LAB 7: THIN LENSES

Measuring the focal length of a lens is a common problem. This lab presents six different ways to measure focal length. Each method will be used to measure the focal length of a positive test lens. For each method, measure the focal length five times and calculate the means and standard deviation of the mean. The write-up should compare the accuracy and precision of each method.

Object-Image Relationship:

Take the positive lens provided (focal length of 150.0 mm) and measure the image distance for five different object positions. Compute the lens power and focal length for each pair of measurements and take the averages. How close do you come to the known value of focal length? The basic problem with this approach is that depth of focus makes it difficult to locate the image plane precisely.

As in a previous lab, graph $1/z'$ vs. $1/z$ (using units of meters). To best-estimate the error in measuring the focal length (y-intercept), fit your data points with 3 straight lines. On the graph of $1/z'$ vs. $1/z$, draw 3 lines of best-fit, maximum slope, and minimum slope that pass through the data points. (The best-fit line may be determined using software and linear regression, but the other two lines should be fit "by eye" using a ruler).

Extend these 3 lines back to intersect the y-axis, providing a measure of the possible error in the intercept of the best-fit line. Use these intercepts to calculate the error in the focal length. (In other words, if you know Δy, the error in the intercept, what is Δf, the error in focal length? HINT: Think "derivative.")

Method of Conjugates:

Using the same lens, image the source onto the screen. Note the object and image distances. Without changing the position of the source or screen move the lens to the other position where an image is formed. Measure the distance that the lens was moved (D), and the distance between source and screen (S). Use equation 7.1 to calculate the focal length. Repeat for five different values of S, and calculate the average value of focal length.

$$f = \frac{S^2 - D^2}{4S} \tag{7.1}$$

The main advantage of this technique is that it overcomes systematic errors in locating the image since f is calculated from the difference between image planes.

* How would you measure a minus, or negative lens?

Both these methods are cumbersome, especially for negative lenses. They may require very long benches if the lenses have long focal lengths. If the lenses have short focal lengths (a few millimeters) special mounts to get close to the lens are required and the error in the focal length will be large.

The Spherometer:

This device measures surface height relative to a plane defined by an outer circle. The distance between the outer circle and a retractable post through the center of the circle is (y), as in Fig. 7.1. The radius of curvature (R) of a spherical surface is related to the sagittal depth or sag (z_S) by:

$$z_S = R - \sqrt{R^2 - y^2} \tag{7.2}$$

$$z_S = R - R \cdot \sqrt{1 - \frac{y^2}{R^2}} \tag{7.3}$$

expanding the radical and rearranging,

$$R = \frac{y^2 + z_S{}^2}{2(z_S)} \tag{7.4}$$

For purposes of this lab, we will neglect the second term and use the following expression:

$$R \approx \frac{y^2}{2(z_S)} \tag{7.5}$$

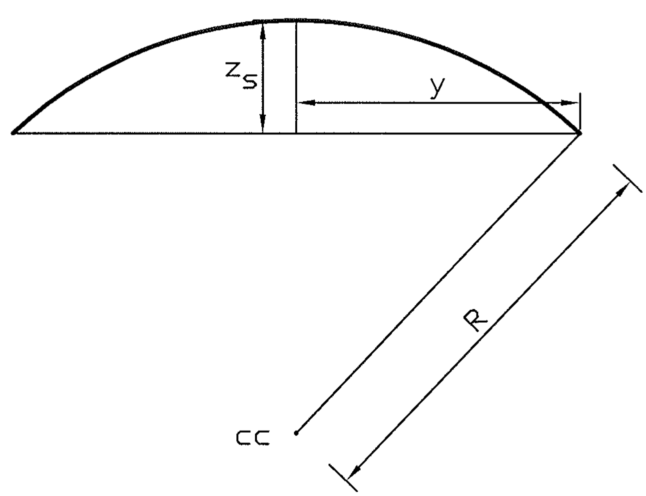

Figure 7.1. The sag of a spherical surface.

Determine the power and focal lengths of the test lens and the negative lens (both are BK7; n_{lens}=1.5168 at 587nm) by measuring the radii of curvature of the surfaces and applying the thin lens formula:

$$\begin{aligned}\phi_T &= \phi_1 + \phi_2 \\ &= (n'-n)\cdot C_1 + (n'-n)\cdot C_2 \\ &= (n_{lens}-1)\cdot C_1 + (1-n_{lens})\cdot C_2 \qquad (7.6) \\ &= \frac{(n_{lens}-1)}{R_1} + \frac{(1-n_{lens})}{R_2}\end{aligned}$$

How do your results compare with the known values as shown below? (Give a quantitative comparison--no need to use statistics.)

	KPX100	KPC040
power [m^{-1}]	6.6667	-20
focal length [mm]	150.00	-50.00

* A good spherometer can measure sagittal depth to an error of 10 microns. If y=1 cm and R=154 mm, to what accuracy (% error) can the power of a surface of a lens be determined? (assume that the refractive index of the lens and D are known exactly).

