Lenses

Purpose

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

b. To study the defects of spherical lenses.

Introduction

A converging (convex) lens is thick at the center and thin at the ends. A diverging (concave) lens is thin at the center and thick at the ends. 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

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

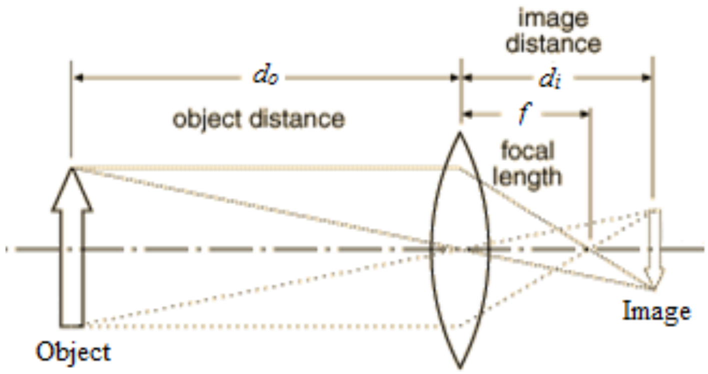

Fig. 1: Image formation by a convex lens.

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.

Image formed by a convex lens for a real object could be real or virtual depending upon the position of the object whereas the image formed by a concave lens for a real object is always virtual. In Part 3, you will explore a method to form a real image for a diverging lens with the aid of a converging lens.

Due to the different refraction of the light rays near the center axis (called principal axis) of the lens and those incident near the ends of the lens far from that axis, there is an aberration (meaning a defect) called spherical aberration. You will also explore spherical aberration in part 4. Finally, in part 5, we will explore chromatic aberration, which is due to the different refractive index of the material of the lens for the different colors of the incident light.

Running the experiment

We will use a simulator in the link: http://physics.bu.edu/~duffy/HTML5/Lenses.html for this exercise. **Note: The simulator shows the 'horizontal position of the object' on the scale as negative for left of the lens. Ignore this negative and follow the "Sign convention for lenses".**

Part 1: Image formation by a converging lens

Open in your browser: http://physics.bu.edu/~duffy/HTML5/Lenses.html

1) Adjust the focal length "f" of the converging lens (convex lens) to 65 cm.
2) Adjust the object height, h_o, to 15 cm.
3) Now, adjust the position of the object at a distance which is greater than 2f (twice the focal length of the lens).
4) Notice where the Image is formed from the converged point of three special rays, P ray, M ray and F ray. Record the image distance, d_i and the image height, h_i. Calculate the magnification from the height of the image and object. Also, calculate the magnification the distance of the object and image.

   Is the image real or virtual?

   Is the image upright or inverted?

(A real image is formed where the light rays actually converge to form the image, and you can view the real image on a screen. A virtual image is an image perceived by the eye, where the rays of light do not converge but diverge but the eye sees the virtual image at the back trace of the diverging rays where the image ***appears*** *to be. See Fig. 2 & Fig. 3 below).*

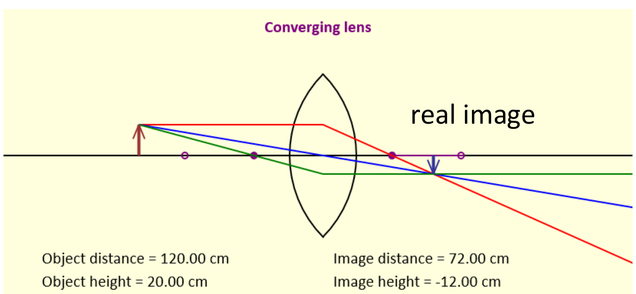

Fig. 2: An example of a real image.

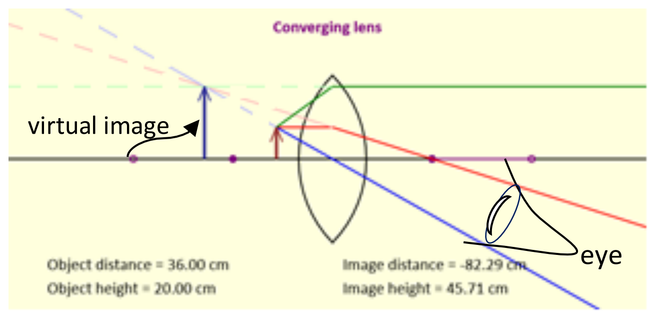

Fig. 3: An example of a virtual

5) Repeat the previous step by adjusting the object at another position which is greater than 2f.
6) Repeat the step (4) for an object distance ~ 2f
7) Repeat the step (4) for two different object distance which is less than *2f* but greater than *f*.

