LENSES

Purpose: (1) To study the lens equation. (2) To study the ordinary defects of lenses.

Apparatus: Mounted optical bench; centimeter scale: lens holder and accessories; one red and one blue glass filter; one converging and one diverging lens.

References:

Part I. Test of lens equation for converging lens

Discussion: For a thin lens of small aperture, the following relations hold:

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \qquad (1)$$

where p is the distance from the object to the lens, q is the distance from the lens to the image and f is the distance from the lens to the principal focus (sign conventions as in the reference), and

$$M = \frac{S_i}{S_o} = \frac{-q}{p} \qquad (2)$$

where S_i and S_o are the sizes of the image and object, respectively, and M is the linear magnification.

As you have seen in Physics 1(1.5) it is often possible to express the theoretical relationship between two variable quantities in some simple form, for example, the equation of a straight line. If the data can be plotted in this way the variations of the individual values from the equation will show up as deviations of the individual points from the line. In Eq. 1, p and q are variables, while f is a constant for a given lens. We may write

$$y = mx + b \quad \text{where} \quad y = 1/q\ ;\ x = 1/p\ ;\ m = -1\ ;\ b = 1/f \qquad (3)$$

Notice that m (= -1) is the slope of the line and b equals the value of the intercept of the line on the y-axis.(and since m = -1, on the x-axis also.)

Procedure:

1. As a preliminary step make an approximate determination of the focal length of the converging lens by forming the image of a distant object and measuring the distance between the image and the lens.

2. Measure the height of the object, the number 4 on the ground glass plate, with the centimeter scale. Place the glass plate in front of the incandescent lamp for illumination.

3. Place the converging lens with the diaphragm that has central opening in front of the lens, at a distance of more than twice its focal length, as determined in (1), from the object. Move the screen so that a clear sharp image is formed upon it (making sure that the ground side faces the lens). Record the positions of the object, lens and screen, and also the size of the image as measured with the centimeter scale. Displace the screen and again reset for sharp image. Repeat the process, giving three screen readings for this part.

4. Reduce the distance between the lens and the object to about twice the focal length. Find the screen position for a clear sharp image. Record the appropriate positions and also S_i , obtaining three readings again.

5. Place the lens so that p is less than two f but greater than f. Again record observations for finding p, q and S_i. Again obtain three readings.

6. Make p less than the focal length. If you cannot obtain an image on the screen look through the lens from the side opposite the object. Try to locate the position of the image by placing your pencil at a point where the image appears to be, being careful not to view the pencil through the lens. You need not record its position.

Part II. Test of Lens Equation for Diverging Lens

Discussion: Diverging lenses produce only virtual images of real objects. Since a virtual image cannot be obtained upon a screen, it is necessary to use some indirect method for obtaining the focal length of a diverging lens. One such method is as follows: a divergent beam of light from an object point O (Fig. 11-1), made convergent by a converging lens L_1 , is intercepted by a diverging lens L_2 before it comes to a focus. The image produced is formed on a screen I_2. The point I_1 where the light *would have* converged to a real image, had it not been intercepted by $L_{2,}$ is a " *virtual object* " for the diverging lens. The focal length is computed from this *virtual* object distance (p_2) and the real image distance (q_2).

Procedure:

Use the same object and converging lens as in part I to produce a real image without the diverging lens. Mount the diverging lens on the bench between the converging lens and the screen, with its optical axis coincident with that of the converging lens. Place the screen 10 cm farther from the object than before, and suitably shifting the diverging lens to produce a sharp image on the screen. Repeat twice, making three determinations, in all , of the position of the diverging lens, *leaving everything else fixed.* Measure the significant distances, as indicated in Fig. 11-1.

