REFRACTION AND LENSES

Purpose:

To understand properties of rays when encountering an object and the formation of images by a lens.

Apparatus:

Optics bench, ray table, slit plate, mask, light source, lenses, cylindrical lens, viewing screen, closed arrow target (object)

Background:

Light can be described in terms of waves. Light travels from a source in the same way as water waves encircle and propagate in all directions after a stone has been dropped in a pond. If we examine closely the waves traveling in the pond, circles of high and low points can be seen traveling radially outward. A vertical cross section of the water would show patterns similar to those of a wave traveling on a string. The circular rings emanating from where the stone was dropped are called wave fronts. Normally when one wants to represent the direction in which the wave is moving directed lines are drawn perpendicular to the wave fronts. These lines are called rays. Studying the properties of rays when they strike objects begins our study of geometric optics.

When a light ray encounters a boundary leading into a second medium, part of the energy passes through to the second medium, and part of the energy is sent back into the first medium. The direction of the ray is changed in both cases. When the ray is sent back into the first medium, it is reflected, and when it moves into the second medium it is refracted.

Angles of light rays are measured relative to the perpendicular or normal line at the interface. A perpendicular or normal line can be drawn from all surfaces. The direction, or the angle, of the incident, reflected, and refracted rays are measured with respect to this normal line. We will use this standard in class and for all problems.

Refraction changes the direction of light when it passes through the boundary. The change in direction is determined by the indexes of refraction of the materials which make up the boundary. The index of refraction is expressed as the ratio of the speed of light in a vacuum, c, to the speed of light in the medium, v

$$n = c/v \qquad \text{Eq. 1).}$$

The way of describing the direction change in the ray is by examining Snell's Law. Snell's Law states the relationship of the incident angle and the refracted angle of the of the ray as it passes from one medium to another and is expressed as

$$n_1 \text{Sin}(\theta_1) = n_2 \text{Sin}(\theta_2). \qquad \text{Eq. 2).}$$

Here n_1 and n_2 are the indexes of refraction of the two mediums that the ray passes through and θ_1 and θ_2 are the angles with respect to the normal at the boundary where the rays make the transition to the second medium.

In optics an object is where rays of light are said to originate. Images are formed when the light rays "converge" at some point in space. There are two types of images, virtual and real. A real image is formed when the rays actually converge at one location and the object appears to be at that location. The example of a real image is a movie projection. An image is virtual if the rays appear to converge at one location, but in reality they do not converge anywhere. An example of a virtual image is the large letters perceived through a magnifying glass.

Curved lenses produce real and virtual images. Whether or not the image is real or virtual depends upon the radius of curvature of the lens and the placement of the object. If the center of the curvature is in front of the lens surface, then the radius of curvature is said to be positive and the lens is called concave. If the center of curvature is behind the lens surface, then radius of curvature is negative and the lens is called convex. A relationship holds for the position of the image, object and the focal point distance and is expressed as

$$\frac{1}{s}+\frac{1}{s'}=\frac{1}{f} \qquad \text{Eq. 4).}$$

Here s is the object distance, s' is the image distance and *f* is the focal length of the lens. A sign convention must be used in order to insure accurate results. The sign convention is as follows:

- s is always + (positive).
- s' is + if the image is on the opposite side of the lens from the object.
- s' is – (negative) if the image is seen by looking through the lens at the object.
- *f is* + for a converging lens.
- *f* is - for a diverging lens.

Lenses can also affect the size of the image created. The magnification for thin lenses turns out to be described the same way as for mirrors and is given by

$$M=\frac{h'}{h}=\frac{-s'}{s} \qquad \text{Eq. 5)}$$

Here M is the magnification, h' is the image size, and h the object size, s' is the distance from the image to the lens, and s is the distance from the object to the lens. Note that the - sign of h' indicates whether or not the image is inverted as compared to the object.

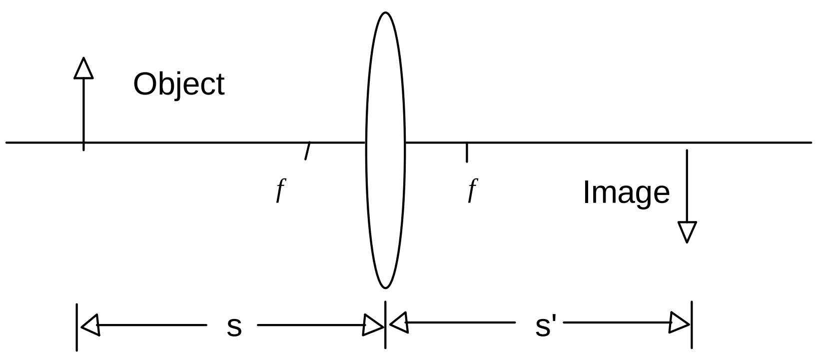

Figure 1.) This is an illustration of a converging lens with the image and object distances. The lens has a focal length of ***f****. In the case drawn both S and S' are positive. The image is real so a screen placed at the real image distance should find a focused image just like a movie projection in this case.*

