Introduction to Simple Lenses

Objective: The student is introduced to a simple spherical positive lens to observe the fundamentals of imaging. Various methods are demonstrated to determine the focal length of a positive lens. The effects of a negative lens are introduced by modifying an imaging system.

Theory: A simple lens consists of two surfaces used to modify the wave front of an E-M traveling wave, namely light. A lens is characterized by the radius of curvature (R) of its surface. One convention is summarized in Figure 1, where a positive value for ‘R’ requires the center of the radius of curvature be to the right of the Vertex of that surface. The vertex is the point on the surface through which the optical axis passes. The result is that if the first surface of the lens is positive, then the lens itself is classified as positive or called Convex. Similarly, a negative lens would have its first surface characterized by a –R value, and is classified as Concave. Various forms of each lens are shown in Figure 1.
Each lens is characterized by its **focal length** \( f \), which is either positive or negative. The focal length is the distance from the vertex of the lens (taken to be the center of the lens for a thin lens) to the object/image when the object/image is located at infinity. The coupling of the object and image locations is referred to as conjugate pairs. Figure 2 illustrates this concept by placing the point source at infinity, so the wave front is planar when it enters the lens, which then causes the wave to converge back into a point at the **Image Focal Point**, \( F_i \), located the focal length away from the lens. Likewise if the source or object is placed at the **Object Focal Point**, \( F_o \), also a distance equal to the focal length of the lens, the image will form at infinity.

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**Figure 2: Illustration of focal length for a positive lens**

For any other locations of the object, the image location can be found using the thin lens equation:

\[
\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}
\]

where \( s_o \) is the distance from object to lens and \( s_i \) is the distance from image to lens. The ratio of the image distance to the object distance is called the magnification, which is shown in equation form below where the minus sign indicates the image is flipped about the optical axis.

\[
M = -\frac{s_i}{s_o}
\]

**Experiment:**

a) Use a light source and a small aperture to create a point source object. Using a thin positive (convex) lens, image the aperture onto a screen when the object is far off. A good distance for this experiment is to have the source on a table, and have the lens and screen on another table across the room.
b) Use auto-collimation to characterize the same lens. The set up is shown in figure 3, where the basic concept is that an object at the object focal point will send rays out parallel to the optical axis to form an image at infinity. The mirror reflects those rays and the lens believes that the source is now at infinity, and hence the image is formed at the focal point. Thus the source to lens distance is ‘f’.

![Figure 3: Experimental Set-Up for Auto-collimation](image)

![Figure 4: Focal Length Measurement Using a Laser](image)

c) Using a HeNe laser mounted on a micrometer stage set your lens perpendicular to the beam so that the beam passes through the center of the lens. Place a screen behind the lens to observe the dot. Set the laser-to-lens and the lens-to-screen distances to convenient lengths. Move the laser some distance 'H' off-axis and record the corresponding displacement of the image spot ‘h’. Record 2 more sets of data. Figure 4 shows the set-up.
d) Using a white light source, illuminate the reticle to act as a finite object for your lens. Image the reticle on the screen so that the image is larger than the object. Record the size of the image, distance from object to lens, and distance from lens to image. Compare your ratio of image distance to object distance with the magnification of the image.

e) Modify the set-up in part d by moving only the lens. This time obtain a minified image, as opposed to a magnified image. Use the following relationship and your data to find ‘f’:

\[ f = \frac{L^2 - d^2}{4L} \]

where ‘f’ is the focal length of the lens, ‘L’ is the fixed object-to-image distance and meets the criterion \( L > 4f \), and ‘d’ is the distance that the lens had to be moved to convert the magnified image into the minified image.

f) Using the set-up in part d, obtain a 10X image and record the positions of the components of the optical system. Insert a negative lens a few inches from the screen. Move the screen and negative lens to obtain the 10X image again. Record the distances.

Results and Discussion:

1) Explain how, and show data, to find the focal length using each technique (a through e). Explain any variations in the results you obtain. Which method do you believe to be the most accurate and why?

2) Prove, mathematically, the relationship in part e is true.
3) In part f, model your results with ray traces. Does the two lens system offer any advantages/disadvantages?