Physics 215 - Experiment 13

Geometric Optics

Fig. 13-1 Geometric Optics Equipment

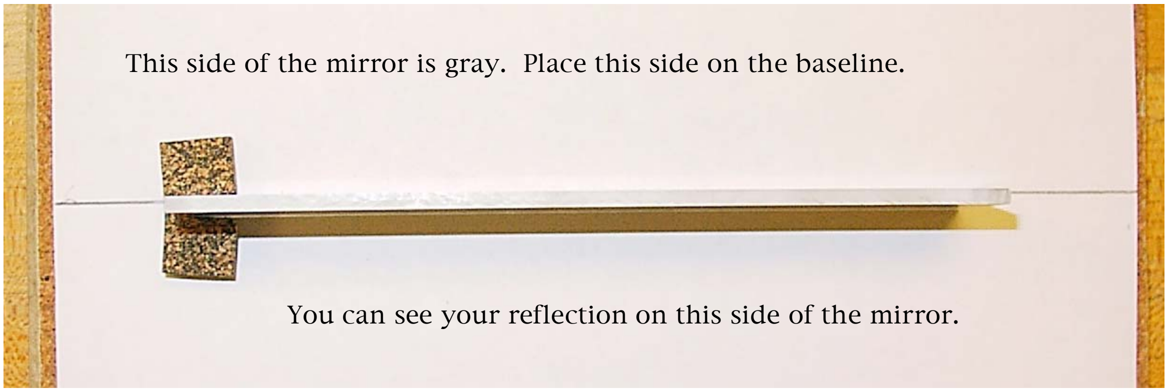

Fig. 13-2 Mirror Placement: The "Plexi-Ray Kit" contains a small piece of cork or ring with a notch in it. Use this cork to stabilize the mirror during your experiment.

Equipment

Plexi-Ray Kit
Cork Board
Protractor
30-cm Ruler
Paper

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Advance Reading

Urone, Chapter 24:

Sections 24-1 through 24-4.

Objective: The objective of this experiment is to study the behavior of light using the ray model.

Theory: The **Law of Reflection** states that when light reflects from a flat surface, the angle of reflection equals the angle of incidence:

$$\theta_i = \theta_r \qquad \text{(Eq. 13-1).}$$

When light passes from vacuum into a transparent medium, it slows down. The ratio of the speed of light in vacuum to the speed of light through a transparent medium is the **index of refraction, n**, of that medium. $n \geq 1$ at all times since

$$n = c/v \qquad \text{(Eq. 13-2).}$$

The **Law of Refraction (Snell's Law)** describes the behavior of a ray of light that passes from one medium into another:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad \text{(Eq13-3)}$$

where n_1 and n_2 are the indices of refraction for the two media.

When a **critical angle**, θ_c, is reached, θ_2 equals 90°, and **total internal reflection** will occur.

Parallax is the apparent displacement of an object as seen from two points that are not on a straight line with the object. This means that the object and two different observation points are not collinear. The angle θ in Fig. 13-3 represents the parallax effect.

