Physics 197 Lab 7: Thin Lenses and Optics

Equipment:

Item	Part #	Qty per Team	# of Teams	Total Qty Needed	Storage Location	Qty Set Out	Qty Put Back
Basic Optics Light Source	PASCO OS-8517	1	12	12			
Power Cord for Light Source		1	12	12			
Ray Optics Set (Concave Lens)	PASCO Basic Optics	1	12	12			
Optics Bench	PASCO OS-85518	1	12	12			
100 mm Convex Lens in holder	PASCO	1	12	12			
200 mm Convex Lens in holder	PASCO	1	12	12			
Screen	PASCO	1	12	12			
Grid for Telescope	PASCO Manual p.36	1	12	12			

Layouts:


Figure 1, Experiment A
Lensmaker’s Equation


Figure 2, Experiment B
Focal Length of a Thin Lens

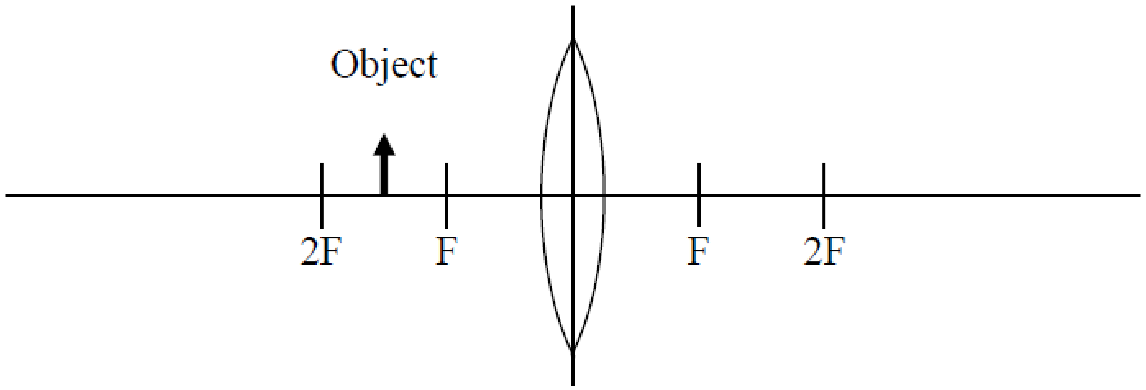

Figure 3, Experiment C
Telescope

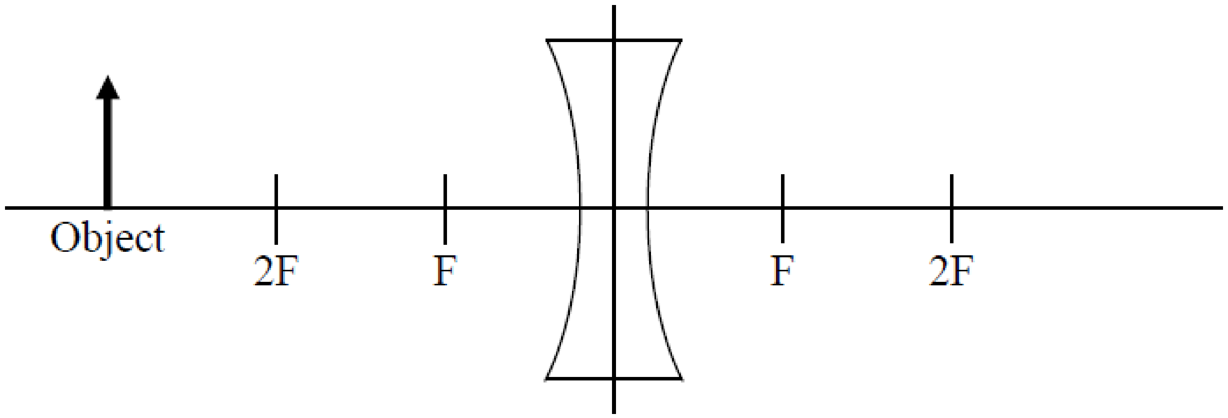
Summary:

