Lens Aberrations

In this lab we will explore how a lens deviates from ideality, the subject of *aberrations*. You will observe how the focal length depends on the angular distribution of light (spherical aberrations) and on wavelength (chromatic aberrations). Since these effects may be small, you will need to make several measurements, plot the results to reveal systematic deviations, and perform least-squares fits to compare with theory.

A. Select a plano-convex lens, about 3.5 inches in diameter, and find its focal length. Use the method of image formation with the thin lens formula; also calculate f from the lens curvatures, measured with a spherometer, and n given in the Appendix. Calculate uncertainties in f and compare results.

B. Place the lens about 1.25f from the object with the planar surface facing the lamp. Place the smallest aperture (the cardboard with a 15 mm hole) immediately in front of the lens. Be careful to position it on the optical axis. Focus the image and measure the image distance s_i. With this aperture, assume that the measurement is aberration-free.

C. Replace the aperture with different ring stops and remeasure s_i. Measure the radii, h, of the rings.

D. Make a plot of h vs $\Delta(1/s_i)$ and fit to a quadratic function as suggested by the equations in the Appendix. Also, use a linear fit by plotting h^2 vs $\Delta(1/s_i)$. **Q1.** What is the goodness of fit? What measure should you use?

E. Rotate the lens (planar side away from the source) and repeat steps B-D.

F. Using the equations in the Appendix, calculate the parameter S from the measurements. **Q2.** How does your calculation compare with the least-squares fit parameters? **Q3.** If some of the points deviate systematically from the fits, explain why this happens.

G. Place one of the colored filters in front of the lens and measure the focal length using the thin lens equation. Repeat with the other filters. Leave s_o unchanged to improve accuracy.

H. Plot $1/f$ vs. n using the values of the refractive index given in the Appendix and fit to a linear function. **Q4.** Compare your fit results to the radii measured with the spherometer. Make an assessment of the accuracy of the two different types of measurement.

APPENDIX

See Hecht for an intuitive understanding of aberrations. Useful equations to compute spherical aberrations come from *Principles of Optics* (Hardy and Perrin). The change in the image distance (Δs_i) as a function of ray height (h) is given by:

$$\Delta\frac{1}{s_i} = \frac{h^2}{f^3}\left(Au^2 + Buv + Cv^2 + D\right) = \frac{h^2}{f^3}S$$

where $u = \frac{R_1 + R_2}{R_1 - R_2}$ is the *shape factor* (for $R_1 \to \infty$, $u \to 1$) and

$v = \frac{s_i - s_o}{s_i + s_o} = 1 - \frac{2f}{s_i}$ is the *position factor* and

$$A = \frac{n+2}{8n(n-1)^2}$$

$$B = \frac{n+1}{2n(n-1)}$$

$$C = \frac{3n+2}{8n}$$

$$D = \frac{n^2}{8\left(n-1\right)^2}$$

Assume $n = 1.51$ when using these equations.

For chromatic aberration, you can use the Lensmaker's Equation and values of n for the glass at the filter transmission maxima given in the table below.

Color	λ(nm)	n
blue	420	1.5357
cyan	490	1.5280
green	540	1.5239
yellow	590	1.5206
red	640	1.5160