PHYS222 Experiment 27
Thin Lenses

Advanced Reading:
University Physics Vol.3 by OpenStax, Chapter 2 Section 2.4.

Equipment:
1 Optical Bench
3 lenses holders
3 optical bench clamps
1 cross-haired light source
1 screen
1 Bi-convex lens
1 Bi-concave lens

Objective:
The object of this experiment is to observe the characteristics of (thin) convex and concave lenses and to measure the focal lengths of these two types lenses.

Theory:

In a previous experiment light was found to change direction when it passed (at an angle) between media with different indices of refraction. This property can be utilized to bend (refract) light in useful ways. A convex lens (made of glass with $n > 1$) can be used to focus light rays and form a real image as the light travels from air ($n \approx 1$) to glass and back to air. A real image is one that can be projected on a screen. A concave lens forms a virtual image that cannot be projected on a screen.

An important property of a lens is its focal length. The focal length f of a thin lens is given by:

$$\frac{1}{o}+\frac{1}{i}=\frac{1}{f} \qquad \text{Eq. 27-1}$$

where o is the object distance and i is the image distance. For an object that is infinitely far away, the image distance and the focal length are the same. For lenses used in the lab ($f < 30cm$) objects over 20 meters away can be considered infinitely far away.

A convenient method of measuring the focal length of a positive lens (forms a real image) is to use the conjugate foci method. If an object and the image are located a distance greater than 4f apart, then the following equation can be used:

Figure 27-1
Conjugate Foci Method - 1st measurement

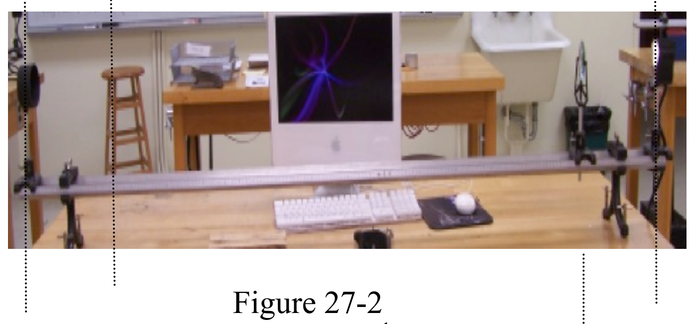
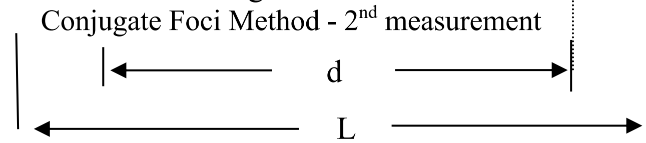


Figure 27-2
Conjugate Foci Method - 2nd measurement



$$f=\frac{L^2-d^2}{4L} \qquad \text{eq. 27-2}$$

(See figures 27-1 & 27-2.) This equation arises from equation 27-1 by noting that the object and the image distance can be switched and the focal length will stay the same.

While this (switching) in itself is an interesting phenomena, the utility of this method is that it yields *a smaller uncertainty* than the other two methods used in this experiment.

Procedure:

Part 1: Measurement of the focal length of a converging lens

This will be done three ways:
(1) Using distant objects

(2) Using the lens formula
(3) Conjugate Foci Method

Distant Object method

1. Place a lens and screen on the optical rails. Point the apparatus towards the window. Move the screen until a clear image is formed of something outside the window. You should determine a range of uncertainty. Your TA will explain this.

2. Measure the distance from the lens to the screen. This is i or image distance. If we assume that the object distance is very large compared to the image distance, then the image distance is equal to the focal length of the lens.

Note the character of the image. Is it inverted or not? Is the magnification > 1 (i.e., image size larger than the object itself) or magnification < 1 (i.e., image size smaller than the object itself)?

Lens Equation Method

3. Plug in the light source. Adjust the set-up so that a clear image of the object falls on the screen. See data table given in uncertainty website).

4. Measure the image and the object distances. Use equation 27-1 to find the focal length of the lens. Measure at least 4 image/object distances and calculate an average focal length.

Conjugate Foci Method

5. Place the light source and screen as far apart as the optical bench allows (maximum value is 180 cm). **First** find one image when the lens is near the screen. Record this location. **Next** move lens where is the same distance from the light source as it was from the screen. This is the conjugate position. Record this location. See Figs 27-1 & 27-2.

Part 2: Measurement of the focal length of a diverging lens

In this part of the experiment a real image will be used as a virtual object. *Before starting step 8 below explore the behavior of a negative lens by looking at an object from various distances. Note what you observe. Can you project an image on a screen? Does image ever go out of focus? Is it is always upright?*

6. **Record all positions in part 2 in your lab data notebook**. Place the light box at some position O. Form an image of the light box on the screen with the converging lens. **Record this image position as I.** *This image will serve as a virtual object for the next part of the experiment.*

7. Next, place the diverging lens in the system at **some point between convex lens and the location where image I was formed on screen.** (See figure 27-2.) While keeping the diverging lens stationary, form a clear image on the screen by **moving the screen away** from the lenses to a new position I'.

The distance from the **concave lens** to the new screen position **(**at I') is the ***image distance*** i **.** The distance from the **concave lens** to position of the **first image formed** (at position I) is the (virtual) **object distance** o . See figure 27-3.

