Exercise 5
Chromatic Aberration

**Aim:** To design a doublet with minimum chromatic aberration possible.

In this segment, we design a lens and then use a doublet having the same focal length but optimized for minimum chromatic aberration. The index of refraction of a material is a function of wavelength. This is known as dispersion and is represented by the Abbe value of the material. Figure 1 shows the result when polychromatic collimated light is incident on a positive lens element. Because the index of refraction is higher for shorter wavelengths, these are focused closer to the lens than the longer wavelengths. Longitudinal chromatic aberration is defined as the axial distance from the nearest to the farthest focal point.

![Figure 1 Demonstration of longitudinal chromatic aberration](image1)

Lateral color, shown in Fig. 2, is the difference in image height between blue and red rays. Stated simply, magnification depends on color. Lateral color is very dependent on system stop location.

![Figure 2 Demonstration of lateral colour](image2)
As in the case of spherical aberration, positive and negative elements have opposite signs of chromatic aberration. By combining elements of nearly opposite aberration to form a doublet, chromatic aberration can be partially corrected. It is necessary to use two glasses with different dispersion characteristics, so that the weaker negative element can balance the aberration of the stronger, positive element. Achromatic doublets are superior to simple lenses because achromatic doublets correct for spherical as well as chromatic aberration, they are often superior to simple lenses for focusing collimated light or collimating point sources, even in purely monochromatic light.

Exercises:

**Single Lens:** Model a lens, whose first radius of curvature is 100 and second radius of curvature is 100. Let the second surface be the aperture stop. Let the entrance beam radius be 5mm and field angle be 20 degree. Let the thickness of the lens be 10 mm initially. Position the IMS at the point where axial ray height goes to zero. Now, generate an error function to get the effective focal length (EFL) of 100 by defining OCM21-100 so that OCM21 is minimized. Set the thickness of the lens as variable and iterate. Save the ray analysis graphs i.e. lateral color shift, OPD curves, chromatic focal shift and chromatic lateral shift graphs to facilitate comparison with the effect of incorporating a doublet.

**Optimization by using a doublet:** In order to change the above lens to a doublet, enter F2 in the glass column of surface 2. (You can use other flint glasses as an additional exercise). Specify the third surface to be flat so that the same lens can be optimized for minimal spherical aberration and coma. Let surface 3 be the aperture stop. Place the image surface at the position where axial ray height goes to zero.

Now generate an error function with operands as PAC (Primary axial color), PLC (Primary lateral color), SAC (Secondary axial color), SLC (Secondary lateral color) and EFL(to be taken as 100). Take the first and second radius of curvature and thickness of the second surface as variable. Now iterate and save the same graphs as above. Compare them on identical scales.

Note: While comparing make sure the axes before and after optimization are the same.

The resulting aberrations, in both cases can be studied using OPD, lateral shift and focal shift curves. In order to observe these, go to the graphics window; click the symbol corresponding to Setup window/toolbar and select ray analysis.
These designs will give you curves of the nature shown in Fig. 3.

**Single lens**  **Doublet Lens**

![Graphs showing lateral color curves for singlet and doublet designs](image)

Figure 3 Lateral colour curves for the singlet and doublet designs

In order to obtain OPD curves, lateral shift and focal shift, go to graphics window; click the symbol corresponding to Setup window/toolbar and select ray analysis.

**Single lens**  **Doublet Lens**

![Graphs showing OPD curves for singlet and doublet designs](image)

Figure 3 OPD curves for the singlet and doublet designs
Practice Exercise:

1. Design a lens with a specific focal length of 80 mm. Constrain the focal length to that value and change the lens shape. Let the f\#=f/10 covering a ±15
° field of view.

2. Plot curves of the following aberrations: spherical aberration, lateral colour and tangential field curvature against lens shape, when the stop is each time adjusted to be in the natural stop position.

References:
Figures 1, and 2 are taken (with permission) from the OSLO manual.
LAMBDA RESEARCH CORPORATION, USA (www.lambdares.com)