REFLECTION & REFRACTION

OBJECTIVE: To study and verify the laws of *reflection* and *refraction* using a plane mirror and a glass block. To see the ***virtual images*** that can be formed by the reflection and refraction of light.

THEORY: Two common ways that the path of light gets bent are reflection and refraction. Both usually occur when light is traveling in one medium and then hits a boundary with a different medium. For example, when light traveling in air hits a piece of glass, some of the light is reflected back into the air and most of the remaining light is refracted into the glass. (A small amount of light energy may be absorbed by the glass.) The Law of Reflection and the Law of Refraction (more commonly called Snell's Law) predict the amount of bending that the light undergoes upon reflection and refraction.

GENERAL PROCEDURE: We will determine the path of light rays by sighting along pairs of pins stuck through paper into the soft board. By connecting the holes left in the paper by the pairs of pins with a straight line, the paths of the light rays can be recorded. The angles and distances can then be measured with protractor and ruler. The results of this experiment will depend on the accuracy and neatness of your work. A sharp pencil is required since a dull point may throw off an angle by as much as five degrees. Before any pins are stuck in the paper, the reflecting and refracting surfaces of the object should be outlined on the paper with a sharp pencil approximately in the center of the paper.

Part 1: Reflection and Image Formation By a Plane Mirror

THEORY: The Law of Reflection states that if the incoming light forms an *angle of incidence* (θ_i) with a line normal to the surface, then the light reflected off the surface will form an *angle of reflection* (θ_r) with the normal line which is equal to the angle of incidence. This is shown in Figure 1.
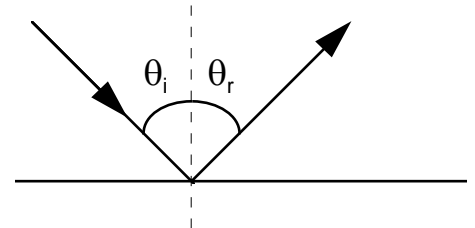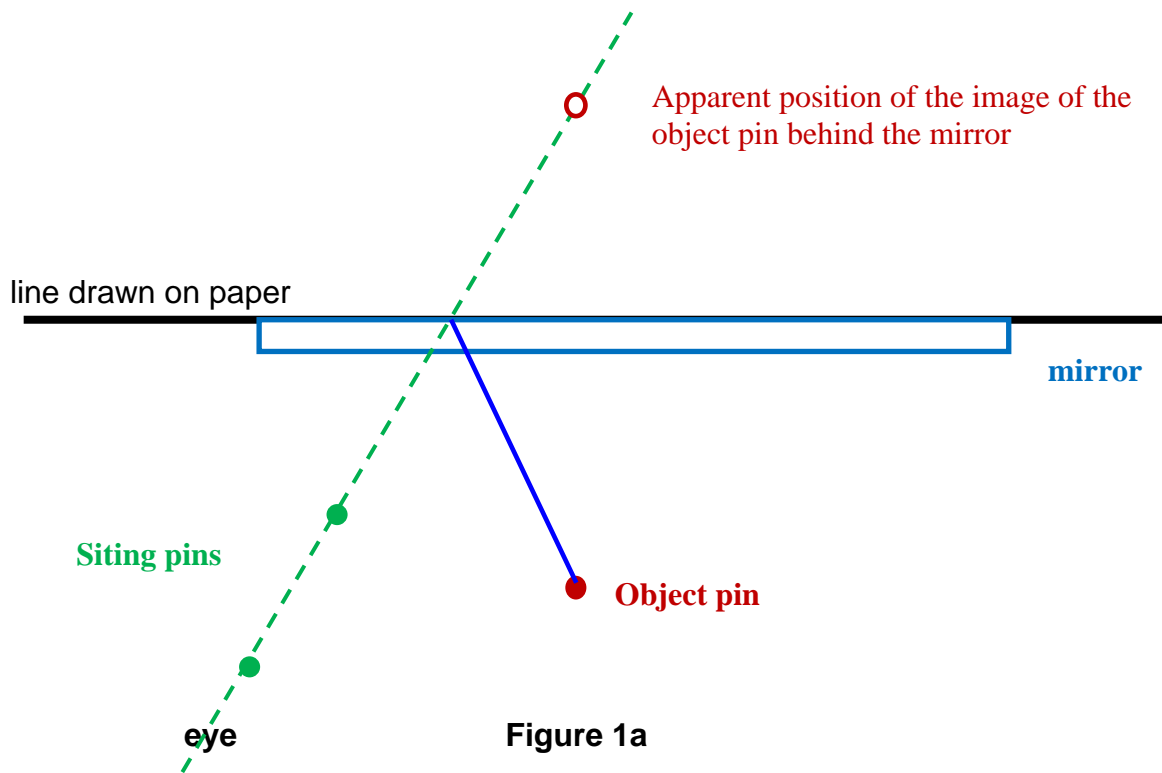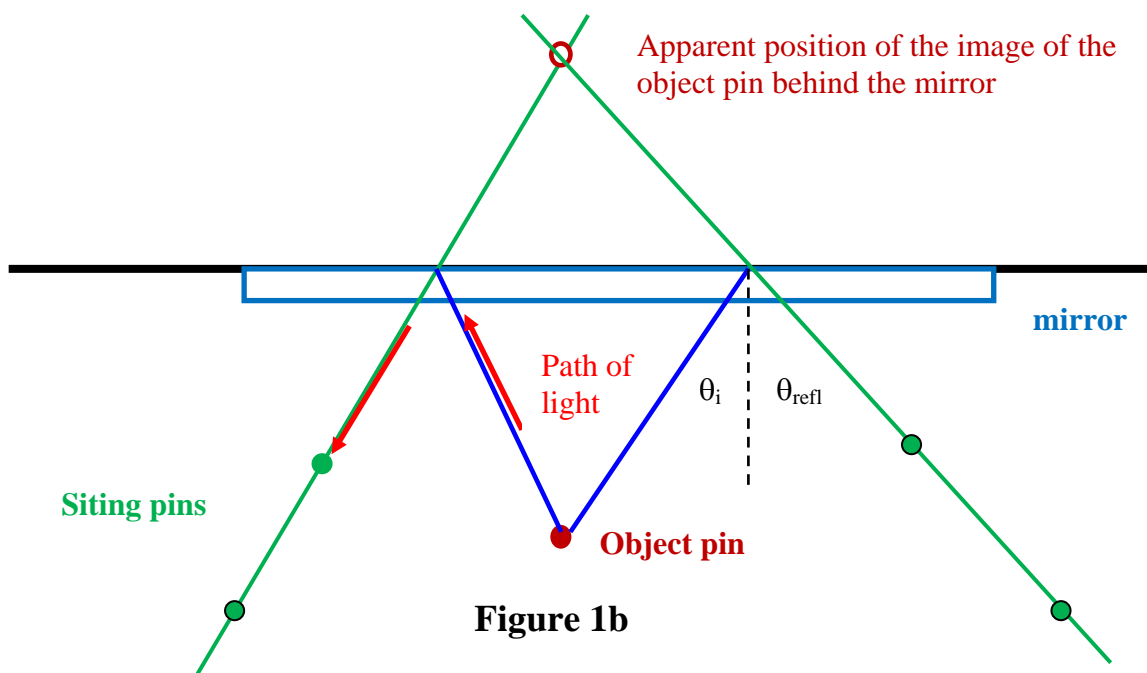

Fig. 1

PROCEDURE:
1. On a piece of paper draw a line across the middle of the paper to represent the reflecting surface of the mirror. Place the paper on the soft board.

2. Place the mirror on the paper with the **back of the mirror on the line** for the reflecting surface. Push a pin into the paper at a point a couple of inches (about 5 cm) from the mirror. This pin will be your **OBJECT**, and the location of its IMAGE will be determined.