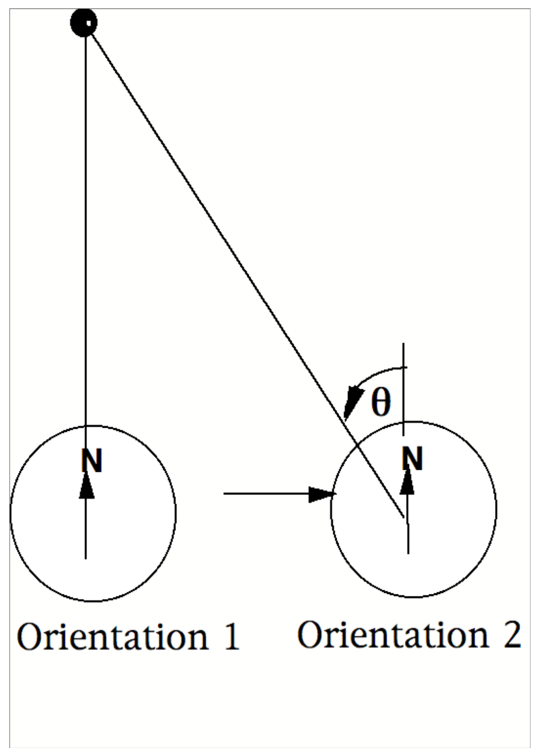

Fig. 13-3: Parallax - One Object

The effect is larger when the object is nearer. The effect is very useful for determining the position of the virtual image.

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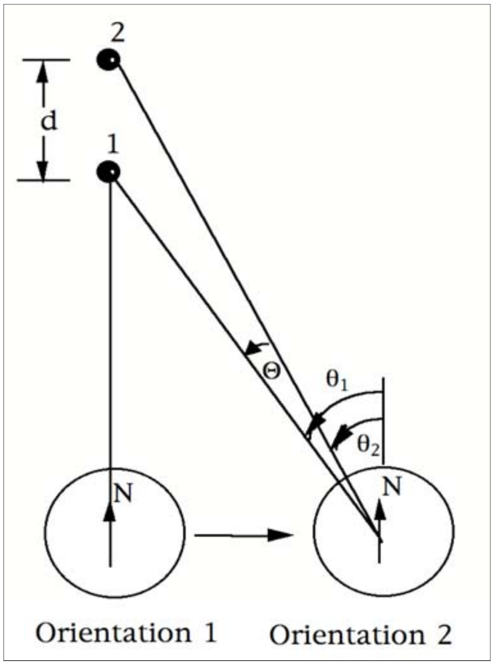

Fig. 13-4: Parallax - Two Objects

Consider two objects that are aligned from your initial position (they appear to be one object). When you change your position, each object will appear to be displaced, but by a different amount. The objects appear to separate some angular displacement $\Theta = \theta_2 - \theta_1$ (Fig. 13-4).

For this part of the experiment you will use the *reflection of a pin* (a virtual image) as one object and *a second pin* (real) as a second object. If the second pin is placed at a location other than the location of the virtual image, note that when you change your position there is a shift in the apparent position of the two objects. You will see two images (Fig. 13-4). There are two possibilities:

1) The pin is in front of the virtual image. Parallax is larger for the pin.

2) The pin is behind the virtual image. Parallax is smaller for the pin.

If the pin is placed at the same location as the virtual image and you change your position (orientation), there will be no change in the apparent position of the two objects (i.e., there is no separation of the objects). You will see only one image, thus eliminating parallax.

Procedure Notes:

- All arrangements must be perpendicular to you.
- When placing more than one pin, separate them as much as possible (e.g., one pin close to the mirror, the other pin close to the edge of the paper).
- When aligning objects and images, close the eye that is closer to the center of the paper.
- When drawing specified lines, "normal..." requires the use of a protractor to measure 90°. Do not estimate.
- The reflective surface of a mirror is typically protected by a layer of glass. Place the reflective surface of the mirror, not the glass, on the baseline (Fig. 13-2).
- All angles are measured with respect to the normal.

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Procedure

Part 1: Parallax

1. Draw a line across the center of a sheet of paper (baseline). Draw a line normal to the baseline down the center of the paper (Fig. 13-5).