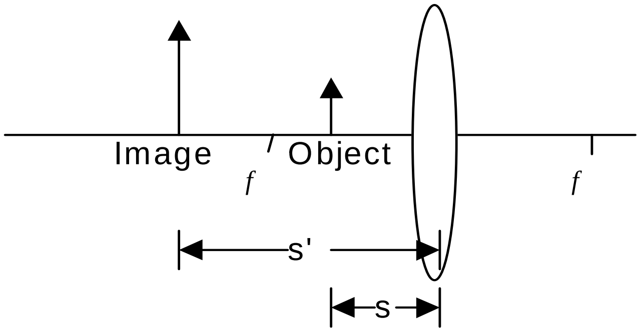

Figure 2.) This is another illustration of a converging lens. In this case the object is within the focal length of the lens so S is positive and S' is negative. This is just like the magnifying glass example mentioned above.

In the first part of the lab you will see the effect of refraction of a beam of light. In the second part you will measure image and object distances for lenses. The cylindrical lens allows refraction noticeably occur at only one interface as the light beam passes through the Lucite.

Setup:

Part 1:

Set-up the equipment as seen in figure 3 below. We will use this set up to determine the index of refraction for the Lucite cylindrical lens. We will assume that the index of refraction of air is one. Starting with an incident angle of 0 degrees and observing every 10 degrees, record the incident and refracted angles of the ray. This procedure should be done twice at the exact same angles of incidence. The two values of the refracted angles, for the corresponding incident angle, should be averaged together. With this data use the computer to create a graph of the sine of the incident angle (y) versus the sine of the refracted angle (x). Determine the slope of this line.

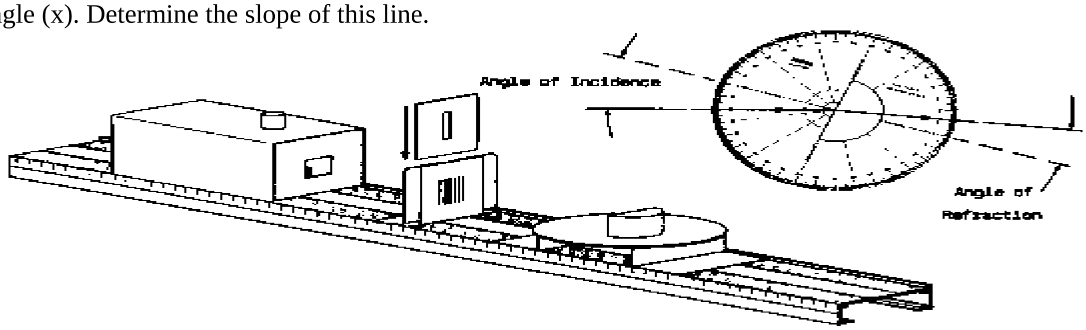

Figure 3. Illustration of Snell's Law experiment.

In the above experiment we looked at the refraction of a ray as it passes from air into the Lucite lens. The Lucite lens has an index of refraction that is greater than air. This time repeat the above procedures but have the incident ray strike the curved surface of the cylindrical lens. To do this, rotate the ray table by 180 degrees. Figure 4 illustrates how the incident and refracted rays are to be read in this part of the experiment. When light passes from a medium that has a high index of refraction to a medium with a low index of refraction there may be an incident angle in which the light is not transmitted through to the second medium. In this case the refracted angle could be said to be 90 degrees or greater. If you pay close attention to the reflected ray during this part of the experiment you will notice that when the critical angle is reached and total internal reflection occurs the reflected ray becomes very bright indicating all the light is reflected and none refracted. Carefully note the angle at which the incident ray is completely reflected internally in this experiment and stop taking data. Make another graph of sine of the angle of refraction (y) versus the sine of the angle of incidence (x). Determine the slope of this line. Compare this with the slope from the beginning of part 1.

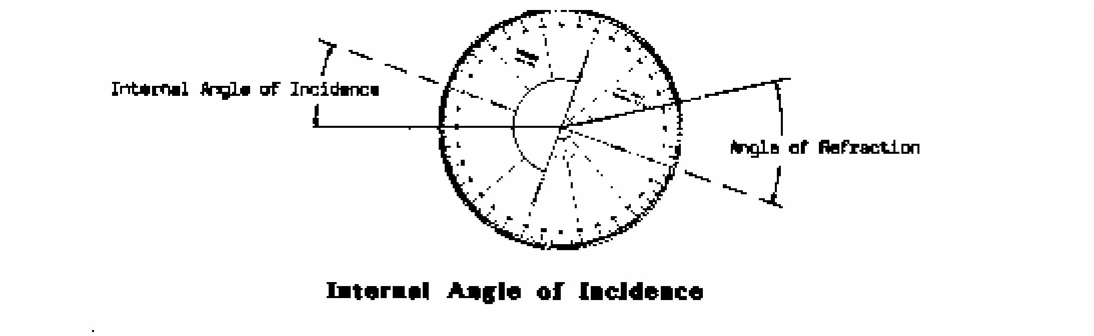

Figure 4. Illustration of how to determine the incident and refracted angles for the second part of the Snell's Law experiment.

