Date: 22/08/2020

Defects in the images: Aberration

While deriving relations between objects and image distances, and focal length of lens, it is assumed that

(i) All the incident rays make small angles with the principal axis.

(ii) The aperture of the lens is small.

However, in practice, to have bright image, we use lenses of large aperture.

Also to have a larger field of view, rays having greater angular elevations are incident on the lenses.

Moreover, due to finite size of the object, rays from different portion of the object are incident on the lens at different angle and height.

It is well known that the deviation produced in any ray depends upon the height of the point of incidence and the angle of incidence.

Therefore, paraxial and non-paraxial (or marginal) rays come to focus at different points.

Due to the above mentioned reasons, the image formed is very often, not as predicted by relations derived using simplifying assumptions.

The image formed by the lenses can have many defects. Such optical defects in the formed images are called aberrations.

“The deviation from the actual size, shape and position of an image compared to predicted one using the thin lens formula, are called the aberration produced by a lens”

The aberrations can be divided broadly in two categories

(i) Monochromatic (or Siedel) aberrations

(ii) Chromatic aberrations

(i) **Monochromatic (or Siedel) aberrations**: The aberrations which are present even if the incident light contains a single wavelength (i.e., the incident light is monochromatic) are called monochromatic aberrations.

Primarily, monochromatic aberrations arise due to the participation of both paraxial and non-paraxial rays in image formation.

There are five types of monochromatic aberrations:

(i) Spherical aberration

(ii) Coma

(iii) Astigmatism

(iv) Curvature of the field

(v) distortion

(ii) **Chromatic aberrations**: It is well known that the refractive index and hence the focal length of a lens is different for different wavelengths of the incident light.

For a given lens, the refractive index of violet light is higher than that of red light.

Thus, if the incident light on a lens is not monochromatic, a number of colored images, corresponding to each wavelength, are formed.

Even if the images are formed only by paraxial rays, they are formed at different positions and are of different sizes.

> *"The aberrations which arise due to the presence of more than one wavelength in the incident light are called chromatic aberrations"*

Chromatic aberration

The chromatic aberration is due to the fact that the refractive index of a material of a lens is different for different wavelengths (color) of light. Hence, the focal length is different for different wavelengths. According to lens maker's formula, the focal length (f) of a lens having radii of curvature r_1 and r_2 is given by:

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

Where, μ is the refractive index, which is different for different wavelengths (in accordance with Cauchy's law: $\mu = A + \frac{B}{\lambda^2}$). Hence the focal length f is also different for different wavelengths.

Due to the above mention reason, the image of an object, when seen in white light, is colored and blurred. This defect is known as chromatic aberration.

The chromatic aberrations are of two types:

(i) Longitudinal (or axial) chromatic aberration

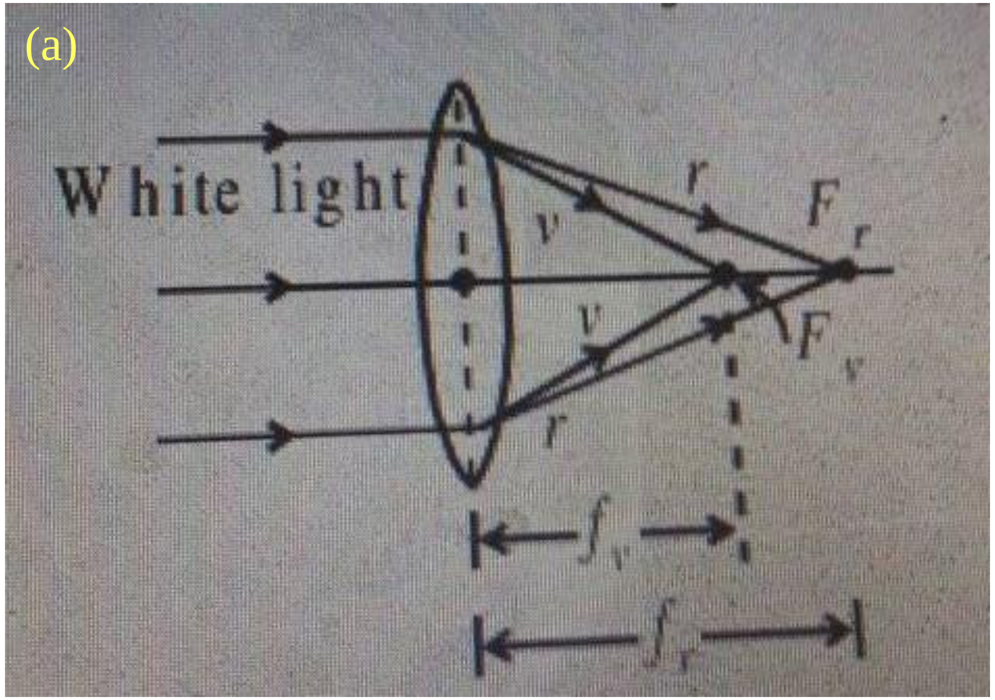
(ii) Lateral (or transverse) chromatic aberration