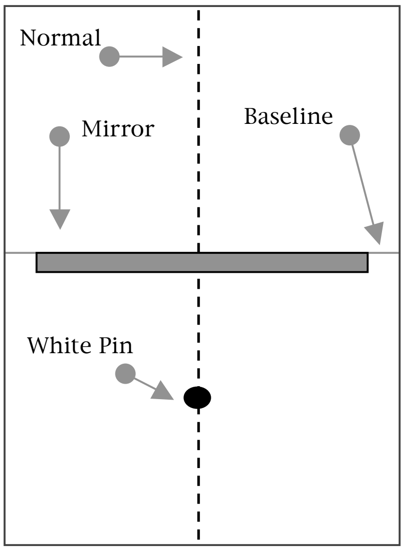

Fig. 13-5: Parallax

2. Place the paper on the corkboard and the mirror on the baseline. Place a white pin midway on the normal in the front of the mirror. The image of this pin will be *object 1*.
3. Place a second pin on the normal behind the mirror. This pin will be *object 2*.
4. Observe from an orientation to the right or left of the normal. If *object 1* and *object 2* are not aligned, move *object 2* towards or away from you, along the normal, until they are aligned.
5. Measure and record the distance from the mirror to *object 1*, d_o, and the distance from the mirror to *object 2*, d_i.

Part 2: Image from a Mirror

6. The image seen in any plane mirror (flat mirror) does not appear to be at the surface of the mirror, but rather, to be located some distance behind the surface. This image is known as a **virtual image**. The image appears to be located the same distance behind the mirror as the object is in front of the mirror.

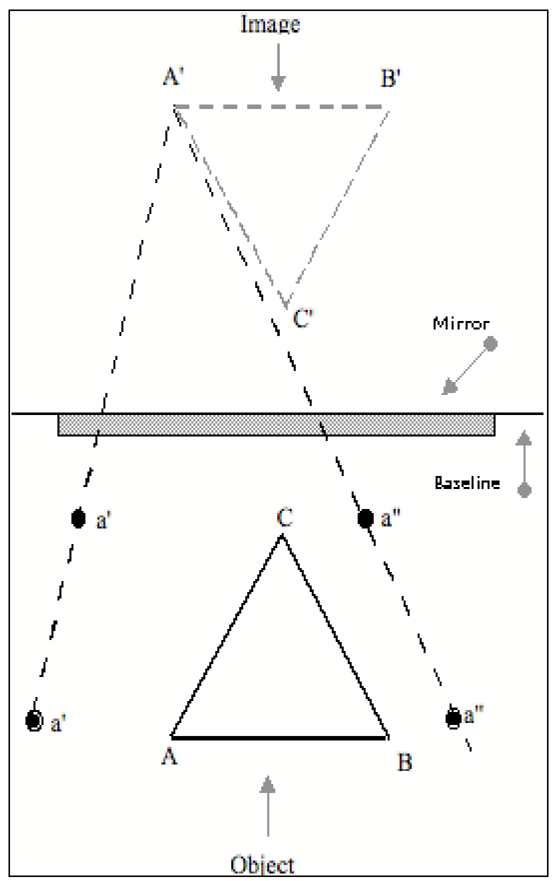

Fig. 13-6: Image From a Mirror

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7. Refer to Fig. 13-6. Draw a baseline across the center of a sheet of paper. Place the triangular plexiglass in the center of the front half of the paper, trace around it, and return it to the kit.
8. Label the vertices of the triangle *A, B,* and *C*. Place the paper on the corkboard and the mirror on the baseline.
9. Place a white pin at *A*; choose a point of observation to the left and place two pins (sighting pins) *aligned with the image* of the point *A* pin. Label the positions of the sighting pins *a'*.
10. Remove the sighting pins, choose an observation point to the right, and *align the pins with the image* from this position. Mark the sighting pin positions as *a"*.
11. Repeat for vertices *B* and *C* (obtain two sight lines for each vertex).
12. Remove all pins and the mirror. Place the paper on the table and draw a line through the two *a'* points across the length of the paper. Repeat for each pair of points. Mark the intersection of the *a'* and *a"* lines as *A'*. Repeat for *B'* and *C'*.
13. Connect the points *A', B',* and *C'*.
14. Measure these dimensions: $\overline{A'B}$, $\overline{BC}$, AND $\overline{A'C'}$.
15. Compare to the object triangle dimensions.

