

Reflection and Refraction

1 Object

To determine focal lengths of lenses and mirrors and to determine the index of refraction of glass.

2 Apparatus

Lenses, optical bench, mirrors, light source, screen, plastic or glass disk.

3 Theory

3.1 Reflection and Refraction

For reflection, the angle of incidence i should equal the angle of reflection r as shown in figure 1. When a light ray is transmitted from one material into another the process is called *refraction*.

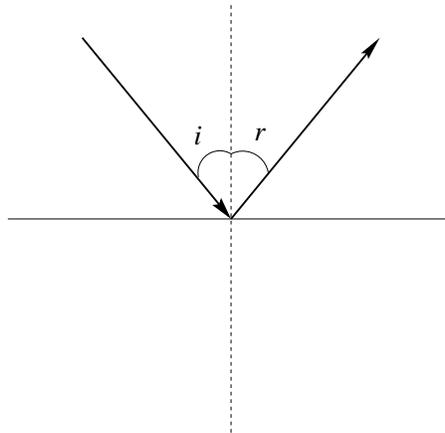


Figure 1: Reflection off of a smooth, flat surface – often termed specular reflection.

It is customary to measure all angles with respect to the *normal*, which is perpendicular to the interface between the media at the point of incidence. Snell's law describes what happens at such an interface

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \quad (1)$$

where n_1 and n_2 are the indices of refraction of the two materials, θ_1 is the incident angle, and θ_2 is the refracted angle. The index of refraction is defined as the ratio of the speed of light in vacuum (space) over the speed of light in the material in question. Mathematically, $n \equiv c/v$. For air, $n \simeq 1$, and for water $n = 1.33$, whereas often $n = 1.5$ for glass. It has also been found that n will vary as a function of wavelength (or color) of light. Thus, white light entering a second material will have its different colors refracted at different angles and often the separate colors will become observable. A geometrical derivation for Snell's Law can be found in most Physics texts. In general when light hits the interface between two different media, some of the light will be reflected and some will be refracted, with each obeying the above laws, accordingly. This is shown in figure 2. The amount reflected versus refracted depends on several variables, including the indices of refraction and the incident angle.

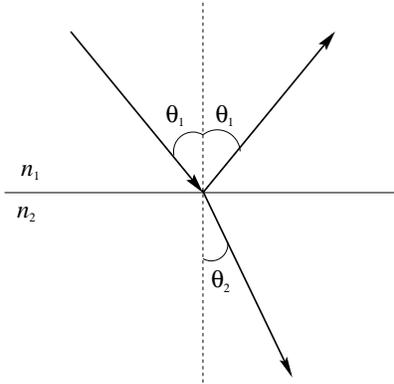


Figure 2: Refraction (and reflection) at the interface of two different media. The reflected ray obeys the Law of Reflection, and the refracted ray obeys Snell's Law.

In Snell's law, if $n_1 > n_2$, then the refracted ray will bend away from the normal, meaning that $\theta_2 > \theta_1$. As θ_1 is increased, θ_2 also increases, until $\theta_2 = 90^\circ$. Under these conditions no light is refracted into the second material and the angle θ_1 is referred to as the *critical angle* of incidence for *total internal reflection*.

3.2 Lenses

By applying the laws of reflection and refraction to mirrors and lenses, respectively, one arrives at the following expression:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \quad (2)$$

where p is the distance from the mirror/lens to the object (*object distance*) and q is the distance from the mirror/lens to the image (*image distance*); f means the *focal length* of the mirror/lens in use. The focal length is defined as the point at which all parallel rays of light meet after reflecting off of the mirror or passing through the lens. For *diverging* mirrors/lenses, it is the point from which the diverging rays appear to come. This is shown for lenses in figure 3.

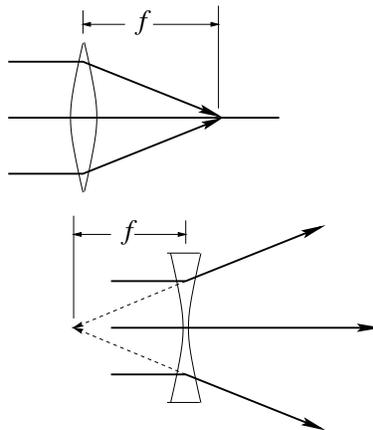


Figure 3: Parallel rays incident on a convex (converging) lens (top) and onto a concave (diverging) lens (bottom). The focal lengths are labelled f .

When multiple lenses are used, one treats one lens at a time. Equation 2 is applied to the first lens using its focal length f_1 to find the image distance q_1 , given a known object distance p_1 . This image then becomes the object for the second lens, where one needs to figure out the object distance p_2 and then use it with the focal length of lens #2 (f_2) to find the final image distance q_2 . This process repeats for as many lenses as are in the array.