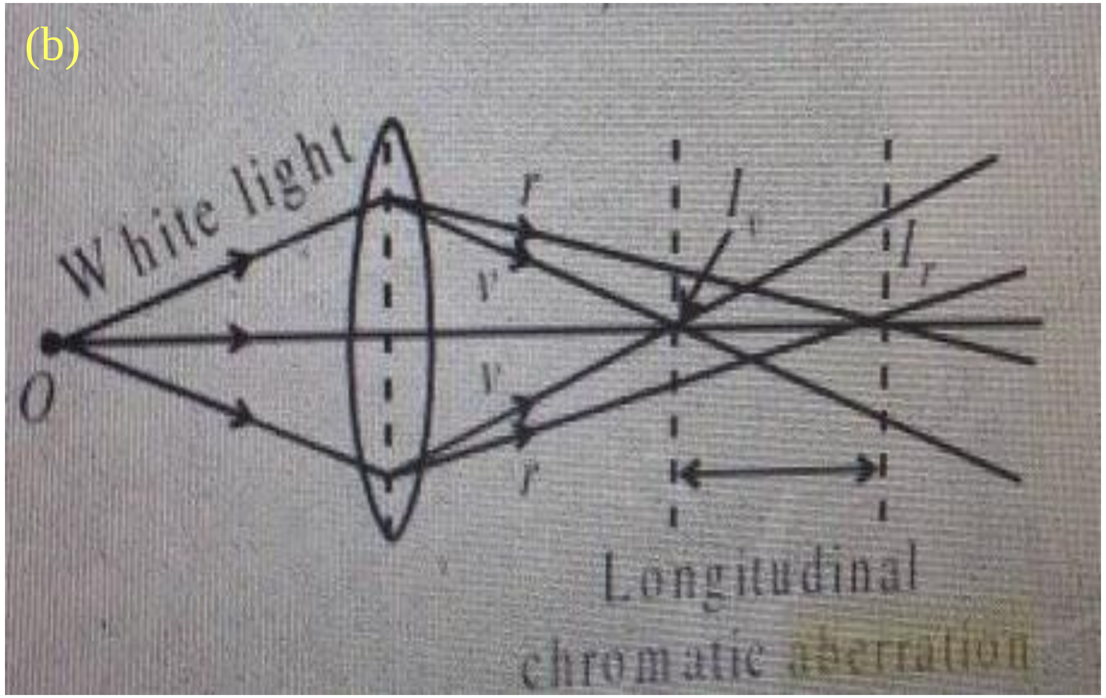
Longitudinal chromatic aberration

The refractive index of violet color μ_v is greater than that for red color μ_r $(\text{i.e.}, \mu_v > \mu_r)$. Therefore, the focal length for violet color f_v is smaller than that for red color f_r. The foci of the other intermediate colors lie in between these two. Thus when a beam of white light is incident parallel to the principal axis on a convex lens [Fig. (a)], the violet rays converge first (i.e., closest to the lens) and the red rays converge last, i.e., farthest from the lens. If the screen is placed at F_v the center of the image will be violet while the outermost region will be red. If the screen is placed at F_r, the center of the image will be red while the outermost region will be violet.

The separation between focal point of violet color F_v and that of red color F_r on the principal axis measures the longitudinal aberration.

Longitudinal aberration = F_r-F_v





If an object is situated at the point O on the principal axis [Fig. (b)], its violet image is formed I_v, and the red image is located at I_r. The separation between I_v and I_r measures the longitudinal chromatic aberration when the object is at finite distance. That is

The longitudinal chromatic aberration is taken as positive when measured from I_v to I_r along the direction of incidence. Thus, in the case of convex lens, it is positive while in the case of concave lens, it is negative.