General Physics II Lab (PHYS-2021)
EXPERIMENT OPTC–3:
Lenses and Image Formation

1 Introduction

When light travels from one medium to another, part of the light can be **transmitted** across the media surface and **refracted** as shown in Figure 1.

- **Refraction** means that the light beam bends.
- This bending takes place because the light beam's (*i.e.*, photon's) velocity changes as it goes from one medium to the next, following the relation:

$$\boxed{\frac{\sin\theta_r}{\sin\theta_i} = \frac{v_r}{v_i} = \text{constant}\ .} \tag{1}$$

  - v_r and θ_r are the velocity and the angle of the refracted beam with respect to the normal line of the surface.
  - v_i and θ_i are the velocity and the angle of the incident beam with respect to the normal line of the surface.

The **index of refraction**, n, of a material is defined as

$$n \equiv \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}} = \frac{c}{v}\ . \tag{2}$$

Eq. (1) can be re-expressed as a function of $n \Longrightarrow$ **Law of Refraction** better known as **Snell's Law**:

$$\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2\ ,} \tag{3}$$

where the '1' label indicates the first medium the light is in and the '2' label indicates the second medium (see Figure 1).

In today's lab we will carry out experiments with lenses and how they form images. This experiment will involve placing lenses and sources on an optical bench along with an image screen to determine the focal length of both converging and diverging lenses. A **converging lens** is thicker at its center than at its edges (see Figure 2 on Page 3), whereas a **diverging lens** is thinner at its center than at its edges (see Figure 3 on Page 3). For a converging lens, light rays are refracted towards the focal point, F, on the other side of the lens. Meanwhile for a diverging lens, light rays are refracted in a direction away from the focal point, F, on the near side of the lens.

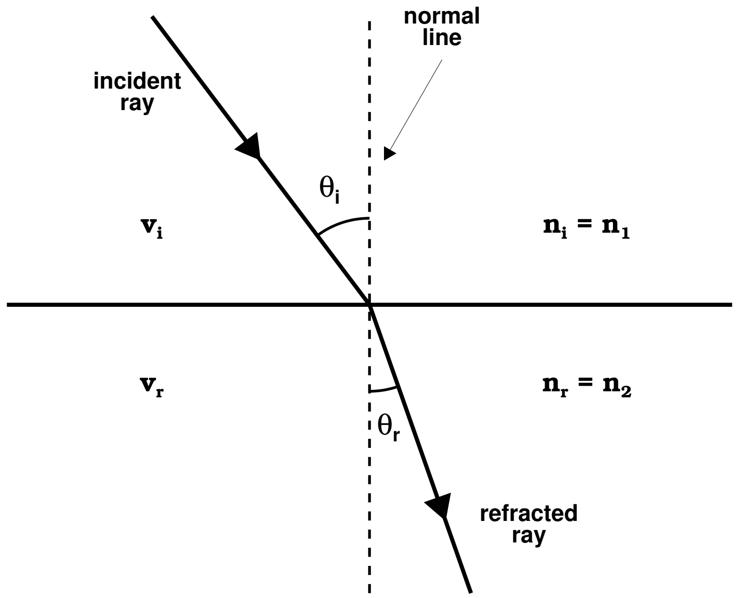


Figure 1: Snell's Law: The Law of Refraction.

1.1 The Lens Maker Equation

The focal length for a lens in air is related to the curvatures of its front and back surfaces of a lens via the **lens maker's equation**:

$$\boxed{\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right),} \tag{4}$$

where n ≡ index of refraction of the lens,
f ≡ focal length (*i.e.*, distance from the lens to the focal point F),
R_1 ≡ radius of curvature of front surface, and
R_2 ≡ radius of curvature of back surface.

1.2 Image Formation with Thin Lenses

Just as we had for mirrors, we will make use of the *simple lens/mirror equation*:

$$\boxed{\frac{1}{p} + \frac{1}{q} = \frac{1}{f}\ ,} \tag{5}$$

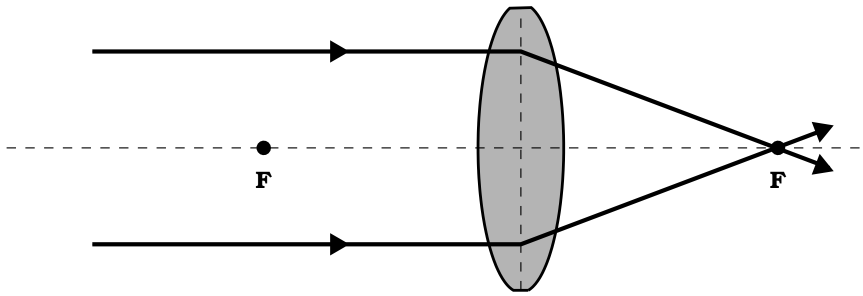


Figure 2: A converging lens.