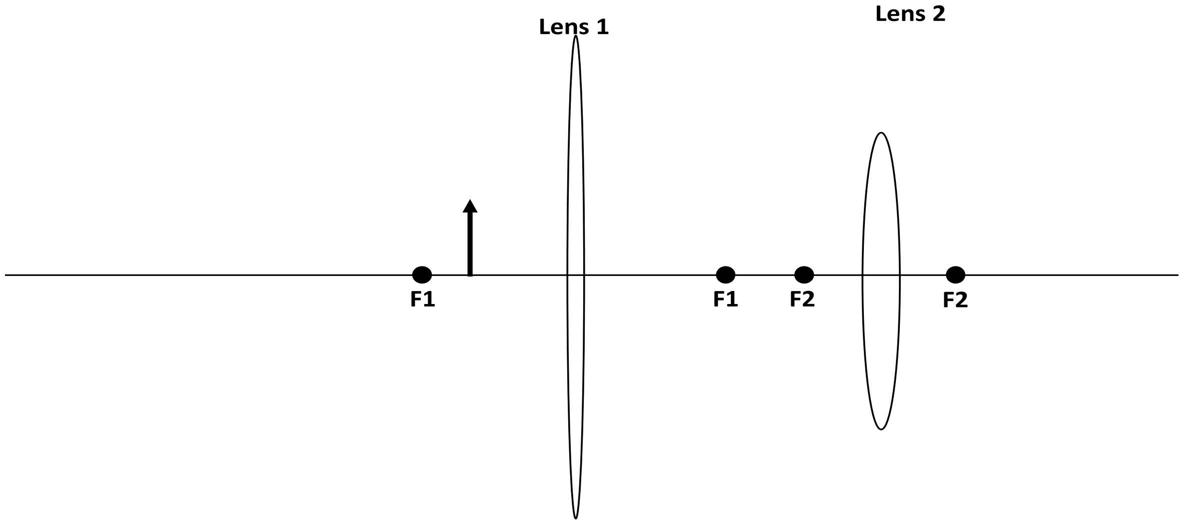
In this lab, students will investigate some properties of thin lenses. In Experiment A (figure 1) the lensmaker’s equation relating the curvature of a lens to its focal length will be examined. In Experiment B (figure 2), students will vary the distance between a source (illuminated pattern), a convex lens, and a screen to study the equation relating these quantities when the system is in focus. Finally, students will measure the magnification of a telescope consisting of two convex lenses by looking through the telescope at a screen (figure 3).

PreLab:

Trace rays for the following three optical configurations, and include them in your notebook. Draw at least two sets of rays to locate the image. State whether the image is upright or inverted, virtual or real, and enlarged or reduced. Also calculate the magnification of the image.

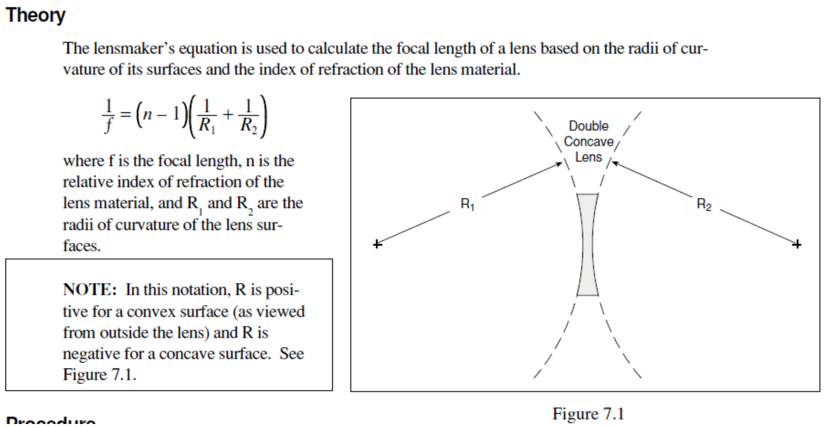






Laboratory: Much of the following text is pasted from the PASCO Experiment manual for the Basic Optics Kit,Part number O12-05628C, Experiments 7,9, and 10.

Experiment A: Lensmaker's Equation.



Theory

The lensmaker's equation is used to calculate the focal length of a lens based on the radii of curvature of its surfaces and the index of refraction of the lens material.

