Phys 132L
Fall 2018

Laboratory 13: Image Formation by Lenses – Prelab

1 Focal point of a concave lens

Parallel light rays pass through a concave lens as illustrated in Fig. 1. Using the diagram, indicate the focal point of this lens.

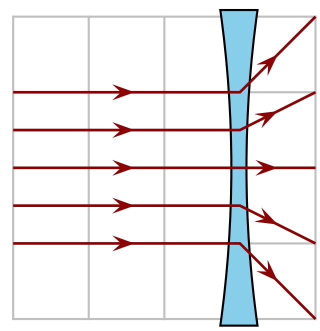

Figure 1: Concave lens

2 Image formation by a convex lens

A convex lens has focal length 100 mm. The lens produces an image from an object is placed 50 cm from the lens. Determine the distance from the lens to the image and the magnification of the image.

Laboratory 13: Image Formation by Lenses – Activity

Image production by convex lenses can be described with reference to Fig. 2. 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.

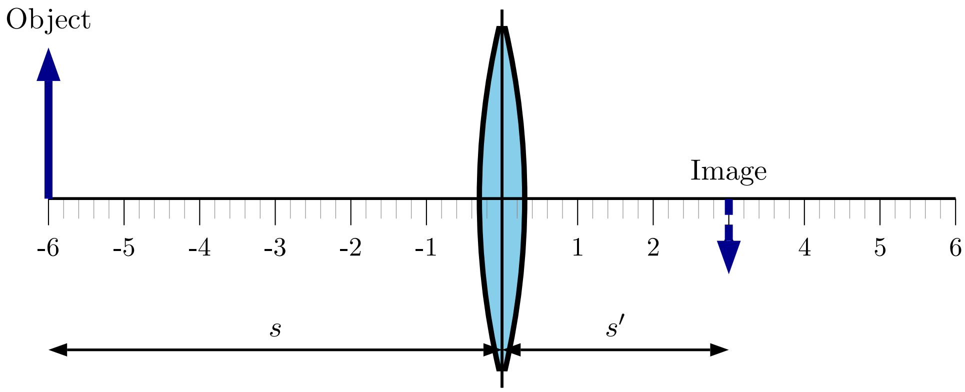

Figure 2: Image production by a convex lens when the object is located beyond the focal point of the lens. The distance from the lens to the object is denoted s and from the lens to the image s'.

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. 2) 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.

1 Image Formation: Basic Ray Optics

Much of this exercise is based on "Experiment 6: Convex and Concave Lenses" of the PASCO Basic Optics System manual.

a) Set up the light source box so that it produces three light rays. Place the ray box and a convex lens on a sheet of paper so that the rays strike the lens at the angle as illustrated in Fig. 3. Trace the edges of the lens. Trace the incident and transmitted rays.

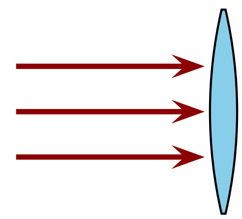

Figure 3: Parallel rays entering a lens.

b) Verify that these rays all pass through a single point. This is called the focal point of the lens. The distance from the center of the lens to the focal point is called the focal length. Determine the focal length for this lens from your ray tracing diagram.

c) Repeat this entire exercise for the concave lens. These rays should not converge. However, they appear to emanate from a single point (the focal point) to the left of the lens. Locate this point. Determine the focal length of this lens.

d) The focal length of a lens describes how a lens bends light rays that enter the lens traveling parallel to each other. It depends on the radii of the curvature of the lens surfaces. The radius of curvature of a surface is the radius of a circle which "fits" the curved surface. By nesting the lenses together, verify that the radii of curvature of all sides are the same. Thus the focal lengths should be the same. Explain why your measured focal lengths are not identical (almost always the convex lens gives a larger focal length). The explanation has to do with the rays that are produced by the light ray box; ideally they should emerge parallel to each other. Are they for your box? If not, how does this defect explain the discrepancy?

e) Set up the ray box so that it shines three colored light rays into the convex lens. Observe the point where the rays overlap beyond the lens. What color is this?

2 Image Formation: Qualitative Observations

Select the PASCO "100 mm focal length lens," which you will use throughout this section of the laboratory. The object is the "arrow" and "cross-hairs" pattern on the light source box.

a) Position the object at a location between 12 cm and 14 cm from the lens. Locate the image by **adjusting the screen position** until a clear image is formed. Now slide the object to a new location further 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?

b) Consider the size of the image and the object in the previous step. Did the size of the object increase, decrease or stay constant? Did the size of the image increase, decrease or stay constant?

c) 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, the distance from the image to the lens, the size of the object, and the size of the image?

d) In each of the above cases, describe the orientation of the image relative to the object.

e) Based on your observations and using the notation of Fig. 2, 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) $ss' = \text{constant}$

f) One observation which could select amongst the relationships of part e) is to shift the object further and further from the lens and observe the location of the image. Remove the lens and the screen from the track and hold it at distances beyond 1.0 m from the object. Position the screen to locate the image. As the distance between the lens and the object increases to infinity, observe the distance between the lens and the image. Does this 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.

3 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) The focal length of the lens can be measured directly by placing an object very far from the lens and measuring the location of the image. In this case $s \to \infty$ and Eq. (1) gives $s' \to f$. Take the lens and a meter stick outside. Produce an image of the sun (it will be a small point of light) on the sidewalk and measure the distance from the lens to the image. This is the (experimental) focal length of the lens. Record your measurement below.

$$f_{\text{exp}} = \underline{\hspace{6cm}}$$

b) Return the lens to the track. Measure the vertical size of the object and record it below.

$$h = \underline{\hspace{6cm}}$$

Place the object at various locations so that s is between than 12 cm and 40 cm Locate the image and measure s' and h'. Record your measurements in the table.

s	s'	h'	f_{calc}	m from Eq. (2)	m from Eq. (3)

c) Determine f_{calc} 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_{calc} from these results and enter it below:

$$f_{\text{calc}} = \underline{\hspace{6cm}}$$

Determine the percentage difference between f_{calc} and f_{exp}.

d) 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.**

e) Consider one of the situations of the previous set of experiments. Produce a clear image on the screen. Place a sheet of paper over the lens so that it obscures the upper half of the lens. Is there still a clear image on the screen? Does the presence of the paper change any observable feature of the image? If so, describe it. Repeat this with the lower half obscured.

4 Image Formation: Object within the Focal Point

The process by which a convex lens produces an image changes dramatically when the object is located between the focal point and the lens.

a) Move the lens so that the distance from the object to the lens is about half the focal length of the lens. Check whether it is possible to adjust the screen position until a clear image is formed. Is this possible?

b) Now look into the lens (the light does not need to be on). Describe whether a clear image is viewed or not. Is the image upright or inverted? Is it larger than or smaller than the original object?

c) Move the lens closer to the object. Does the size of the image increase, decrease or stay the same?