4 Procedure

4.1 Lenses

1. Using the optical bench allow light from a distant light source ($p \rightarrow \infty$) to fall on a converging lens. Move the lens until a clear image is formed on the screen. The screen should be on the opposite side of the lens from the light source. Record the distance from the lens to the screen – q . Repeat this for the two other converging lenses, and record the focal lengths for later use.
2. Using a small light source (arrows), move the lens until the image of the light source is clearly focused on the screen. Record the distance from the light source to the lens (p) and the distance from the lens to the screen (q). Repeat this for three different object distances.
3. Repeat the above step for the other two lenses from the first part.
4. Using the same light source as above, place two lenses between the light and the screen. Adjust the placement of these lenses until a clear image forms on the screen. Record the distance from the light source to the first lens (p_1), the distance from the second lens to the screen (q_2), and the distance between the two lenses (D). Repeat this process four times for other lens combinations. Use the diverging lens in one combination, but only as the second lens.
5. Using any two lenses, adjust the distances until the magnification is two. Record the same information as earlier in this procedure section on your data sheet.

4.2 Mirrors and lenses

1. Position the concave mirror symmetrically to the axis as shown in figure 4 and have the central ray of the light source along the axis. Draw the incoming parallel rays and the reflected rays, as well as the reflection surface of the mirror. Using your sketch, find the focal length of the mirror.

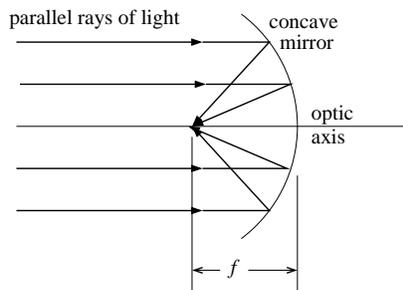


Figure 4: Parallel rays incident on a concave mirror.

2. Repeat for a convex mirror, and be sure to extend the rays back to find the focus.
3. Repeat the same procedure for the convex and concave plastic lenses.
4. Place the semicircular glass plate frosted face down on the polar graph paper so that the middle of the straight edge of the plate is at the center of the paper with the straight edge along the $90^\circ - 90^\circ$ line. Project a single ray into the middle of the straight edge of the plate (center of the paper) so that the angle of incidence in air is 10° . Record the angle of refraction. Repeat for angles of 20, 30, 40, 50, and 60 degrees. Record angles of refraction to the nearest 0.5° .
5. Project a light ray into the circular surface of the glass plate so that it is normal to the circular surface and emerges from the straight surface into air at the center. The angle of incidence is now in the glass, and the angle of refraction is in air. Start with a small angle of

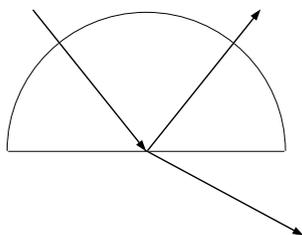


Figure 5: A light ray incident normally on a glass semi-circle showing the reflected and refracted rays.

incidence and rotate the incident ray to larger angles, keeping the ray incident at the center of the straight edge of the glass's straight edge. When the refracted ray becomes 90° , then the incident angle is the critical angle – record it. Rotate the incident ray further and note what happens.

5 Calculations

5.1 Lenses

1. Determine the focal length of each lens using equation 2. Using a percent error, compare your values to those on the lenses.
2. Using equation 2 calculate the focal length of each lens. This is done four times for each lens. Calculate a mean and error for each lens and compare to the given value.
3. Calculate the focal length of the second lens in the combination. Use the given value for the focal length of lens #1, and compare your results that obtained above. As mentioned above, you must use equation 2 twice, once for each lens, to arrive at your answer. For the data for the last measurement (magnification of 2), check the validity of the expression for the magnification of a lens

$$m = -\frac{q}{p} \quad (3)$$

For two lenses the total magnification is the product of the individual magnifications of the two lenses:

$$m_T = m_1 m_2 \quad (4)$$

A negative magnification means that the image is inverted with respect to the object.

4. For the semi-circular glass, calculate the index of refraction of it using equation 1. Calculate a mean and error for these values of n .
5. From your critical angle data for total internal reflection, calculate the index of refraction of the glass again using equation 1. Compare this value to that just obtained above.

6 Questions

1. For your magnification of 2 lenses, sketch a ray diagram to scale and label all distances clearly.
2. Is the magnification of a converging lens always less than 1? Explain.
3. Explain how optical fibers use total internal reflection.