Experiment 20: Thin Lenses

Figure 20.1: Optical Bench Arrangement

EQUIPMENT

Optical Bench
(2) Lens Holders
(4) Optical Bench Clamps
Object Box (Light Source)
Small Screen
Large Screen (clipboard, paper)
Bi-Convex Lens (Converging Lens)
Bi-Concave Lens (Diverging Lens)
30-cm Ruler
Flashlight (1 per person)
Lens Cleaning Towelettes (TA's Table)

Advance Reading

Text: Thin lenses, converging lens, diverging lens, lens equation, object distance, image distance, refraction, focal length, magnification, index of refraction, real image, virtual image.

Objective

The objective of this experiment is to measure the focal lengths of a converging lens and a diverging lens and investigate magnification.

Theory

Light refracts (bends) when passing through media with difference indices of refraction. This property can be very useful, especially when a *thin lens* is used. A thin lens' thickness is much less than its diameter.

A converging (convex, positive) lens is thicker in the center than at the edges. It can be used to focus parallel light rays and form a *real image* as the light travels from air to glass and back to air ($n_{air} \approx 1.0$, $n_{glass} \approx 1.5$). A real image is formed by light actually passing through the image. A real image can be projected on a screen. The image exists regardless of whether or not a screen is in position to show it.

A diverging (concave, negative) lens normally forms a *virtual image*. Light rays do not actually pass through a virtual image. It cannot be projected on a screen. When you look at yourself in a mirror, you are looking at a virtual image. If the object is real, the image is virtual. However, when a diverging lens is used in combination with a converging lens, for instance, the object can be virtual, the image real. Parameters must be met for a real image to be formed; read the *Part 2* procedure carefully.

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

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \tag{20.1}$$

where d_o is the object distance and d_i is the image distance. These distances are measured from the lens.

Consider Eq. 21.1. For an object that is infinitely far away ($d_o \to \infty$).

Rays of light from an object very far away from a thin lens will be approximately parallel when they reach the lens. The light rays will then refract as they pass through the lens. For a converging lens, rays parallel to the optical axis refract towards the normal and focus at a point (small area) called the *focal point*, F. The distance between the center line of the lens and the focal point is the *focal length*, f. Refer to Fig. 21.2. Fig. 21.2 through Fig. 21.6 are courtesy of Giancoli's *Physics*[1].

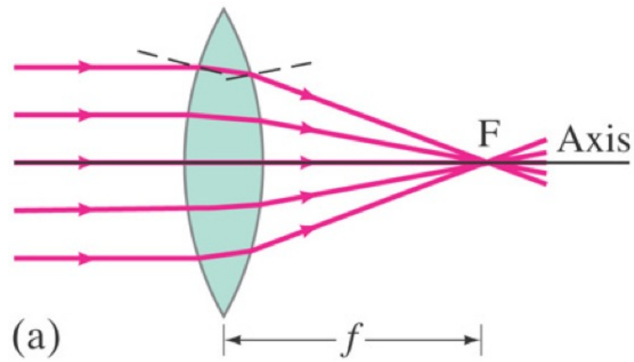

Figure 20.2: Ray Tracing: $d_o \to \infty$, $d_i \equiv f$

For a converging lens, rays of light that are parallel to each other but not parallel to the optical axis will still refract towards the normal, but will focus at the *focal plane.*

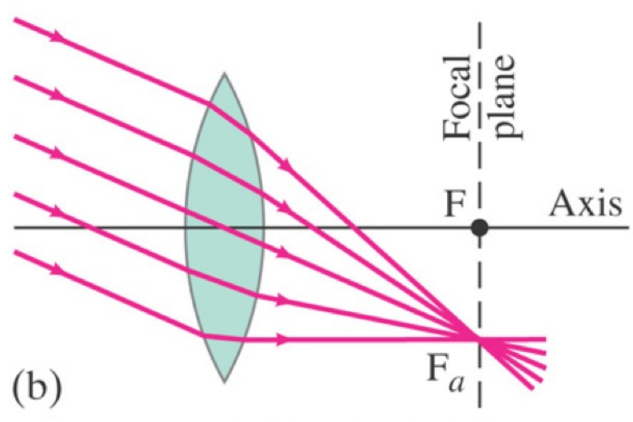

Figure 20.3: Ray Tracing: Focal Plane

[1]Giancoli, Douglas C., 2005. *Physics*, 6th Edition. Pearson Education, Inc., Upper Saddle River, NJ.