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

where f is the focal length, n is the relative index of refraction of the lens material, and R_1 and R_2 are the radii of curvature of the lens surfaces.

NOTE: In this notation, R is positive for a convex surface (as viewed from outside the lens) and R is negative for a concave surface. See Figure 7.1.

Figure 7.1

Procedure

① Place the ray box on a white piece of paper. Using five white rays from the ray box, shine the rays straight into the concave lens. See Figure 1. Trace around the surface of the lens and trace the incident and transmitted rays. Indicate the incoming and the outgoing rays with arrows in the appropriate directions.

② Remove the lens. To measure the focal length, use a rule to extend the outgoing diverging rays straight back through the lens. The focal point is where these extended rays cross. Measure the distance from the center of the lens to the focal point.

Record the result: f = ________________

③ To determine the radius of curvature, put the concave lens back in the path of the rays and observe the faint reflected rays off the first surface of the lens. The front of the lens can be treated as a concave mirror having a radius of curvature equal to twice the focal length of the effective mirror. Trace the surface of the lens and the incident rays and the faint reflected rays. Measure the distance from the center of the front curved surface to the point where the faint reflected rays cross. The radius of curvature of the surface is twice this distance. Record the radius of curvature:

R = ________________.

④ Note that the lens is symmetrical and it is not necessary to measure the curvature of both sides of the lens because R is the same for both. Calculate the focal length of the lens using the lensmaker's equation. The index of refraction is 1.5 for the Acrylic lens. Remember that a concave surface has a negative radius of curvature.

f = _____________________________

⑤ Calculate the percent difference between the two values of the focal length of the concave lens.

% difference = ____________

Questions

① Is the focal length of a concave lens positive or negative?

② How might the thickness of the lens affect the results of this experiment?

Experiment B: Focal Length of a Thin Lens

Purpose

To determine the focal length of a thin lens.

Theory

For a thin lens: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

where f is focal length, d_o is the distance between the object and the lens, and d_i is the distance between the image and the lens. See Figure 9.1.

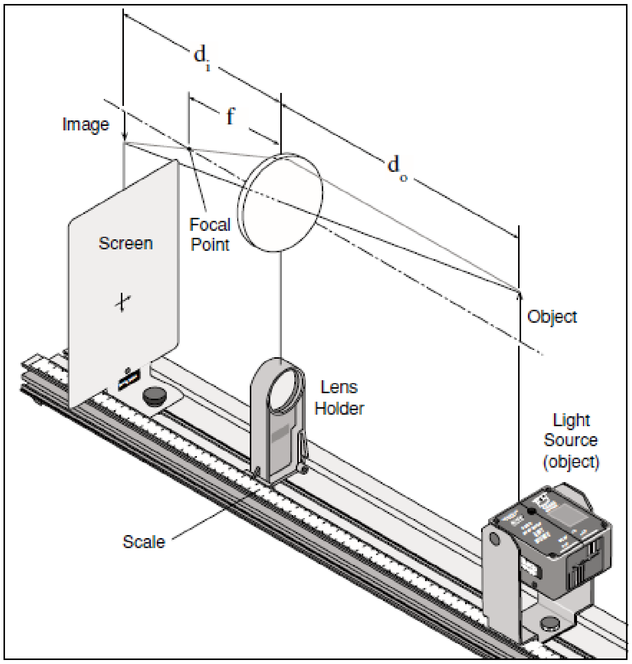


Figure 9.1

Procedure

I. FOCAL LENGTH USING AN OBJECT AT INFINITY

① Using one of the positive lenses focus a distant light source on a paper.

② Measure the distance from the lens to the paper. This is the image distance.