3. Try determining the position of the IMAGE of the pin in the mirror by pointing with your finger to the place it seems to be. This should be somewhere behind the mirror, and so your finger should also be behind the mirror. This is the position we will try to more accurately determine with the following procedure.

line drawn on paper

Apparent position of the image of the object pin behind the mirror

mirror

Siting pins

Object pin

eye   **Figure 1a**

4. With your eye level with the surface of the paper, determine a reflected ray by lining up **two siting pins** with the IMAGE of the first pin in the mirror. Use the base of the pins, not the tops, in doing the aligning. When you have them lined up, push the pins into the paper. See Figure 1a above. Your partner should determine a second reflected ray in the same manner on the other side using a second pair of pins.

5. Interchange positions with your partner so you can check your partner's pins to see if they align with the image.

6. Remove the pins and mirror. In order to locate the position of the IMAGE on your paper, **draw two lines**, see Figure 1b below, one through each pair of pinholes. Be sure you extend these lines to where they meet behind the mirror. The point of intersection is the location of the IMAGE.

Apparent position of the image of the object pin behind the mirror

mirror

Path of light

θ_i θ_{refl}

Siting pins

Object pin

Figure 1b

7. Replace the mirror (with the back side of the mirror on the line), and repeat steps 4, 5, and 6. You should now have **four** lines that meet approximately at the same place, the image location.

8. In order to actually follow the path of the light, draw two lines each beginning at the OBJECT [just like the light does] to the intersection of the mirror with each of the lines previously drawn. The light actually begins at the OBJECT pin and bounces off the mirror and then proceeds just like it came from the IMAGE position behind the mirror. Draw **red arrows** to indicate this path.

9. Measure and label the angles of incidence, θ_i, and reflection, θ_{refl}, for the light rays. Theoretically, they should be equal. Are they (within experimental error)?

10. Measure and label the object and image distances, i.e., the distances from the object to the mirror and the image position to the mirror. Theoretically, they should also be equal. Are they?

Additional thoughts: Do your two eyes work in this way to give you depth perception? If you flexed the mirror so it seamlessly bent inward or outward, how would the image appear?

REPORT:
1. Does your experiment appear to support the Law of Reflection?
2. What kind of image is formed by a plane mirror. a *real* or *virtual* image? (A real image can be seen on a piece of paper if the paper is placed at the location of the image. A virtual image cannot be seen on a piece of paper. It only appears that light comes from the image to our eyes.)
3. Where is the image located?

Part 2: Refraction and Image Formation By a Plane Surface

THEORY: Light travels at different speeds in different materials. In vacuum, the speed of light is 3×10^8 m/s, and in other materials it is slower. The index of refraction is defined to be the speed of light in vacuum, called c, divided by the speed of light in the material, v; and since the speed of light in the material is always slower than in vacuum, the index of refraction of transparent materials is always greater than 1: $n \equiv c/v$. Snell's Law states that if the incoming light is traveling in a medium with an index of refraction of n_1 and forms an angle of θ_1 with a line normal to the surface as shown in Figure 2, then the light that enters the second medium of index n_2 will form an angle of θ_2 with the normal line where the refracted angle is given by the equation:
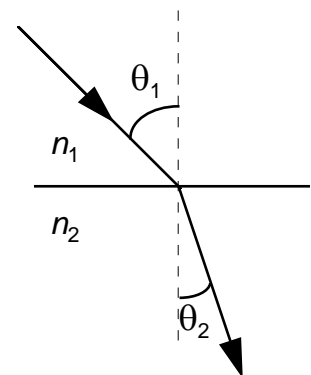
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Fig. 2

Snell's Law predicts that the light will get bent toward the perpendicular line if $n_1 < n_2$ (such as for light in air entering glass) and will get bent away from the perpendicular line if $n_1 > n_2$ (such as for light in glass entering air).

PROCEDURE:
1. Place a fresh piece of paper on the soft board. Lay the glass block down on the paper near one end. Outline the glass block so you may remove it and then replace it at the same location.

2. Place one pin right next to a long side near the middle of the block on the side nearest the edge of the paper. This pin will be our OBJECT. Since it is touching the glass block, we can assume that it is actually just in the glass block.

3. Now view this pin from the opposite side. See Figure 2a below. Again look through the glass and point with your finger to where the IMAGE of the pin seems to be. This is the position we will try to determine more accurately.