Rays of light from a nearby object will arrive at the lens at various angles. The light rays will then refract as they pass through the lens and, for a converging lens, form an image at a distance d_i (refer to Fig. 21.4).

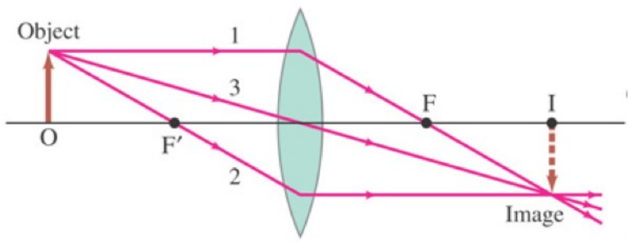

Figure 20.4: Ray Tracing: Nearby Object

As mentioned, a diverging lens will usually form a virtual image. The image can be seen but cannot be projected onto a screen.

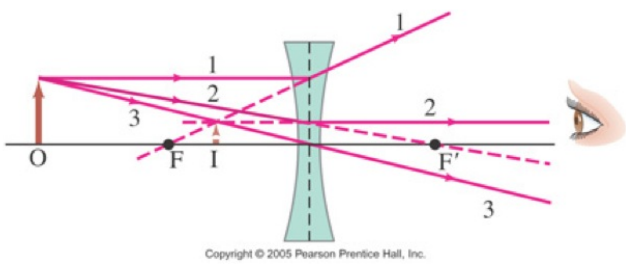

Figure 20.5: Ray Tracing: Diverging Lens

To determine the focal length of a diverging lens in lab, we will need to use two lenses. The *real image* from the converging lens will become the *virtual object* for the diverging lens. Refer to Fig. 21.6; although our arrangement must be somewhat different than shown below, the figure has the same concept we require.

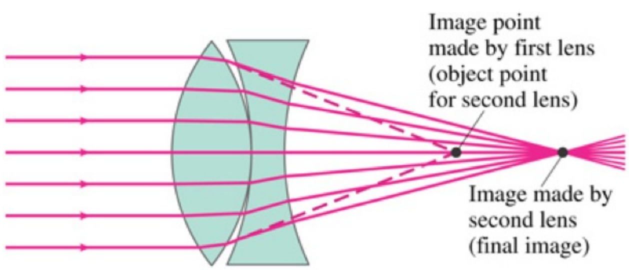

Figure 20.6: Ray Tracing: Combination Lenses

Lateral magnification, M, is defined as the ratio of the image height, h_i, to object height, h_o. The object height is assumed to be positive; the image height is positive if the image is upright and negative if the image is inverted.

$$M = \frac{h_i}{h_o} \tag{20.2}$$

Magnification is also proportional to the relative distances of object and image from the lens:

$$M = -\frac{d_i}{d_o} \tag{20.3}$$

The sign conventions for object distance and image distance remain the same. These are calculated as in Eq. 21.4 and Eq. 21.5.

The lab will be dark (lights off) for the remaining experiments this semester. It is important that your flashlight be pointed *below horizontal* at all times. This limits the bleaching of visual purple, which permits night vision. Please turn off the flashlight when it is not in use and before you leave lab.

Name: ____

1. Define the terms of the relationship $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$ (Eq. 21.1) and state how each term is measured. (20 pts)

2. State the sign conventions for d_o and d_i. (20 pts)

3. What is the difference between a real image and a virtual image? (20 pts)

4. Define the terms of the relationship $M = \frac{h_i}{h_o}$ and state the sign conventions. (20 pts)

5. What does *optical axis* mean? (10 pts)

6. What two methods will be used to calculate the focal length of a converging lens? (10 pts)

Name: ______________________________ Section: __________ Date: ____________

Worksheet - Exp 22: Thin Lenses

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Theory

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A converging (convex, positive) lens is thicker in the center than at the edges. It can be used to focus parallel light rays and form a *real image*. A real image can be projected on a screen. The image exists regardless of whether or not a screen is in position to show it.