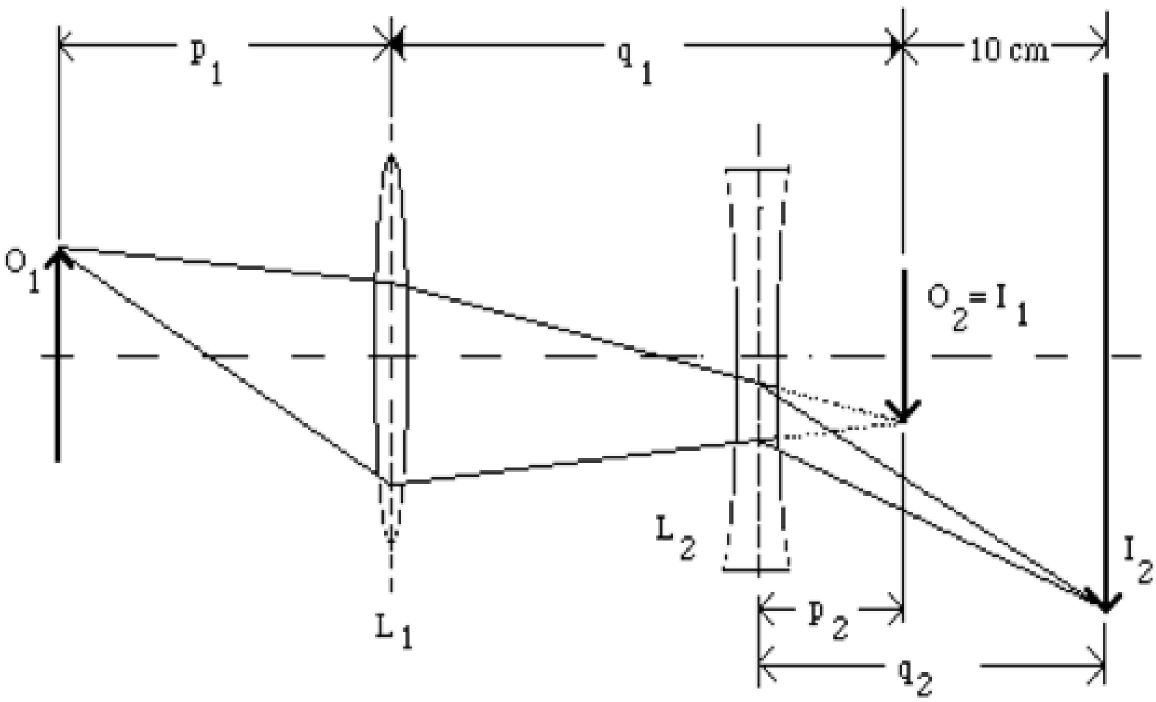

Fig. 11 - 1 Diagram for test of diverging lens.

Part III. Spherical Aberration

Procedure:

1. Place the converging lens with the diaphragm which permits only light near the axis to pass through it, at a distance of about 2f from the object. Locate the image and record data for p and q.

2. Replace the diaphragm by one permitting only peripheral rays to pass. Without changing the position of object and lens, locate the image and record the position of the screen.

Part IV. Chromatic Aberration

Procedure:

Keep the object and lens in the same position as in Part III and the diaphragm which permits only peripheral rays to pass through the lens. Hold up a red filter between the incandescent lamp and the object. Obtain a sharp image on the screen. Take measurements for obtaining p and q. Replace the red filter by the blue filter; refocus, and record the new screen position.

Calculations:

Part I: From the average screen setting for each of the lens settings (parts 3, 4 and 5) compute the focal length by means of Eq. (1). Also compute the average value of S_i for each part. Find the mean of the three values of f obtained above.

Plot the three average values of 1/q vs. 1/p, using the same scale for both coordinates and including the origin in your graph. Obtain the value of the focal length using both intercepts.

Tabulate the average values of p, q, S_o, S_i, q/p, S_i/S_o and the computed f for all three sets of observations. Also record on your results sheet the direct observations with which you began this experiment, the mean value of f from your computations, and the two values of f obtained from the graph.

Part II: Determine p_2 and q_2 from your data, and use them in Eq. (1) to compute the focal length of the diverging lens. Remember that the *object* for the negative (diverging) lens in this case is *virtual*, so that the object distance, p_2, is negative.

Part III: Compute the two values of f corresponding to the axial and peripheral rays. Compare these two values on your result sheet.

Part IV: Compute the two values of f corresponding to the red and the blue sources. Again compare.

Questions to be answered in the Report:

1. If your converging lens were placed in water, what would the value of its focal length be?

2. If the distant object used in determining the focal length of the converging lens in part I (1) were actually 40 meters away, what percentage error in f would result?

3. An object and a screen are D cm apart. A lens is placed in a position so as to produce on the screen an image which is larger than the object. If the lens is now moved a distance of d cm, a second image is formed on the screen which is smaller than the object. Calculate the focal length of the lens.