

In this lab you will explore several types of aberrations of a real lens. The techniques you will use are similar to those used before for finding the focal length of a lens, but you will explore how the focal length changes with position and color. Since the effects are small, you will need to make several measurements and to plot the results to establish a trend. This will also facilitate comparisons of your measurements to theory. You will need to utilize a plotting program (such as Kalidagraph) that will let you fit a least-squares line to your data. Remember to include the error bars for your measured values on your plot.

- A. Choose a converging lens with two different radii of curvature, preferably a plano-convex lens, with a diameter of at least 2 inches. Measure the focal length of your lens following the thin lens formula. Further measure the radii of the lens using a spherometer. Using a representative value of  $n$  from the Appendix, compute  $f$  from the lens-maker formula. Determine uncertainties and compare your two results for  $f$ .
- B. Place the lens about  $1.25f$  away from the object with the flat (or less convex) side facing the object. Place the smallest aperture you will be using (if necessary make a small hole in cardboard) immediately in front of the lens. Be careful to position the aperture 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 measure new  $s_i$ . In each case measure and record the radius  $h$  of the stop.
- D. Plot  $h$  vs shift  $\Delta(1/s_i)$  and fit a parabola to your results as suggested by the equations in the Appendix. If your plotting program is not capable of fitting a parabola, plot  $h^2$  vs  $\Delta(1/s_i)$  and fit a straight line. **Q1.** What measure could you use to tell the goodness of the fit?
- E. Rotate the lens (less convex side away from the object) and repeat the steps above B-D.
- F. Using the equations in the Appendix, calculate the parameter  $S$  for your setup, employing the radii and image and object distances from your measurements. Consider both orientations of the lens. **Q2.** How does your calculation compare to  $S$  following from the least-squares fit parameters? **Q3.** Do some of your points significantly deviate from a parabola? Why do you think this happens?
- G. Place one of the colored filters in front of the lens and measure the focal length (error included) using the thin lens equation. Repeat actions with the other filters. Your measurements will be easiest to compare to each other if you do not change  $s_o$ , just  $s_i$ .
- H. Plot  $1/f$  vs.  $n$  using the values of the refractive index given in the Appendix and fit a straight line to your results. **Q4.** Compare the proportionality coefficient in your fit to that deduced from the radii measured with the spherometer. Which methodology yields a more accurate result?

## APPENDIX

See the textbook by the Pedrotti for both qualitative and quantitative discussions of the aberrations, possibly at different locations there depending on edition. A qualitative discussion of the aberrations can be moreover found in Technical Library at [cvilaseroptics.com](http://cvilaseroptics.com) under [Performance Factors](#).

### Spherical Aberration

The derivation of an equation for spherical aberration is too lengthy to be given here. For a thin lens, expansion of pertinent equations under the assumption of small effects yields

$$\Delta \frac{1}{s_i} = S \frac{h^2}{f^3},$$

where  $\Delta \frac{1}{s_i}$  is the shift in inverse image position relative to that formed by paraxial rays,  $h$  is the distance away from the axis at which an oblique ray traverses the lens and  $f$  is the paraxial focal length. The factor  $S$  depends on characteristics of the lens and on object position

$$S = \frac{1}{8n(n-1)} \left[ \frac{n+2}{n-1} \sigma^2 + 4(n+1)p\sigma + (3n+2)(n-1)p^2 + \frac{n^3}{n-1} \right].$$

Here  $n$  is the index of refraction for the lens,  $\sigma$  is the so-called Coddington shape factor

$$\sigma = \frac{R_2 + R_1}{R_2 - R_1},$$

where the radius is positive if the center of curvature points to the side of (real) object and negative if away. Finally  $p$  is position factor

$$p = \frac{s_i - s_o}{s_i + s_o},$$

where  $s_i$  is position for paraxial rays. Assume  $n = 1.52$  for these equations.

### Chromatic Aberration

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

Color	$\lambda(\text{nm})$	$n$
Violet	420	1.5357
Blue	490	1.5280
Green	540	1.5239
Yellow	590	1.5206
Red	640	1.5160