③ Take the limit as the object distance goes to infinity in the Thin Lens Formula:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

Solve for the focal length. $f =$ ______________

II. FOCAL LENGTH BY PLOTTING $1/d_0$ vs. $1/d_i$

a. On the optical bench, position the lens between a light source (the object) and a screen. Be sure the object and the screen are at least one meter apart.

b. Move the lens to a position where an image of the object is formed on the screen. Measure the image distance and the object distance. Record all measurements in a table. The table should have 12 rows, numbered 1-12. There should be columns for Object distance, Image distance, Image size, $1/d_0$, and $1/d_i$.

c. Measure the object size and the image size for this position of the lens.

d. Move the lens to a second position where the image is in focus (Do not move the screen or Light Source). Measure the image distance and the object distance.

e. Measure the image size for this position also.

f. Move the screen toward the object until you can no longer find two positions of the lens where the image will focus. Then move the screen a few centimeters further away from the object. Repeat Parts b and d for this position of the screen and for 4 other intermediate positions of the screen. This will give you 6 sets of data points (a total of 12 data points) for object and image distance. You do not need to measure image size anymore for the last 10 data points.

g. Plot $1/d_o$ vs. $1/d_i$ using the 12 data points. This will give a straight line and the x- and y- intercepts are each equal to 1/f.

h. Find the percent difference between the two values of the focal length found from the intercepts. Then average these two values and find the percent difference between this average and the focal length found in Part I.

i. For the first two sets of data points ONLY, use image and object distances to find the magnification at each position of the lens.

$$Magnification = M = d_i / d_o$$

Then, using your measurements of the image size and object size, find the magnification by measuring the image size and the object size.

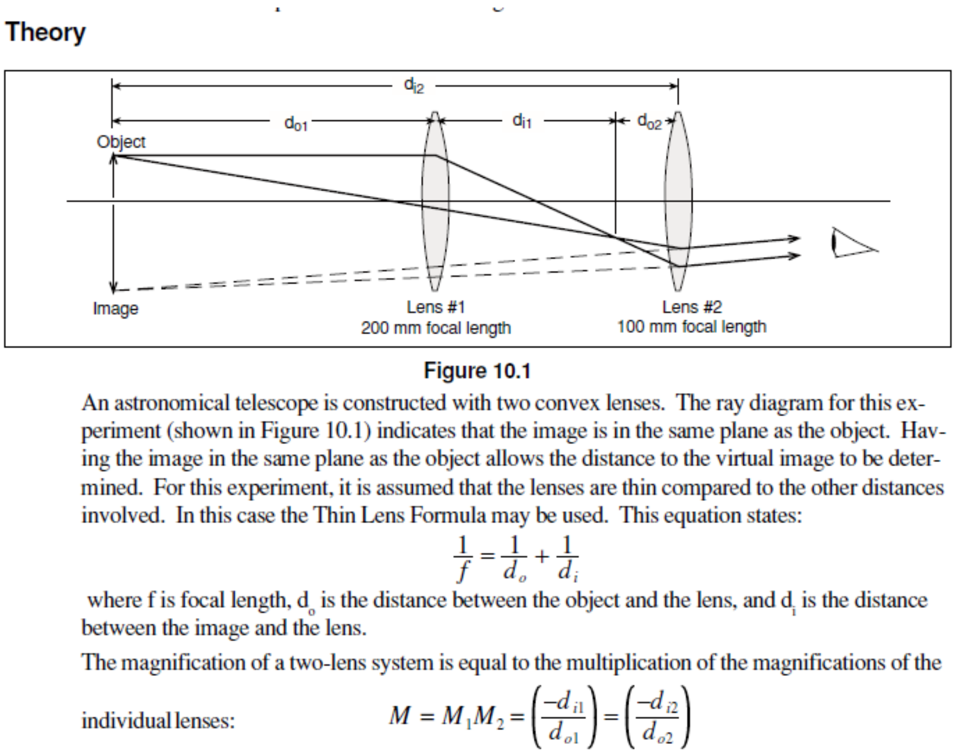
$$|M| = image\ size/object\ size$$

Find the percent differences.

QUESTIONS

① Is the image formed by the lens erect or inverted?
② Is the image real or virtual? How do you know?
③ Explain why, for a given screen–object distance, there are two positions where the image is in focus.
④ Why is the magnification negative?