HINT: Derive an expression for the % error in R, (i.e. $\left|\frac{\Delta R}{R}\right|$), in terms of $\left|\frac{\Delta z_S}{z_S}\right|$.

Numerically calculate $\left|\frac{\Delta R}{R}\right|$.

Derive the relationship between $\left|\frac{\Delta \phi}{\phi}\right|$ and $\left|\frac{\Delta R}{R}\right|$

The Double Pinhole:

Invented by Scheiner in the 1600's, many variations of this technique are used today. For example, the modern autofocus camera uses this basic method. Figure 7.2 illustrates the technique. Cover the positive test lens with a double pinhole aperture. Place an object a known distance greater than f in front of the lens. Near the image plane, you will see two slightly displaced images (you may wish to use the microscope to view them). Move the ground glass screen until the images overlap. This accurately locates the image plane. As in the first experiment measure the image distance for five object distances using the double pinhole method to locate the image plane. Compare your results with this technique to the first experiment.

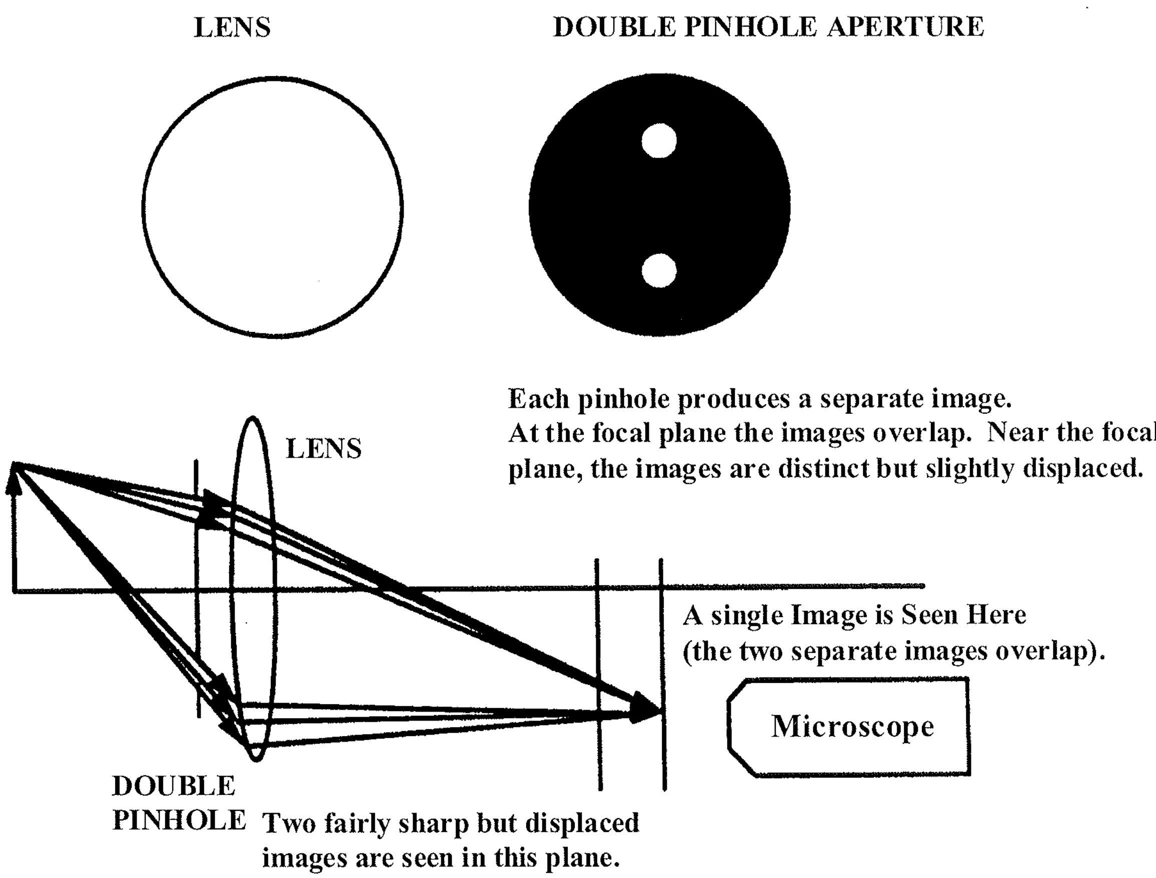

Figure 7.2. The Double Pinhole Method.

Autocollimation:

This method is both rapid and accurate. Place a mirror immediately behind the positive test lens and tilt it slightly. Place a piece of paper next to the diffuse pinhole source in the same plane. When the reflected image is in focus the object and image are at the focal point. The depth of focus problem is largely overcome. Measure two positive lenses in addition to the test lens and see how close you come to the nominal values as shown below. To measure a negative lens with this method place a known positive lens in contact with the test lens and measure the focal length of the combination. Calculate the power of the combination, then use equation (7.6) to calculate the power and focal length of the negative lens.

	KPX088	KBX064	KPX100	KPC031 (KPX088)
f.l. [mm]	75.6	100.0	150.0	-150.0