperated by a finite distance and lying in perpendicular planes. This defect of the image is called as astigmatism.



The distance between PP' & QQ' along the principal axis is called astigmatic difference.

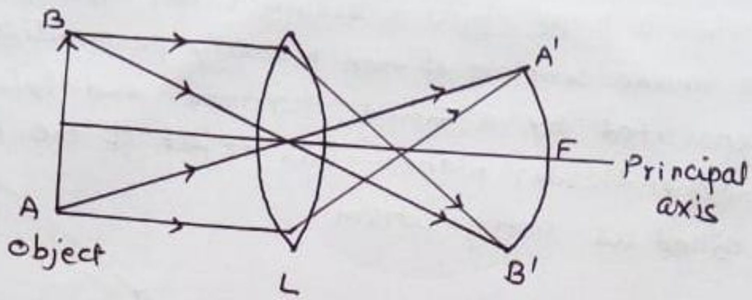
Reduction:

(i) The rays making large angles with the axis of the lens are cut off by placing a stop at proper position.

(ii) By making use of suitable combination of convex and concave lens.

(iii) In an optical system of severel lenses, by adjusting their positions, astigmatism can be reduced.

* (4) Curvature of field:



For an extended object, a curved image is formed. The central portion of the image nearer to principal axis is in focus, but image blurrs as we go away from the axis. This defect is called curvature of field.

Reduction:

$$\frac{1}{R} = \sum \frac{1}{\mu_n f_n}$$ (for system of thin lenses) where, R is the radius of curvature of final image.

For image to be flat, R must be at infinity.

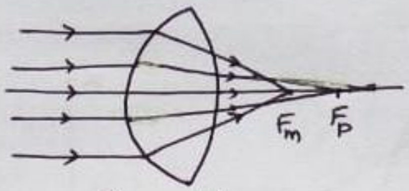
$$\therefore \sum \frac{1}{\mu_n f_n} = \frac{1}{\infty} = 0$$

and $$\frac{1}{\mu_1 f_1} + \frac{1}{\mu_2 f_2} = 0$$ **Petzwal's condition**

If μ_1 & μ_2 are same, f_1 & f_2 have opposite signs. Hence the reduction is possible with a combination of suitable concave and convex lens.

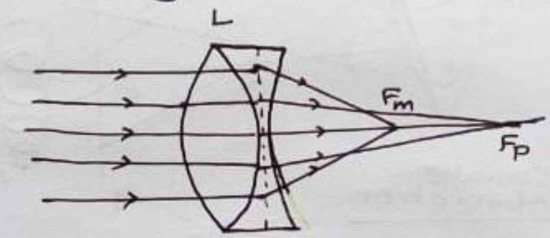
with $\mu = 1.5$, $\frac{R_1}{R_2} = -\frac{1}{6}$

A lens having this ratio is called a crossed lens. (The lens must be biconcave or biconvex)

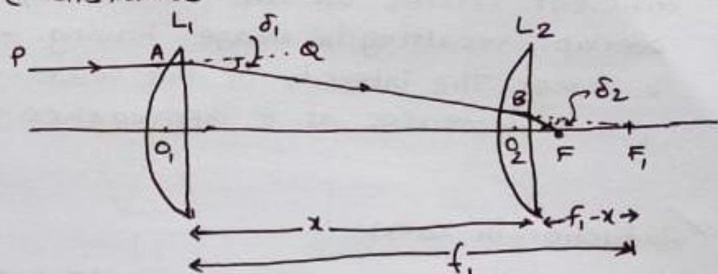


Crossed lens.

iv. By combining suitable concave and convex lens.

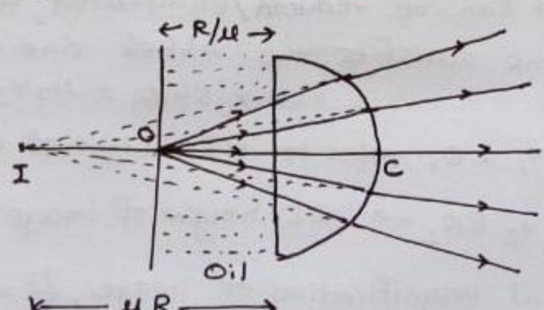


v. Combination of two planoconvex lenses seperated by finite distance.



$f_1 - f_2 = x$ is the condition for minimum spherical aberration.

vi. By using an aplanatic lens.

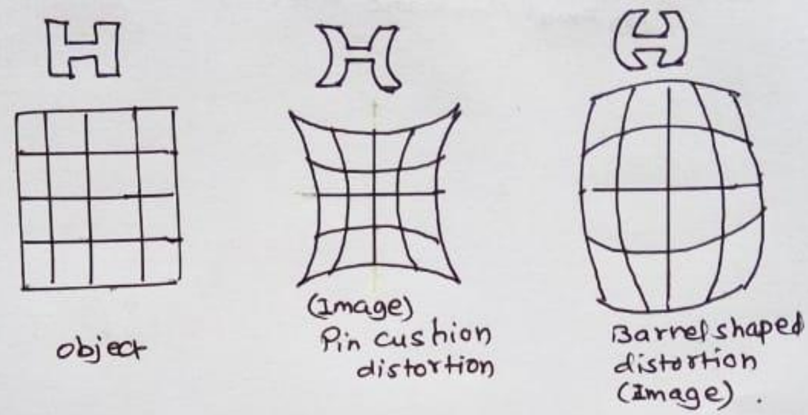


A lens free from defects of spherical aberration and coma is called an aplanatic lens.

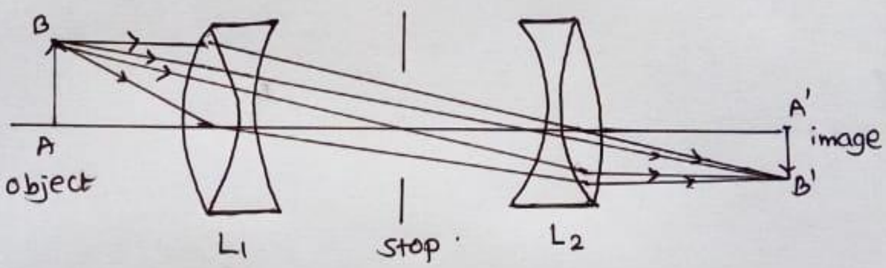
*(5) Distortion:

The variation in the magnification produced by a lens for different axial distances result in the aberration called distortion.

There are two types of distortion:
(a) Barrel shaped and (b) pin-cushion.



Reduction:



A stop is placed between two symmetrical lenses, so the pin cushion distortion produced by the first lens is compensated by the barrel shaped distortion produced by the second lens to get reduced distortion.

Projection and camera lenses are constructed in this way.

*(4) Chromatic Aberration:

The rays of white light after refraction through a lens form a number of coloured images of different sizes at different positions. This defect is known as chromatic aberration.

There are two types....

(a) Axial Chromatic Aberration & (b) Lateral chromatic aberration.