Object pin

Glass plate

siting pins
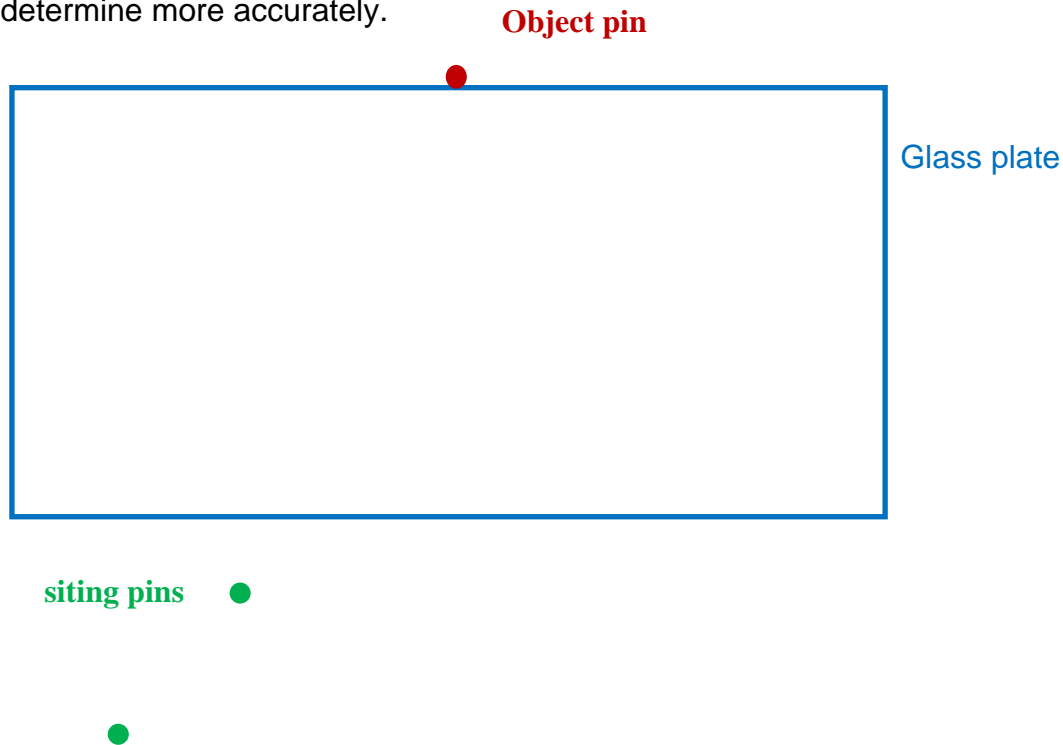
eye   Figure 2a

4. Align two pins with the IMAGE of the pin in the glass (just as you did in the previous part). Your partner should do the same on the other side. Do this again, so you each have two pairs of aligning pins.

5. Now remove the pins and glass block from the board, and draw the sighting lines connecting the sets of two pinholes you and your partner made. Extend the lines to the area where the glass block was. Where the lines intersect is the IMAGE location. You probably will observe that sighting lines that have smaller angles of incidence intersect farther away from the front of the block.

6. Measure the distance from the front of the block to the OBJECT pin. This is the 'real depth' (d_{real}) of the pin in the glass. Measure the distance from the front of the block to the IMAGE location. This is the 'apparent depth' (d_{app}) of the pin. From theory the following formula can be derived as long as angles are small:

$$d_{app} = d_{real} / n$$

where n is the index of refraction of the glass. (The value of n indicates how much bending the glass does.)   Because this holds only for small angles, measure the apparent distance using sighting lines with small angles of incidence. From this expression, calculate the index of refraction of the glass. Estimate the uncertainty in this value based on the experimental uncertainty in locating the image position.

7. Now determine the actual paths of the light rays: draw a line from the object pin to the place where the ray emerges from the glass for each set of pins. Note how the light is bent at the air-glass interface.

8. Measure the angles θ_1 and θ_2 for at least two of the light rays and use Snell's Law to calculate values of the index of the glass. Average your values.

REPORT:
1. Is the image formed by the refraction of the light real or virtual in this case?