A diverging (concave, negative) lens normally forms a *virtual image*. Light rays do not actually pass through a virtual image. It cannot be projected on a screen. When you look at yourself in a mirror, you are looking at a virtual image. If the object is real, the image is virtual (with a diverging lens). However, when a diverging lens is used in combination with a converging lens, for instance, the object can be virtual, the image real. Parameters must be met for a real image to be formed; read the *Part 2* procedure carefully.

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

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

where d_o is the object distance and d_i is the image distance. These distances are measured **from the lens.**

PROCEDURE

Part 1: Converging Lens
Method I - Use the lens equation ($\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$)

1. Mount the lens, screen, and light source on the optical bench. Adjust the height of the object, lens(es), and screen so that the optical axis passes through the center of each element.

2. Adjust the position of the lens and the screen until a clear image of the object is projected onto the screen. Considering the lens equation, how many combinations of d_i and d_o are possible?

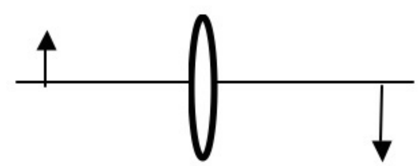
3. Using the diagram to the right, record the position of each device: O, L, i. Positions are measured directly from the optics bench; a line is scribed on each holder for accuracy.

4. Calculate d_o, d_i, and f.

$$d_o = L - O$$

$$d_i = i - L$$

O: __________ L: __________ i: __________



d_o: ______________ d_i: ______________

f = __________________

(6 pts)

O is the position of the object.

L is the position of the lens.

i is the position of the image.

d_o is the calculated object distance (absolute value).

d_i is the calculated image distance (absolute value).

Method II - Use a distant object ($d_o \to \infty$)

5. Hold lenses carefully by the edge. Project the image of a distant object on a screen. One way to achieve this is to take the lens and a ruler to a long hallway. Hold the lens such that light from a distant light source at the other end of the hallway passes through the lens and focuses on the wall.

6. Adjust the distance between the lens and the screen until a clear, distinct image of the distant light source is projected onto the screen.

7. Measure the distance from the lens to the screen. This distance is f. The lens equation shows that when d_o is large, $d_i \to f$.

   $f =$ ___________

8. Is the image inverted? Magnified? Reversed? (4 pts)

9. Compare f (% difference) from the two methods. (4 pts)

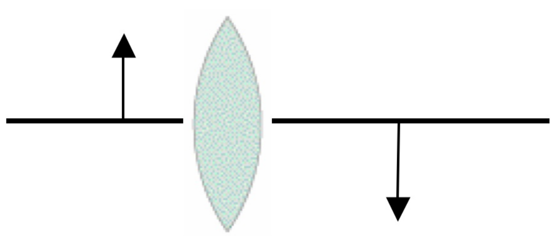
10. Draw a ray diagram for Method I. Use at least two rays. (8 pts)

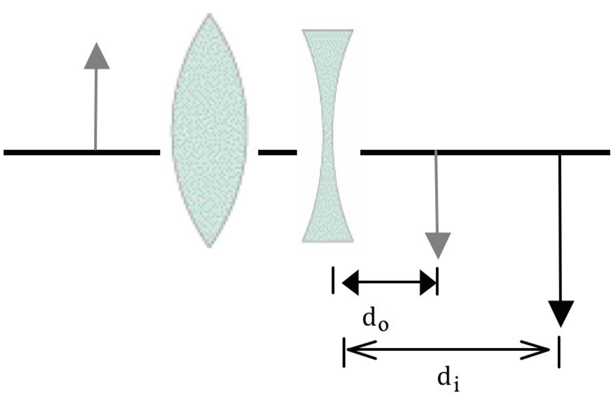
11. Draw a ray diagram for Method II. Use at least two rays. (8 pts)

Part 2: Diverging Lens

To determine the focal length of a diverging lens, the lens must create a measurable, real image as in *Part 1*. However, light cannot be focused through a diverging lens to form a real image unless that light was already converging. To accomplish this, a *real image* from a converging lens will be used as a *virtual object*.[2]

12. Form a real image using a converging lens. *Note:* d_o should be greater than $2f$.
13. Place the diverging lens between the converging lens and its (real) image; refer to the figure below. The *real image* from the converging lens is now a *virtual object* for the diverging lens.
14. Determine the position of the diverging lens' image by adjusting the screen's position.