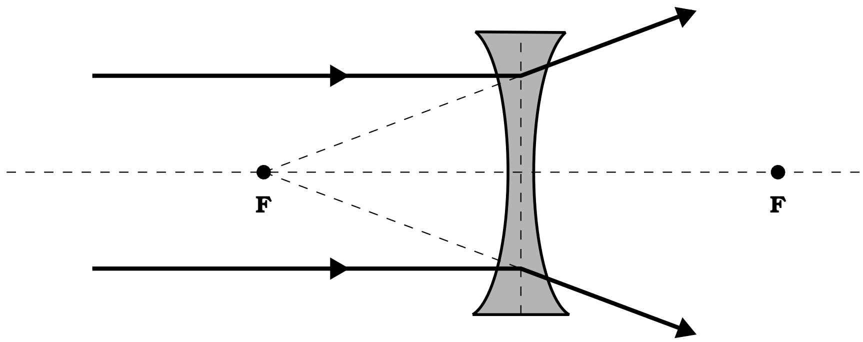


Figure 3: A diverging lens.

where p is the object distance from the mirror, q is the image distance, the focal length is f. Like we had for mirrors, the magnification of the image is given by

$$\boxed{M \equiv \frac{\text{image height}}{\text{object height}} = \frac{h'}{h} = -\frac{q}{p}.} \tag{6}$$

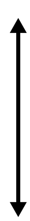
The sign conventions for lenses are the same as for mirrors except for q, when $q > 0$ the image is on the opposite side of the lens and when $q < 0$ the image is on the same side of the lens as the object (see Table 1 on the next page).

1.3 Ray Tracing Rules for Thin Lenses

Following what we did for mirrors, we will first discuss the ray tracing rules for thin lenses (see Figure 5 on Page 8).

- The first ray (*i.e.*, Ray 1) is drawn parallel to the optical axis from the top of the object. After being refracted by the lens, this ray either passes through the focal point, F, on

Table 1: **Sign Conventions for Thin Lenses**

	+ SIGNS	−
p	object in front of lens (real object)	object in back of lens (virtual object)
q	image in back of lens (real image)	image in front of lens (virtual image)
h	object is erect	object is inverted
h'	image is erect	image is inverted
M	image is in same orientation as object	image is inverted with respect to object
R_1, R_2	center of curvature in back of lens	center of curvature in front of lens
f	converging lens	diverging lens
symbol		

the other side of the lens (for a *converging lens*), or appears to come from the near side focal point, F, in front of the lens (for a *diverging lens*).

- The second ray (*i.e.*, Ray 2) is drawn from the top of the object and through the center of the lens. This ray continues on the other side of the lens as a straight line.
- The third ray (*i.e.*, Ray 3) is drawn through the focal point, F, on the near side for *converging lenses* and emerges from the lens on the opposite side, parallel to the optical axis. For *diverging lenses*, one draws Ray 3 starting from the top of the object and projects it to the focal point on the far side of the lens. When this ray passes through the lens, this ray comes out parallel to the optical axis as shown in the bottom figure of Figure 5.

2 Procedure

Table 2: Items Used in the Mirrors and Image Formation Lab

1.2 meter optical bench (OS-8508)	light source (OS-8517)
2 mounted converging lenses	1 mounted diverging lens
image screen (OS-8460)	metric ruler/straight edge
graph paper	

PASCO Part Number in parentheses.

Caution! *Be careful not to touch or scratch the surface of the lenses!*

Caution! *Be sure not to block the lamp-housing circular air vent at the top of the housing! If blocked, the housing will overheat and burn out the light bulb and transformer.*

Note: It is important that you properly align the light source, lens and the image screen each time you do an experimental setup, *i.e.*, the lens is approximately perpendicular to the bench axis, and the screen is positioned properly to capture the image. Some trial-and-error efforts are usually required to capture the best alignment.

For these experiments, you will (1) obtain a solution experimentally with the optical bench, (2) obtain a solution by constructing a ray-tracing diagram, and (3) analytically obtain (*i.e.*, calculating) a solution using the equations in these lab instructions.

For the experimental portion of this lab, the 3 lenses will be labeled L_1 (a converging lens of focal length $f_1 \approx 10$ cm), L_2 (a converging lens of focal length $f_2 \approx 20$ cm), and L_3 (a diverging lens of focal length $f_3 \approx -15$ cm). The general methods used here are somewhat similar to those used in the OPTC-2 Lab: Mirrors and Image Formation, except instead of using a 'half-screen' for the images to fall upon, we will be using a 'full' viewing screen (also called an image screen).

