3. Achromatic Doublets (F14 Final Q2)

Two thin lens achromatic doublets have focal lengths of $f = 100mm$. The two achromats are constructed out of the following two pairs of glasses:

Achromat #1	N-BaK4	$n_d = 1.569$	$\nu = 56.0$	$P = 0.303$
	N-DF2	$n_d = 1.648$	$\nu = 33.8$	$P = 0.292$
Achromat #2	N-SK16	$n_d = 1.620$	$\nu = 60.3$	$P = 0.305$
	N-LaF21	$n_d = 1.788$	$\nu = 47.5$	$P = 0.301$

a. Determine the focal lengths of each of the elements in the two achromatic doublets.

$$\frac{\varphi_1}{\varphi} = \frac{\nu_1}{\nu_1 - \nu_2}, \qquad \frac{\varphi_2}{\varphi} = \frac{\nu_2}{\nu_2 - \nu_1}$$

$$\varphi_1 = \frac{\nu_1}{\nu_1 - \nu_2} \cdot \frac{1}{f}, \qquad \varphi_2 = \frac{\nu_2}{\nu_2 - \nu_1} \cdot \frac{1}{f}$$

Achromat #1 $\varphi_1 = \frac{56.0}{56.0-33.8} \cdot \frac{1}{100} = 0.00252mm^{-1} \to f_1 = 39.7mm$

$\varphi_2 = \frac{33.8}{56.0-33.8} \cdot \frac{1}{100} = -0.00152mm^{-1} \to f_2 = -65.8mm$

Achromat #2 $\varphi_1 = \frac{60.3}{60.3-47.5} \cdot \frac{1}{100} = 0.00471mm^{-1} \to f_1 = 21.2mm$

$\varphi_2 = \frac{47.5}{60.3-47.5} \cdot \frac{1}{100} = -0.00371mm^{-1} \to f_2 = -27.0mm$

b. Provide an explanation for how the combination of two different glasses in an achromatic doublet result in the correction of chromatic aberration.

Positive and negative lenses with different dispersions (Abbe Numbers) are combined to provide the desired net power for the lens. The elements have equal but opposite longitudinal chromatic aberrations that cancel, correcting the longitudinal chromatic aberrations of the system.

c. What of the two designs has the least excess power?

Achromat #1 $\quad \Delta\nu = 56.0 - 33.8 = 22.2$

Achromat #2 $\quad \Delta\nu = 603 - 47.5 = 12.8$

Larger $\Delta\nu$ means that Achromat #1 has less excess power.

d. If the achromatic is corrected for chromatic aberration, why does an achromat have secondary chromatic aberration?

The solution for an achromat forces the same axial focus for F and C light, but d light can focus at a different location—secondary chromatic aberration.

e. Determine the secondary chromatic aberration for each achromat.

$$\delta f_{Cd} = \frac{\Delta P}{\Delta\nu} f$$

Achromat #1 $\quad \delta f_{Cd} = \frac{0.303-0.292}{22.2} \cdot 100 = 0.0495mm$

Achromat #2 $\delta f_{Cd} = \frac{0.305-0.301}{12.8} \cdot 100 = 0.0312mm$

For a reduced δf_{Cd}, achromat #2 has greater excess power.

4. Three Thin Lenses in Air (F13 Final Q4)

A system is comprised of three thin lenses in air. The first thin lens has a focal length of $f_1 = 100mm$, the second has a focal length $f_2 = -100mm$, and the third has a focal length $f_3 = 100mm$. The separation between the first and second lenses is $t_{12} = 40mm$, and the separation for the second and third lenses is $t_{23} = 60mm$. The second lens is the system stop.

a. Determine the Entrance and Exit Pupil locations.

EP is $66.67mm$ to the right of Lens 1.

XP is $150.00mm$ to the left of Lens 3.

b. Determine the Focal Length and the Back Focal Distance (BFD).

Focal Length $\varphi = -\frac{-0.0076}{1} = 0.0076mm^{-1} \rightarrow f = 131.58mm$

BFD $(-150.00mm) + 197.37mm = 47.4mm$

c. The system Stop has a diameter of 20mm. Determine the Entrance Pupil and Exit Pupil diameters.

EP diameter $33.33mm$

XP diameter $50.00mm$

d. For distant object, the system has an unvignetted Field of View of $\pm 12^o$ in object space. What is the image height in the image plane for this FOV?

$$\overline{u_0} = \tan(12^o) = 0.2126$$

$$Image\ Height = 27.97mm$$

e. What are the required Lens diameters to support this FOV?

Unvignetted: $a = |y| + |\bar{y}|$

Lens 1 diameter $61.68mm$

Lens 2 diameter $20.00mm$

Lens 3 diameter $54.52mm$