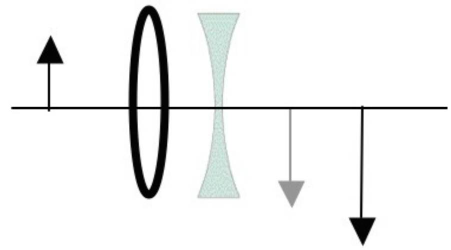


15. Record your data in the digram above.
16. Determine d_o and d_i for the diverging lens.
17. Calculate f for the diverging lens.

Converging Lens:

O: __________ L: __________ i: __________

d_o: ________________ d_i: ________________



Diverging Lens:

L: __________ O: __________ i: __________

d_o: ________________ d_i: ________________

$f_1 =$ ______________ $f_2 =$ ______________

(12 pts)

Compare f of a Diverging Lens

18. Recalculate f using the following equation:

$$f = \frac{VW}{V-W}$$

where V and W are defined as:

$$V \equiv |d_o| \qquad \text{and} \qquad W \equiv |d_i|$$

(6 pts)

19. Compare f values from the lens equation and the equation above for the diverging lens. If you followed the sign conventions closely, the f values should be identical.

[2]For a diverging lens, either the object or the image can be real; the other must be virtual.

20. Consider a *concave* lens made out of air that is immersed in water (perhaps two watch glasses glued to each end of a piece of pipe, with air inside). Will it form a real image that can be focused on a screen? Draw a ray diagram to support your answer. (8 pts)

Part 3: Lateral Magnification, M

Use only the converging lens to investigate lateral magnification. Record all data in the diagrams to the right.

21. **Set $d_o > 2f$** by adjusting the distance between the object and the lens. Find the image using your large screen. Record the position of the image and mark on the screen the top and bottom of the image.

22. Measure the image height, h_i, and the object height, h_o. Be sure to measure the same dimension on both object and image. (2 pts)

    h_i: ______________ h_o: ______________

23. Calculate M:

    $M = \frac{h_i}{h_o}$ $M =$ ________________ (2 pts)

24. Verify the magnification (M) using the following equation:

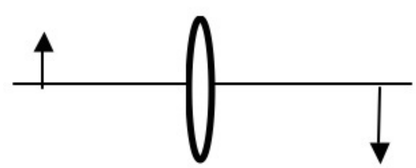
    $M = \frac{-d_i}{d_o}$ $M =$ ________________ (2 pts)

25. Compare the two values of M.

    % diff: ________________ (2 pts)

Converging Lens: $d_o > 2f$

O: __________ L: __________ i: __________



d_o: ________________ d_i: ________________

$f =$ ____________________

(6 pts)

26. **Set $f < d_o < 2f$.** Locate the image.

27. Measure h_i and h_o. (2 pts)

    h_i: ______________ h_o: ______________

28. Calculate M using both of the previous equations and compare the two values. (4 pts)

    $M_1 =$ ______________ $M_2 =$ ______________

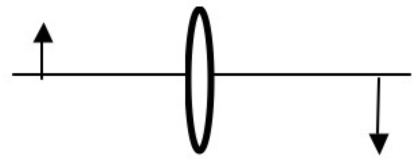
    % diff: ________________

29. **Set $d_o = f$.** Try to find d_i. Consider Method II and Eq. 21.1; where should the image be? (4 pts)

30. **Set $d_o < f$.** Look *through* the lens at the object. Note your observations. (4 pts)

Converging Lens: $f < d_o < 2f$

O: __________ L: __________ i: __________



d_o: ________________ d_i: ________________

$f =$ ____________________

(6 pts)

31. Set the lens carefully aside where it will not be damaged. Unplug the light source and lay the power cord across the optics bench.

32. If a convex lens with $n = 1.30$ and $f = 25$ cm is immersed in a fluid with an index of refraction that is also 1.30, what is the new focal length of the lens? Draw a ray diagram. (10 pts)