Graph plotting:

Using your data, plot a graph of $1/d_i$ (along y axis) and $1/d_o$ (along x-axis).

What should be the slope of the line?

What should the intercepts of the graph represent?

Verify the lens equation and determine the focal length of the lens from the graph.

Part 2: Image formation by Diverging Lens

1) Click Diverging lens at the bottom of the simulator to switch the lens. Notice in Fig. 4, how the rays diverge after passing through the lens. Note the three special rays, the P ray, parallel to the principal axis, the M ray, passing through the midpoint of the lens, and the F ray, passing through the focus. For the diverging lens, the focus, F, is on the same side as the side of the object, the focal length is negative. But, if we consider the other Focus point that is on the opposite side to the side of the object, F'. Note the F ray in Fig. 4 (the green ray), is the ray coming from the object, aiming at the Focus (the other focus point, F', of the diverging lens, which is on the side opposite to the object side). This F ray diverges parallel to the principle axis. Position of the image is determined by back tracing the diverging rays. Hence, the image is virtual.

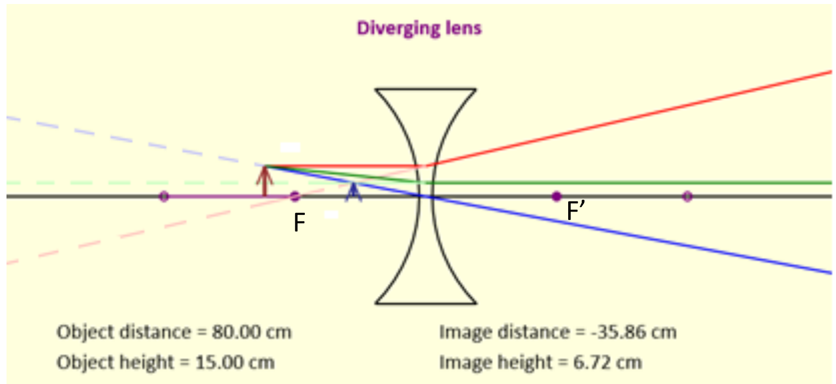

Fig. 4: An example for rays for a diverging lens.

2) Keep the magnitude of the focal length of the lens as 65 cm. (Since this is a diverging lens f is actually negative). Adjust the height of the object to **35 cm**. Verify the lens equation for d_o = 140 cm, 65 cm, and 40 cm.

Part 3: Find the focal length of a diverging lens

You have noticed that diverging lenses produce only virtual images of real objects. Practically it is not possible to measure the position of the virtual image as it cannot be obtained on a screen. It is necessary to use some indirect method for obtaining the focal length of a diverging lens. One such method shown in Fig. 5: a divergent beam of light from an object point O (Fig. 5), made convergent by a converging (convex) lens L_1, and is intercepted by a diverging (Concave) 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 can computed from this virtual object distance (do_2) and the real image distance (di_2). Use the dimensions shown by the cm scale shown in the diagram, determine the focal length of the lenses as follows

1. **Without** L_2, (Assume there is only converging lens, L_1 in Fig 5)

   The image formed by L_1 is I_1. Look at the centimeter scale carefully and determine the object distance (do_1) and image distance (di_2) and calculate the focal length of L_1.

2. Now assume we insert L_2 intercepting the converging rays as shown in Figure 5. Now I_1 becomes the object O_2 for Lens 2. The distance from O_2 to L_2 is do_2. Should we take do_2 as positive or negative?

Determine the object distance, do_2 and image distance, di_2 from the centimeter ruler shown in the Fig. 5. Calculate the focal length of L_2. Check if your answer is position or negative? Explain your result.