2. Where is the image located?

3. Compare your two values for the index of refraction of the glass from Steps 6 & 9. Are they close? Are they reasonable?

4. Does the light bend toward the perpendicular line or away from it as it leaves the glass and enters the air? Is this consistent with the values of refractive index for the glass and air?

5. Describe how the "bending" of the light behaves as your angle of looking increases: that is, does the amount of bending depend on the angle you are looking at? (This is the reason lenses work!)

6. Does water do the same to light that glass does? Justify your answer by referring to some real-life example.


Part 3: Reflection and Refraction

THEORY: In general, a beam of light incident on the boundary between two optical materials will undergo BOTH reflection and refraction. (The amount of light that is reflected or refracted depends upon the refractive indices of the materials and the incident angle of the beam.) If other boundaries are encountered by the first reflected and refracted beams, these beams themselves undergo additional reflections and refractions.

PROCEDURE: On the next page, there are two drawings of a cross-section of a piece of glass. One can be used as a spare in what follows.

Starting with the given incident ray, use Snell's Law and the Law of Reflection to determine, and then trace, the path of light within the glass until there are **three** refracted rays leaving the glass. You will need to use a protractor, a straight edge, and a pencil with a sharp point.

After you have finished, check your work by placing the piece of glass on your paper, aligning the laser so that the beam is directly over the incident ray on the paper, and then seeing whether the actual light rays coming from the glass block are where you predicted them to be. While doing this, mark where the light rays actually do exit the block so that your instructor can see how good your predictions were.

For the glass, $n = 1.57$.

Incident ray $\implies$
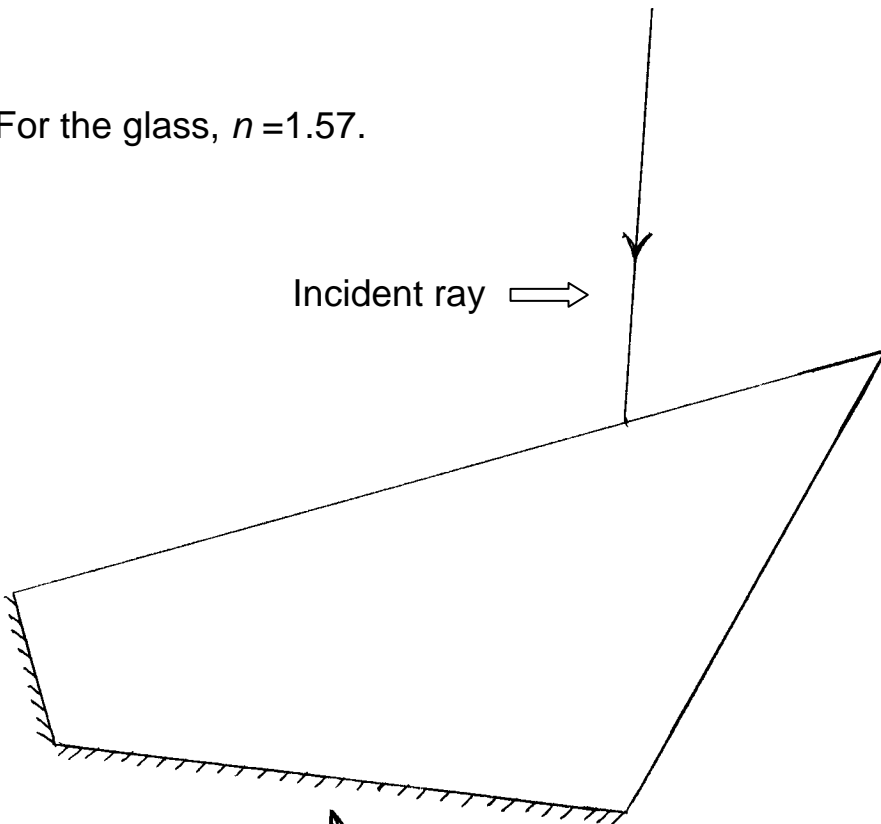
Only reflection occurs at the silvered surfaces.

Incident ray $\implies$