Part 2:

Place the target arrows over the light source. Place a lens in front of the light source at a distance greater than its focal length. Place the viewing screen behind the lens and change its position until a clear image is formed on the viewing screen. Measure the distance the object is from the lens, this is the object distance, and the distance the view screen is from the lens is the image distance. Measure the image height and the size of the object. Using equations 4 and 5, determine the focal length of the lens and the magnification. Compare the focal length written on the lens with that back-calculated from your data, and compare the magnification calculated with image and object sizes with the magnification calculated with the image and object distances. Do these procedures for the 200mm and the 100 mm lens.

Part 3:

Construct a simple telescope by placing the two lenses at a separation equal to the sum of their focal lengths as shown in figure 5. Calculate the magnification M = F/*f* and compare to what you see when you look through the smaller lens (eyepiece).

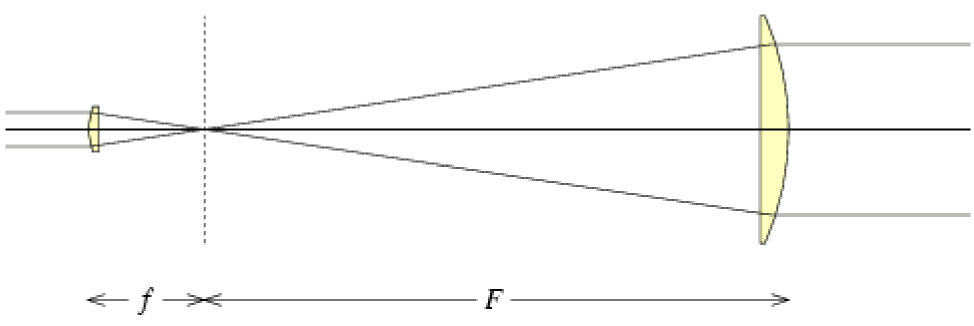

Figure 5. Simple refraction telescope

Part 4:

Construct a simple microscope by moving the telescope lenses from the before slightly apart from one another as show in the figure 6. Place an object just beyond the focal length of the smaller focal length, objective lens and look through the microscope to see the magnified image of the object.

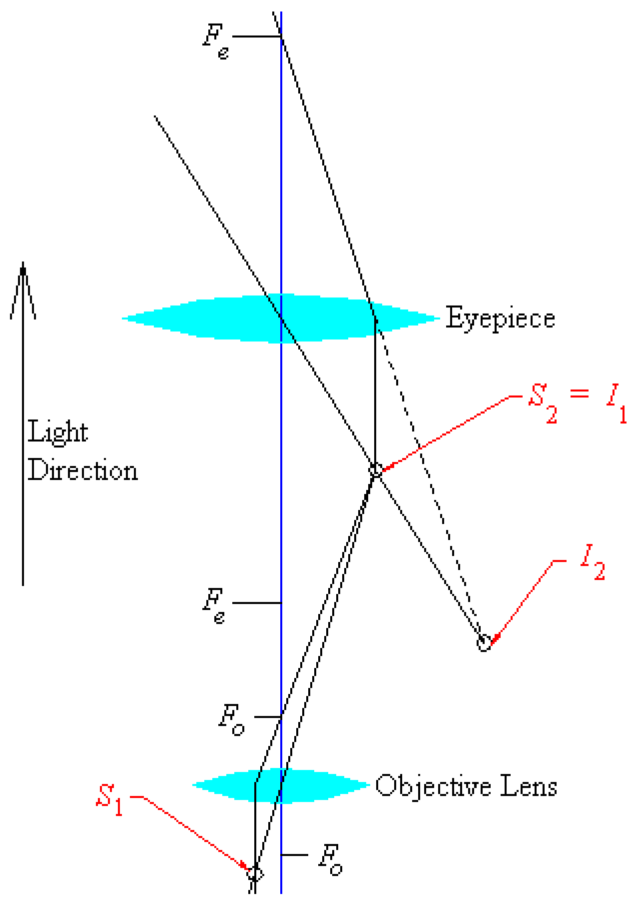

Figure 6: A simple microscope with F_0 as the focal length of the objective lens and F_e as the focal length of the eyepiece. S_1 is the position of the object being observed.

Questions:

1.) Is the index of refraction for the Lucite lens when the light ray travels from air into the Lucite lens the same as for the light traveling from the Lucite lens to air?

2.) What happens to the light ray, in the Lucite to air part of the experiment, at the angle where it no longer passes into the air?

Problems:

1.) A ray of light is incident on the surface of a block of clear ice at an angle of 40^0 with the normal. Part of the light is reflected and part is refracted. Find the angle between the reflected and refracted light rays.

2.) Two light pulses are emitted simultaneously from a source. Both pulses travel to a detector, but one passes first through 6.2 m of ice. Determine the difference in the pulses' time of arrival at the detector.

3.) A virtual image is formed 20 cm from a convex lens, having a focal length of 40 cm. Find the position of the object.

4.) What type of lens is required to form an image of an object placed 10 cm behind the lens, on a wall 2 m from the mirror? What is the magnification of the image?