Laboratory 12: Lenses (Animations)

Image production by convex lenses can be described with reference to Fig. 1. Light travels from an object to the left of a lens, passing through the lens. A clear image is produced at one particular location. In certain specific circumstances, the image appears to the right of the lens and can be observed by placing a screen at that location.

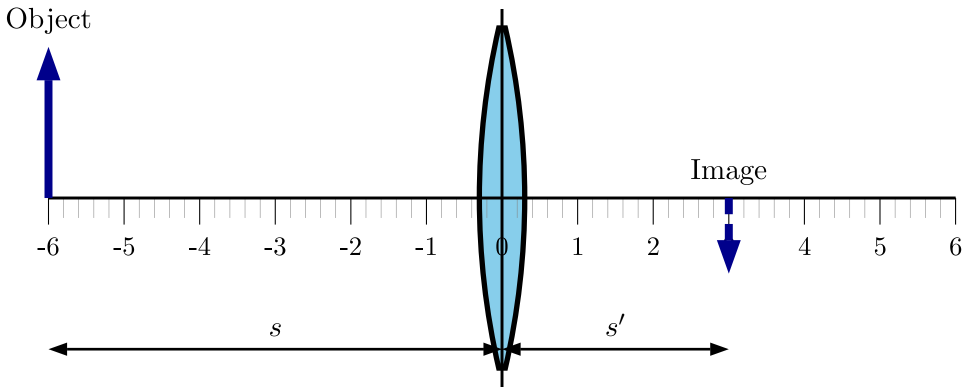

Figure 1: Image production by a convex lens when the object is located beyond the focal point of the lens. The distance from the lens to the object is denoted s and from the lens to the image s'.

This process is described completely by tracing multiple rays from each point on the object through the lens, taking refraction at both surfaces into account. The curved nature of the lens' surfaces complicates this and tracing rays does not yield an exact simple relationship between the positions of the object and the image (i.e. between s and s' in Fig. 1) or between the sizes of the object and the image. This is simplified, in the "thin lens" approximation, where the lens surface is a small section of a large sphere. The purpose of this laboratory is to investigate this scenario.

This exercise uses the PhET simulation, "Geometric Optics," which can be found at:

https://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html

1 Image Formation: Qualitative Observations

Open the PhET "Geometric Optics" simulation.

a) Select the No Rays option (upper left) and the Screen option (upper right). This will display a lamp and a screen. The simulation considers the light that is emitted by a single small point of the lamp (the "object") and displays how this is imaged on the screen.

b) Leave the lamp in the default position set up by the simulation. Move the screen left and right to find the sharpest image (it should be the smallest point).

c) Now move the map further left from the lens and adjust the position of the screen to find a clear image. Did the distance from the object to the lens increase, decrease or stay constant? Did the distance from the image to the lens increase, decrease or stay constant?

d) Repeat the previous two steps for the case where the object is placed even further from the lens. Again describe what happened to distance from the object to the lens and the distance from the image to the lens.

e) Based on your observations and using the notation of Fig. 1, as s increases does s' increase, decrease or stay constant?

Identify all out of the following possible relationships which are **consistent (i.e. agree) with your observations and your answer to the last question** (it is possible that several are appropriate).

i) $s + s' = \text{constant}$

ii) $s - s' = \text{constant}$

iii) $\dfrac{1}{s} + \dfrac{1}{s'} = \text{constant}$

iv) $\dfrac{1}{s} - \dfrac{1}{s'} = \text{constant}$

v) $ss' = \text{constant}$

One can narrow down which of these might be true by considering the what happens as the distance between the lens and object becomes very large. In a lab setting this would be done by placing the object several meters from the lens and observing the image location. The screen size limits this in the simulation. In order to best see the effect the lens must be adjusted.

f) Adjust the lens curvature to the smallest possible value and move the lamp so that its base is just to the left of the $\times$ mark on the horizontal axis left of the lens. Again find the image and move the lamp further left from the lens. As the lamp moves further left and reaches the left edge of the screen does the image location approach 0.0 m or some other fixed value? If it approaches another fixed value, what does this appear to be? Use this result to limit the choices of the previous part to just one possibility.

The distance from the lens to the image when the object is infinitely far from the lens is called the **focal length of the lens.** This is a characteristic of the lens and varies from one lens to another.

g) Based on your observations of part f), determine the focal length of the lens that you used. The distance is that from the vertical line midway through the lens to the image location. The simulation has a ruler that allows you to measure this.

2 Image Formation: Quantitative Observations

Detailed ray tracing for a thin convex lens yields the **thin lens equation**,

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \tag{1}$$

where f is the focal length of the lens. The magnification of the lens is defined as

$$m := \frac{h'}{h} \tag{2}$$

where h' and h are the vertical sizes of the image and object respectively. Ray tracing yields

$$m = -\frac{s'}{s}. \tag{3}$$

The aim of this section of the laboratory is to verify that Equations. (1) and (3) are correct.

a) Select the No Rays option (upper left) and uncheck the Screen option (upper right). This will display a pencil in a frame (to the left) together with its image (to the right).
b) Set the curvature radius to 0.8 m and the index of refraction to 1.53. Ensure that these stay constant throughout this part of the activity.
c) Measure the vertical size of the object and record it below.

$h =$ ______________________________

Place the object at various locations so that it is to the left of the × mark on the left Locate the image and measure s' and h'. Record your measurements in the table.

s	s'	h'	f	m from Eq. (2)	m from Eq. (3)

d) Determine f for each case from the data for s and s' and using Eq. (1) and enter it into the table. Determine the average value of f from these results and enter it below:

$$f = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

e) Consider the magnification. Describe the significance of the negative sign in your results using Eq. (3). Determine the percentage differences between the magnifications in **each case.**

In the following you will adjust the curvature and index of refraction of the lens while keeping the object at a fixed location.

f) Keeping the lens curvature fixed, increase the refractive index. Describe what happens to the location of the image as the index of refraction increases. Use this to explain whether the focal length of the lens increases, decreases or stays the same as the refractive index increases.

g) Keeping the refractive index fixed, decrease the lens curvature. Describe what happens to the location of the image as the lens curvature decreases. Use this to explain whether the focal length of the lens increases, decreases or stays the same as the lens curvature decreases.