For each of the following situations, construct a correct ray diagram on graph paper to *locate* and *describe* the image. You must work carefully with a sharp pencil and a good straight-edge in order to get good, accurate results. **Be sure to fully label each diagram:** p (the object distance from the lens), q (the image distance from the lens), f (the focal length), O (the object), I (the image), h (the object's size), h' (the image's size), etc.

For your ray tracing diagrams, use the whole sheet of paper for each diagram. Label the scale factor that you have used for each diagram (*e.g.*, one division line equals 0.1 cm).

1. Measure the focal lengths of the two **converging lenses** L_1 and L_2 by setting up a real-image configuration on the optical bench, measuring p and q, and then calculating f for each lens as described below. A typical real-image configuration is shown in Figure 4.

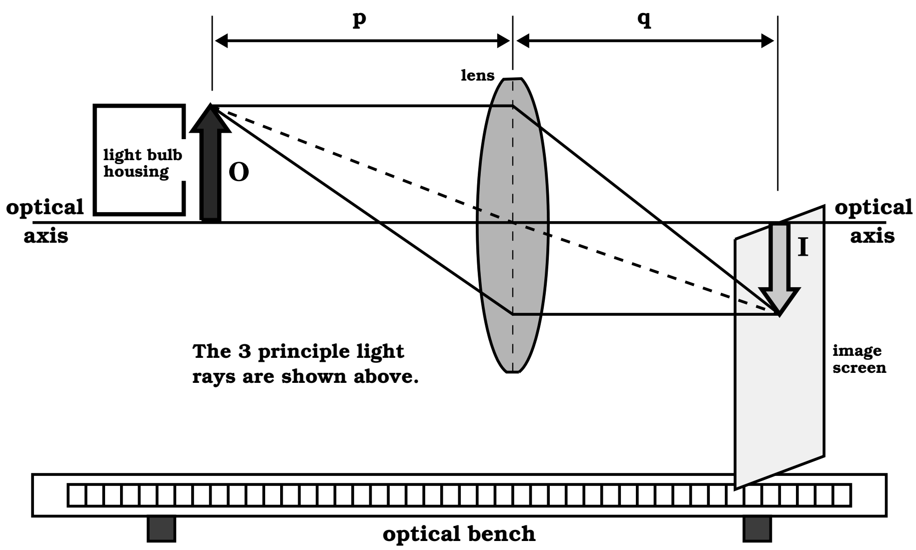


Figure 4: Converging lens real-image configuration on the optical bench.

(a) Find the focal length, f_1, of lens L_1 as follows:

i. Place the object slide, O, on the optical bench at the 0.0 cm position and the image screen at the 50.0 cm position.

ii. Mount L_1 on the optical bench *between* O and the screen and locate the <u>two</u> positions where a sharp image, I, is formed on the screen. One of these positions will be about 10–12 cm from the object slide and the other about 10–12 cm from the screen.

iii. Measure and record (in cm) the object distance p and the image distance q for each of the positions of L_1, and calculate the focal length f_1 using the simple lens/mirror equation (Eq. 5).

(b) Find the focal length, f_2, of lens L_2 as follows:

i. Place the object slide, O, on the optical bench at the 0.0 cm position and the image screen at the 110.0 cm position.

ii. Mount L_2 on the optical bench *between* O and the screen and locate the two positions where a sharp image, I, is formed on the screen. One of these positions will be about 20–25 cm from the object slide and the other about 20–25 cm from the screen.

iii. Measure and record (in cm) the object distance p and the image distance q for each of the positions of L_2, and calculate the focal length f_2 using the simple lens/mirror equation (Eq. 5).

2. Set up a *two-lens* configuration on the optical bench as follows:

(a) Place the object slide, O, at the 0.0 cm position, L_1 at 11.0 cm, and L_2 at 35.0 cm.

(b) Adjust the screen position so that a sharp image is formed.

(c) Measure and record the object distance p_1 for L_1, the image distance q_2 for L_2, and the lens separation distance d.

(d) Now use the simple lens/mirror equation (Eq. 5) to calculate the image distance q_2. Use the values for f_1 and f_2 determined in Step 1. Eq. (5) must be used *twice* – first for L_1 and again for L_2. *Be sure to present your calculations clearly.* Compare your calculated value for q_2 with that measured on the bench.

3. For our final step, we will determine the focal length of the *diverging* lens. Since an individual diverging lens always produces a virtual image, we cannot find the focal length using the real-image configuration used in our first two steps. Instead, we will use two lenses, one diverging and the other converging, and follow the technique described in Step 2.

(a) Place the object slide, O, at the 0.0 cm position, L_1 at 20.0 cm, and the image screen at 60.0 cm.

