

Optics and Instruments 2015:  
Exercises on Optical Design  
(Due on 4 November 2015 at 13:45)

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## 1 Reducing Aberrations with Multiple Elements

1. Design a single f/1.0, symmetric lens to focus light from infinity onto a detector and determine the rms spot size of the image at the center of the field of view.
2. Design an f/1.0 lens consisting of 4 identical, symmetric lenses to focus light from infinity onto a detector. How much longer is the focal length of one of these lenses as compared to the singlet design in part 1? Determine the rms spot size of the image at the center of the field of view.
3. Explain the performance difference between the two designs.

## 2 Achromatic Lens

An achromatic lens is made of two different glasses to minimize the change in focal length as a function of wavelength. The properties of an achromatic lens can be calculated from 1) the focal length  $f$  of the combined lens

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2},$$

where  $f_{1,2}$  are the focal lengths of the individual lenses, and 2) the minimization of the chromatism

$$\frac{f_1}{n_1(\lambda_1) - n_1(\lambda_2)} + \frac{f_2}{n_2(\lambda_1) - n_2(\lambda_2)} = 0$$

where  $n_{1,2}(\lambda_{1,2})$  are the indices of refraction of glass 1 and 2 at wavelengths  $\lambda_1$  and  $\lambda_2$ . Note: The relation of focal lengths is only valid for two thin lenses that are in contact. The condition for the minimization of the chromatism can be found in Hecht, section 6.3.2.

1. Design an achromatic lens with a focal length of 500 mm at wavelengths of 486.1 nm and 656.3 nm and an F-number of 4. Use <http://refractiveindex.info> to obtain the indices of refraction. Use a biconvex BK7 lens with the same front and rear radii of curvature and an F2 lens with one surface having the same radius of curvature as the BK7 lens. Using the thin-lens equation, determine the radii of curvature of the two lenses.
2. Enter the derived properties into the optical design software and compare the rms spot radii at the two wavelengths with those of a single BK7 lens with the same focal length (at 656.3 nm) and diameter.
3. Reverse the arrangement of the two lenses and compare the rms spot radii with the original achromat.

### 3 Positioning Tolerances for Cassegrain Telescope

Design a 200-mm diameter Cassegrain telescope (parabolic primary, hyperbolic secondary, focal plane) with a focal length of 1200 mm.

1. Determine the pixel size of a camera in the focal plane that provides diffraction-limited images at 500 nm.
2. Determine the maximum allowed axial motion of the detector to remain diffraction limited (rms spot diameter =  $1.22 \lambda/D$ )
3. Determine the maximum allowed axial motion of the secondary mirror to remain diffraction limited when the focal plane stays in the same position.
4. Determine the maximum allowed axial motion of the secondary mirror to remain diffraction limited when the focal plane is allowed to move to the best focus position.