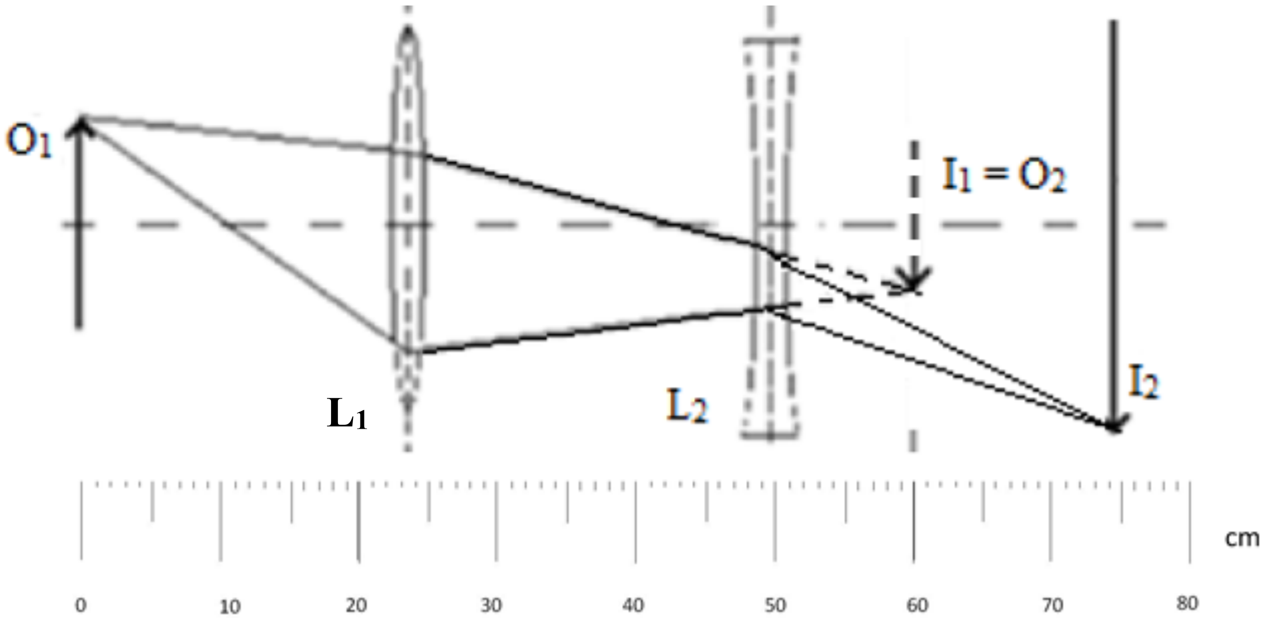

Fig. 5: Forming a real image by a diverging Lens

Part 4: Lens Spherical aberration

Open the site https://ophysics.com/l14.html

1) Observe the focus for the rays far from the principal axis and observe the focus for the rays near the principle axis.

a) Which focus is closer to the Lens? Can you think for a reason?

b) Describe what is meant by spherical aberration of a lens?

c) Change the value of index of refraction of the materials and see how the focal length change. Check what will happen if the index of refraction = 1 (same as surrounding material)?

Part 5: Lens Chromatic aberration

Open the site https://ophysics.com/l15.html

1) Observe the focus for the violet ray and the other focus for the red ray.

a) Which focus is closer to the lens? Do you know why?

b) Describe what is meant by Chromatic aberration of a lens?

c) Change the value of index of refraction of the materials and see how the focal length change. Check what will happen if the index of refraction = 1 (same as surrounding material)?

Answer these questions in part 4 and 5 in your lab report.

Additional question to be answered in the Report

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

Data Sheet

Name: **Group:**

Date experiment was performed:

Part 1: Converging lens

The object height, h_o = 15 cm the focal length of the lens chosen, f = 65 cm

Object location	Object distance, d_o (cm)	Is image virtual or real?	Image distance, d_i (cm)	Height of the image, h_i (cm)	$m = \frac{h_i}{h_o}$	$m = -\frac{d_i}{d_o}$	$1/d_o$	$1/d_i$	f
Beyond 2F									
~ 2F									
Between F and 2F									
Between F and lens									

Attach the graph of $1/d_i$ (along y axis) and $1/d_o$ (along x-axis).

Slope of the line =

x- intercept =

y- intercept =

Focal length, f, from the graph =

Part 2: Diverging lens

h_o = 15 cm f = - 65 cm

1. d_o = 120 cm d_i =
2. d_o = 65 cm d_i =
3. d_o = 40 cm d_i =

Verify the lens equation by using the **lens equation** to **calculate** the expected d_i then compare with d_i given by the simulator (show your work).

Part 3: A method for image formation by a diverging lens

Using the ruler shown in Fig. 5,

d_{o1} = d_{i1} =

Using the lens equation, calculate f_1 of the converging lens, L_1, show your work here:

Using the ruler in Fig. 5,

d_{o2} = d_{i2} =

Using the lens equation, calculate f_2 of the divergence lens, L_2, show your work here: