LENSES

Purpose

a. To study the nature of image formed by spherical lenses.

b. To study the defects of spherical lenses.

Theory

Image formation by thin spherical lenses

Images are formed by lenses because of the refraction of light. For a thin lens of small aperture, the relation of object distance (d_o), image distance (d_i) and focal length (f) is given by

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \qquad (1)$$

where d_o, d_i and f are measured from the lens on the principal axis as shown in Fig. 1.

The magnification of the image is given by

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \qquad (2)$$

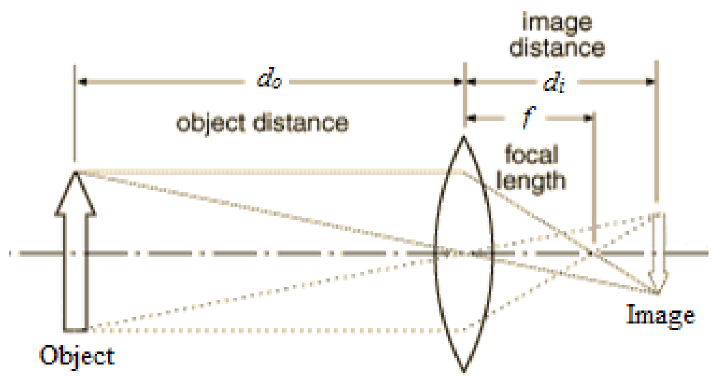

Fig. 1: Distance in image formation by a lens.

where h_i and h_o are the sizes of the image and object respectively, and m is the linear magnification. Both relations given in Eq. (1) and (2) hold for converging (convex) lenses as well as diverging (concave) lenses. Follow the sign convention used in your text book.

In order to verify the theoretical relation given in Eq. (1), we will first determine the positions of images formed by a lens for different positions of an object on an optical bench. From their positions from the lens, we can determine the image distances for different object distances. As you have seen in Physics exercises, it is possible to express a relation of two variable quantities in some simple form, for example, the equation of a straight line. In Eq. (1), d_o and d_i are variables, while f is constant for a given lens. We can write the equation in the form of straight line

$$y = mx + b \qquad (3)$$

where y and x represent $1/d_i$ and $1/d_o$ respectively. Comparing Eq. (1) with (3) we get,

$m = -1$ and $b = 1/f$

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

If the data are plotted for $1/d_i$ vs $1/d_o$ it should follow a straight line with slope -1. From the values of the intercepts, we can determine the focal length of the lens.

Apparatus

2-meter long optical bench, centimeter scale, Light source with rotating disc, Screen mounted in support, aperture assembly, one converging and one diverging lens mounted in support, one red and one blue glass filter

Description of Apparatus

You will use an optical bench (same as dynamic track used in Physics I labs) and Vernier Optics Expansion Kit in this lab as shown in Fig. 2. The optical bench is two meters long and has scale in centimeter along the length of the track. The Optics Expansion Kit has lenses are permanently mounted in plastic supports, white screen mounted in plastic support, a LED based light source and other accessories such as aperture disc. The plastic supports can be snapped on to the track and moved easily along the track. The position of the mounts can be easily read on the scale marked on the track. The light source has a rotating disc on that gives you the option of a radiant object such as a point source, an “L” shape or “4” shape. Fig. 1 below has set the rotating disc for “4” shape object and inverted image on the screen formed by a converging lens.

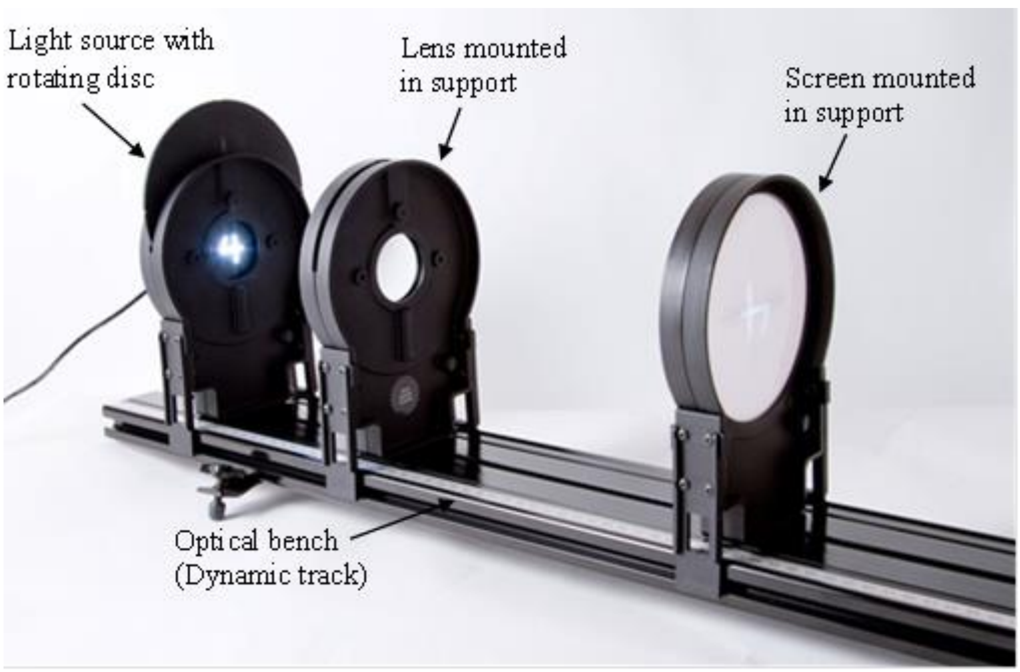

Figure 2: Apparatus and set up for image formation by a converging lens.

Aperture assembly

Blue and red Filters

In this lab, you will perform experiments to verify the lens equations and determine the focal length of a converging in Part I. In part II you will determine the focal length of diverging lens by combination with a converging lens. Why do you think we need combination of lenses in case of diverging lens? Lastly you will study some of the defects in spherical lenses such as spherical aberration and chromatic aberration.

Procedure

Part I. Image formation by Converging Lens

1. As a preliminary step to determine approximate focal length of the converging lens, form image of a distant object on a white paper. Look at the image of a distant object (it could an object outside the window) and measure the distance between the image and the lens. This is your rough focal length for the lens.
2. Mount light source, the converging lens with support, and screen with support on the optical bench as shown in Fig. 1. Keep the light source at one end of the optical bench and the lens should be between the light source and the screen.
3. Now, turn on the light source and adjust the rotating disc to get the object shaped number 4. Measure the size of the object (h_o), the number 4 with the centimeter scale.
4. Move the converging lens from the object to the position at a distance of more than twice its focal length, as determined in step 1. Note down the positions (the readings on the track) of the object and the lens on the optical bench and record in Table 1. Difference of these two readings gives you object distance (d_o).
5. Now, move the screen so that a clear sharp image is formed upon it. You can move the screen little bit back and forth to make sure it is the best image position. Record the position of the screen in Table 1. Difference of the readings for the positions of lens and screen gives you image distance (d_i).
6. Also measure the size of the image (h_i) with the centimeter scale or the scale on the screen and record in the table. Displace the screen and do not look at the previous reading. Sincerely move the screen for sharp image again and record your results in Table 1.
7. Move the position of the lens toward the object to reduce the object distance. Repeat the previous step for two more different object distances beyond 2F. Record the position and image sizes in Table 1.
8. Reduce the distance between the lens and the object to about twice the focal length. Again, find the position of the clear sharp image. Record the appropriate positions and also h_i, obtaining two readings again.
9. Now, move the lens further towards the object so that the object distance is less than $2f$ but greater than f. Repeat step 5 and record your results for the position of object, lens, screen and size of image (h_i) in Table 1. Repeat this step for three different positions of the lens.

   What change did you observe in the size of image as the object moved towards the lens?
10. Move the lens further closer to the object so that the object distance (d_o) is less than the focal length. Try to find the image position. Any luck to obtain an image on the screen!! 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. Image formation by Diverging Lens

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. 3), made convergent by a converging lens L_1, and 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 (do_2) and the real image distance (di_2).

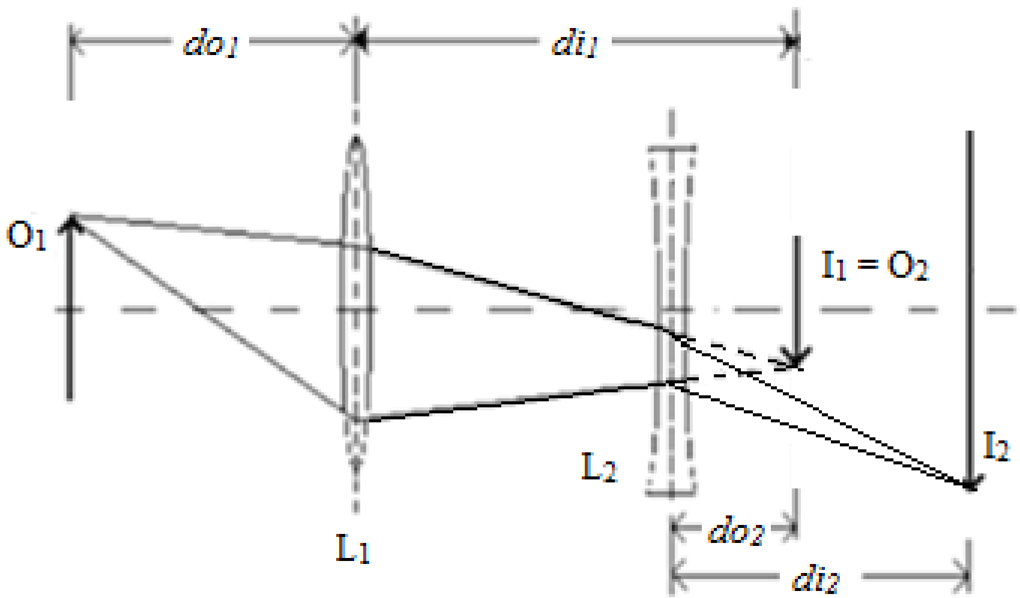

Figure 3: Schematic diagram for determining focal length of diverging lens.