Experiment C: Telescope



Theory

Figure 10.1

An astronomical telescope is constructed with two convex lenses. The ray diagram for this experiment (shown in Figure 10.1) indicates that the image is in the same plane as the object. Having the image in the same plane as the object allows the distance to the virtual image to be determined. For this experiment, it is assumed that the lenses are thin compared to the other distances involved. In this case the Thin Lens Formula may be used. This equation states:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

where f is focal length, d_o is the distance between the object and the lens, and d_i is the distance between the image and the lens.

The magnification of a two-lens system is equal to the multiplication of the magnifications of the individual lenses:

$$M = M_1 M_2 = \left(\frac{-d_{i1}}{d_{o1}}\right) = \left(\frac{-d_{i2}}{d_{o2}}\right)$$

① Tape or use paper clips to fasten the paper pattern to the screen. The crosshatching on the screen acts as the object.
② The 200 mm lens is the objective lens (the one which is nearer to the object). The 100 mm lens is the eyepiece lens (the one which is nearer to the eye). Place the lenses near one end of the optical bench and place the screen on the other end as in figure 3.

Procedure

① Focus the image of the object (the crosshatching on the screen) by moving the objective lens (the one which is closer to the object). To view the image, you must put your eye close to the eyepiece lens.

② Eliminate the parallax by moving the eyepiece lens until the image is in the same plane as the object (screen). To observe the parallax, open both eyes and look through the lenses at the image with one eye while looking around the edge of the lenses directly at the object with the other eye. See Figure 10.3. The lines of the image (solid lines shown in Figure 10.4 inset) will be superimposed on the lines of the object (shown as dotted lines in Figure 10.4 inset). Move your head back-and-forth or up-and- down. As you move your head, the lines of the image will move relative to the lines of the object due to the parallax. To eliminate the parallax, move the eyepiece lens until the image lines do not move relative to the object lines when you move your head. When there is no parallax, the lines in the center of the lens appear to be stuck to the object lines.

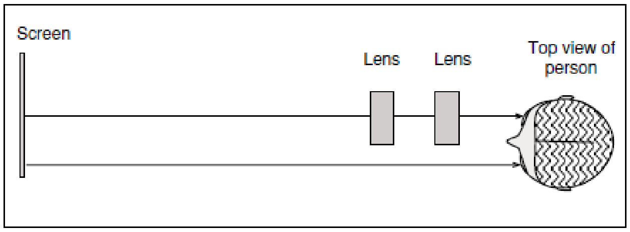


Figure 10.3

NOTE: Even when there is no parallax, the lines may appear to move near the edges of the lens because of lens aberrations.

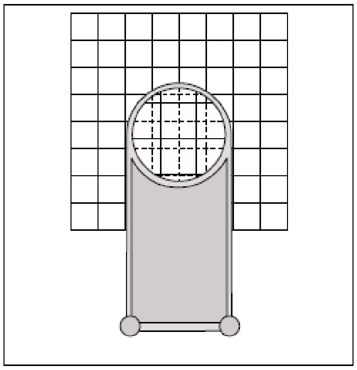


Figure 10.4

③ With the parallax now eliminated, the virtual image is now in the plane of the object. Record the positions of the lenses and the object.

④ Measure the magnification of this telescope by counting the number of squares in the object that lies along one side of one square of the image. To do this, you must view the image through the telescope with one eye while looking directly at the object with the other eye. Record the observed magnification.

⑤ Remove the screen and look through the lenses at a distant object such as a meter stick at the opposite side of the room. Eliminate the parallax and determine the magnification. When viewing an object at infinity through a telescope, the magnification is the ratio of the focal lengths of the lenses. Check to see if this is true for your telescope.

Analysis

To calculate the magnification complete the following steps and record the answers.

① Determine do1, the distance from the object (paper pattern on screen) to the objective lens.

② Determine di2, the distance from the eyepiece lens and the image. Since the image is in the plane of the object, this is also the distance between the eyepiece lens and the object (screen).

③ Calculate di1 using do1 and the focal length of the objective lens in the Thin Lens Formula.

④ Calculate do2 using di2 and the focal length of the eyepiece lens in the Thin Lens Formula.

⑤ Calculate the magnification using the formula in the theory section.

⑥ Take a percent deviation between this value and the observed value.

Questions

① Is the image inverted or erect?

② Is the image seen through the telescope real or virtual?