(b) Place the diverging lens L_3 on the bench between L_1 and the screen. Now adjust the diverging lens position until you get a sharp image on the screen. [Note that the converging lens must be "stronger" (have a shorter focal length) than the diverging lens or else no image can be formed on the screen.]

(c) Measure and record the object distance p_1 for L_1, the image distance q_3 for L_3, and the lens separation distance d.

(d) Apply the simple lens/mirror equation (Eq. 5), as you did in Part 2, to calculate the focal length f_3 of the diverging lens L_3. *Again, be sure to present your calculations clearly.*

4. Summarize all of your findings in a data table.

3 Final Note

This Laboratory Experiment will require a standard **Lab Report** as described in the lab_report_format.pdf document on the course web page at https://faculty.etsu.edu/lutter/courses/phys2021/index.htm.

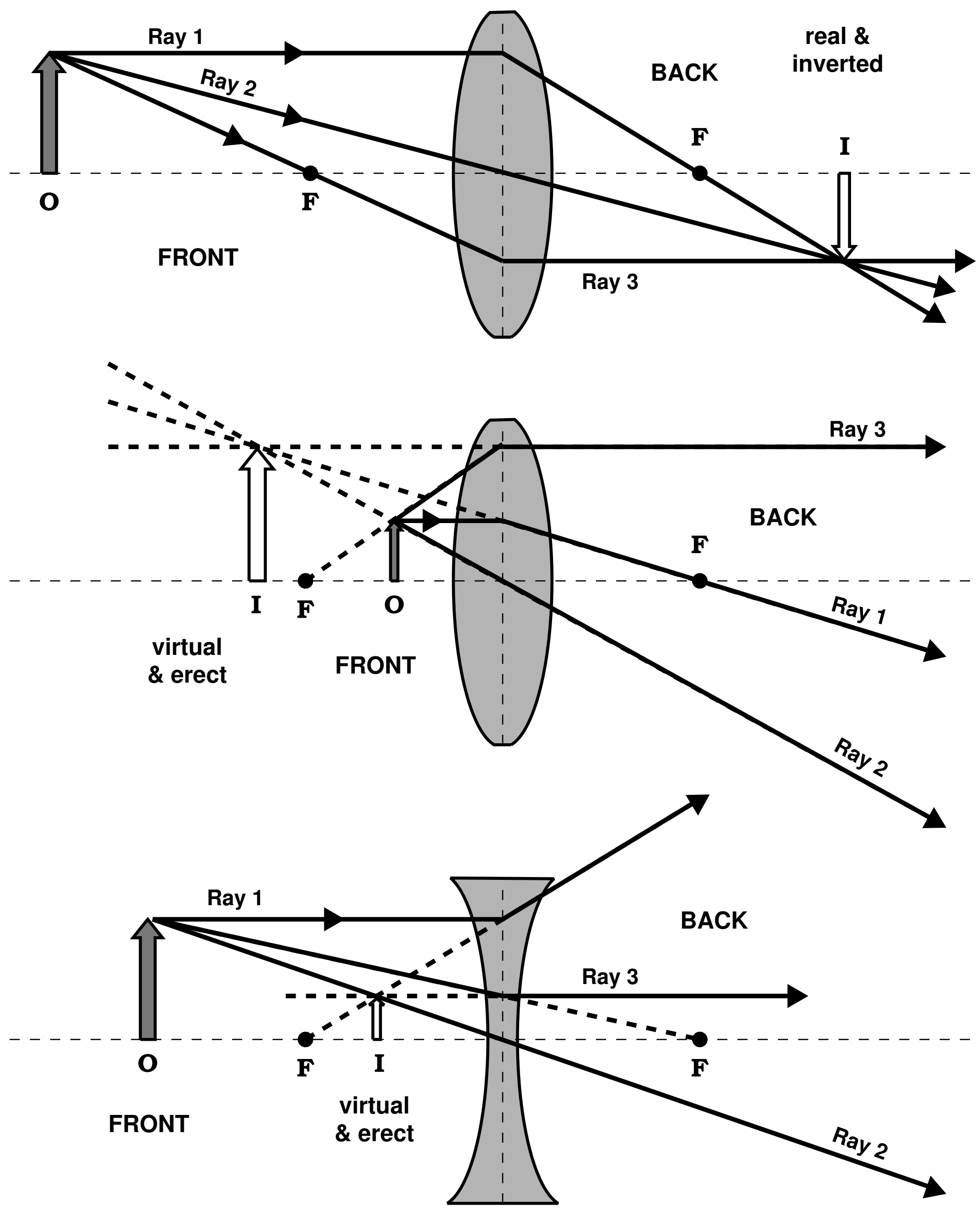


Figure 5: Ray Tracing Rules for Thin Lenses.