Calculate the focal length of the diverging lens. Please note that **o is a negative value.**

8. Move the lens arrangement and repeat two more times. Calculate the average focal length.

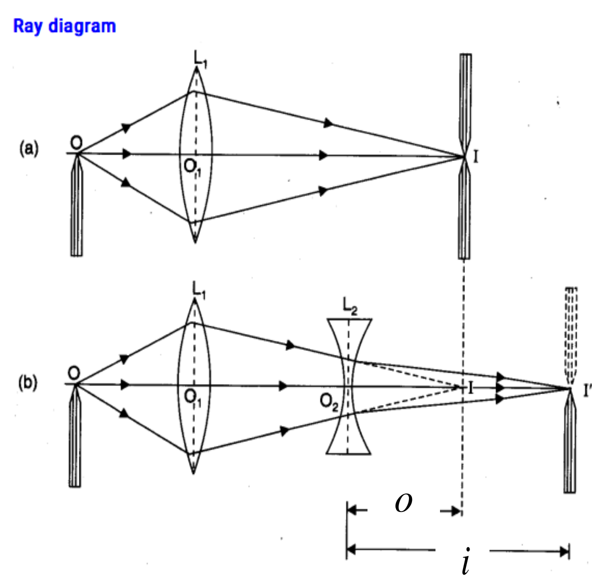


Fig. Focal length of a concave lens.

Figure 27-3.

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Post Lab Questions/Conclusions:

1. Draw one ray diagram each for the distant object method and the lens equation method used to determine the focal lengths of the lenses.

2. A concave lens made out of air is immersed in water (two watch glasses glued to a piece of pipe so that air is inside). Will it form a real image that can be focused on a screen? Why or why not? Justify your answer using a refraction ray diagram.

3. If a convex lens with an index of refraction of 1.5 and a focal length of 20 cm were immersed in a fluid whose index of refraction is also 1.5,
what is the new focal length of the lens. (Hint- This is somewhat of a trick question.)

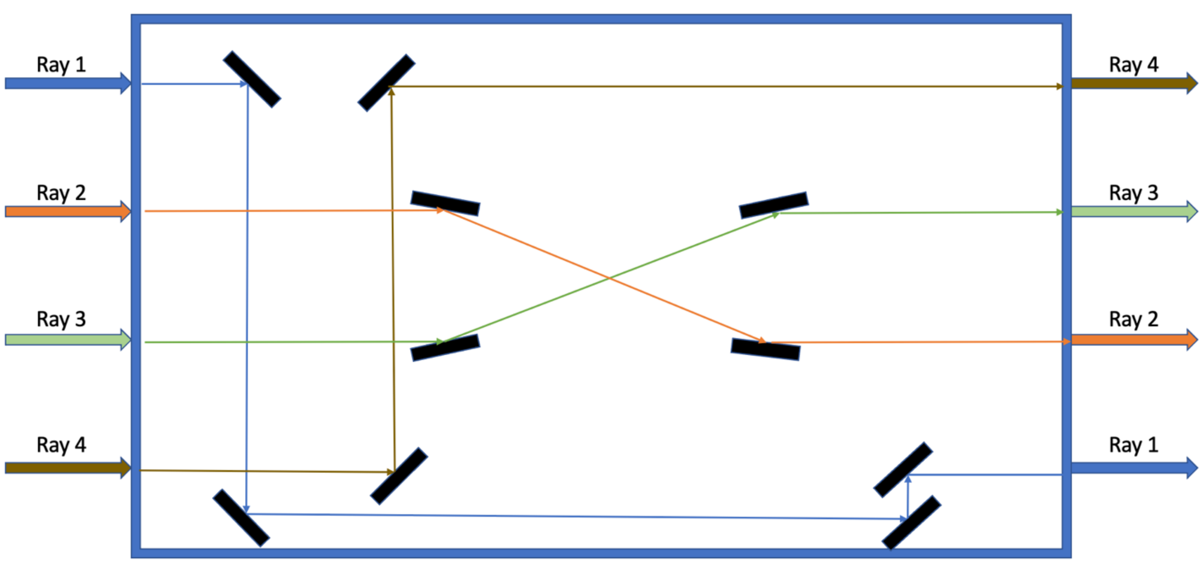
Bonus Point Question (10 points):

No Limit to Your Imagination!

Inside the black box below, there are some unknow optical devices that would change the direction of the light rays.

You can see the result as shown in the diagram above, **four rays going into the black box from the left side end up coming out on the right side of the box in that opposite order.**

Here is a boring answer I am providing as an example of how you should draw the ray diagram:



I have this solution to show that you want to draw all the rays and how their directions are changed by the devices. But the unknown devices don't have to be just plane mirrors.

Use your imagination and figure out what might be the devices inside the box. There are unlimited possibilities and you only need to draw one possibility. You can use **plane mirrors**, **spherical mirrors**, **thin lenses**, **surfaces of different materials** (for example, you can fill up water in the box to a certain height), **diffraction gratings**, anything you like!

Correctness of your setting will be checked and graded; additional bonus points will be assigned for creativity and/or if you can use the minimum number of devices to achieve this result!

You can either print the next page (a bigger picture of the ray diagram), draw clearly by hand, and then upload a photo; or you can use software like PowerPoint to edit the diagram in the file. Please mark clearly the devices in your diagram and the direction those rays go.

For this problem, you can discuss with your lab partner and/or compare your designs. Discussions could open up your mind and help you think out-of-the-box!

Ray 1
Ray 2
Ray 3
Ray 4
Ray 4
Ray 3
Ray 2
Ray 1