1. Use the same object and converging lens as in part I to produce a sharp real image on the screen with do_1 roughly equal to 2.5 times of its focal length without the diverging lens. Record the positions of the object, lens 1 Converging lens), and screen in Table 2. From these readings, you can determine the object distance (do_1) and image distance (di_1) for the converging lens. Do not move the positions of the object and converging for all other steps.
2. Now, mount the diverging lens on the optical bench between the converging lens and the screen as shown in Fig. 3. Move the screen about 15 cm farther from the object than before, and then shift the diverging lens to produce a sharp image on the screen. Record the position of divergence lens and new position of the screen in Table 2. Difference between these two reading gives you the image distance (di_2) for diverging lens and the difference between the readings of the positions of the diverging lens and the positions of the screen in previous step gives you object distance (do_2). As before, repeat this reading again by shifting the position of divergence lens only.
3. ***Keep the positions of light source and converging lens fixed.*** Repeat the previous step for two trials by moving the screen 15 cm further away from previous position for each trial.

Part III. Chromatic Aberration

1. For this part of experiment, reset the experiment set up as in Part I removing the divergent lens. Move the converging lens at a distance of about 2f from the object. Locate the image and record data for d_o and d_i. Place the aperture assembly after the converging lens on screen side. You can select different size of aperture. Once has half circular area opening. Predict, what will happen to the image if you select it? Test your prediction using that aperture.
2. Now, choose a small aperture (not the smallest one). Hold up a **red filter** near the object. Obtain a sharp image on the screen. Take measurements for obtaining d_o and d_i. Replace the red filter by the **blue filter**; refocus, and record the new screen position

Part IV. Spherical Aberration

1. For this part of experiment, choose a small aperture to allow only light near the axis to pass through it. Locate the image and record data for d_o and d_i.
2. Now with the wide aperture in the assembly, put a diaphragm that permits only peripheral rays to pass. Without changing the position of object and lens, locate the image and record the position of the screen.

Computation

Part I: In Table 1, from the average position of the screen for each of the lens settings, object distance and image distance. Compute and compare the magnification from actual size of the object and image, and from object distance and image distance. Compute the focal length using Eq. (1). Tabulate these values in Table 1.

a. Plot a graph $1/d_i$ vs $1/d_o$ using the same scale for both coordinates and including the origin in your graph. What is slope of the graph? Obtain the value of the focal length using both intercepts.

Part II: Determine object distance and image distance for Lens-1 from the observation with Lens-1 only. Also compute magnification.

For different positions of divergent lens (Lens-1) in combination of lens-1, compute the object distance and image distance for Lens-2. Refer Fig. 3 for this calculation. Calculate the focal length of the diverging lens using Eq. (1). Remember that the object for the diverging lens, in this case, is virtual, so that the object distance, do_2, is negative.

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

Part IV: Compute the two values of focal length (f) corresponding to the axial and peripheral rays. Compare these two values on your result sheet.

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.

Data Sheet

Date experiment performed: Name of the group members:

Table 1. Focal length of converging lens

Rough focal length of the convex lens = ……….. Position of object =……………………..Size of the object (h_o) =……………………..

Object location	Position of lens	Position of screen			Size of Image (h_i)	Object distance (d_o)	Image distance (d_i)	$m = \frac{h_i}{h_o}$	$m = -\frac{d_i}{d_o}$	$1/d_o$	$1/d_i$	f (cm)
		Trial-1	Trial-2	Aveg.								
Beyond 2F												
~ 2F												
Between F and 2F												

Table 2. Focal length of converging lens

Lens 1 (Converging lens)						For Lens 2 (Diverging lens)						Overall Mag. $M = m_1.m_2$
Position of object	Position of lens-1	Position of screen	Object distance (d_{o1})	Image distance (d_{i1})	*Mag.* (m_1)	Position of lens-2	Position of screen	Object distance (d_{o2})	Image distance (d_{i2})	f_2	*Mag.* (m_1)	

For Red filter: d_o = d_i = f_{red} =

For Blue filter: d_o = d_i = f_{blue} =

For Paraxial rays: d_o = d_i = f_{parx} =

For Peripheral rays: d_o = d_i = f_{perif} =