Part 3: Reflection

16. Draw a baseline across a sheet of paper, near the top. Draw a normal line down the center of the paper. Draw a line to the left of the normal (incident line) with an angle θ_i between 20° and 70° (Fig. 13-7).

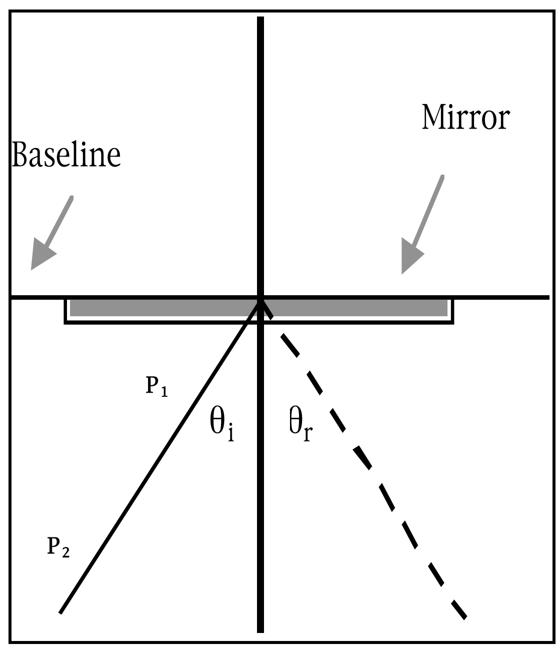

Fig. 13-7: Reflection

17. Place the paper on the corkboard, the mirror on the baseline, and two white pins positioned on the incident line. Label these pin points P_1 and P_2.
18. Look at the mirror from the right side of the normal so that you can

see the reflection of the first two pins. Adjust your position so that the image of the white pins is aligned.

19. Align two pins on the paper so that they are aligned with the image of the white pins. Label these two points P_3 and P_4.
20. Return the mirror and pins to the kit; place the paper on the table. Draw a line connecting points P_3 and P_4 to the baseline. Measure and record θ_i and θ_r.
21. Your partner will repeat this procedure for a different θ_i.

Part 4: Refraction

22. Place the plexi-glass square at the center of a sheet of paper and trace around it.

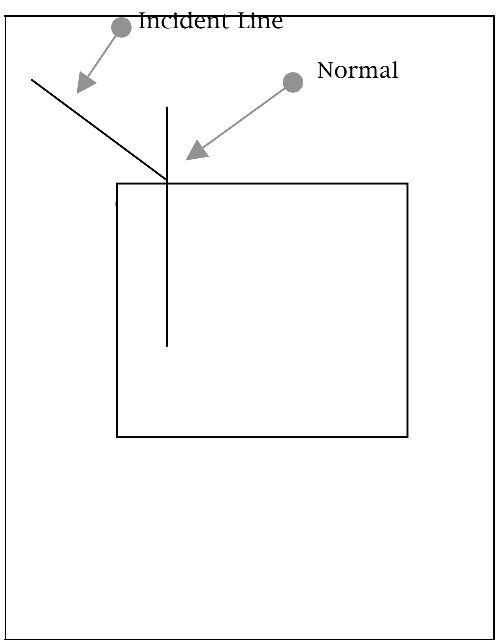

Fig. 13-8: Refraction - Initial

23. In the upper-left corner of the traced square, draw a line normal to the square, about 1-cm from the corner (Fig. 13-8).
24. Draw an incident line left of the normal (θ_i between 20° and 70°). Place the paper on the corkboard, the square on its traced outline, and two white pins on the incident line. Label their positions P_1 and P_2.
25. Look *through* the plexi-glass square from the edge opposite the pins.
26. Adjust your position until the two white pins are aligned, then place two sighting pins in the paper that align with the two white pins. Label these points P_3 and P_4.
27. Return the pins and the plexi-glass to the kit; place the paper on the table.

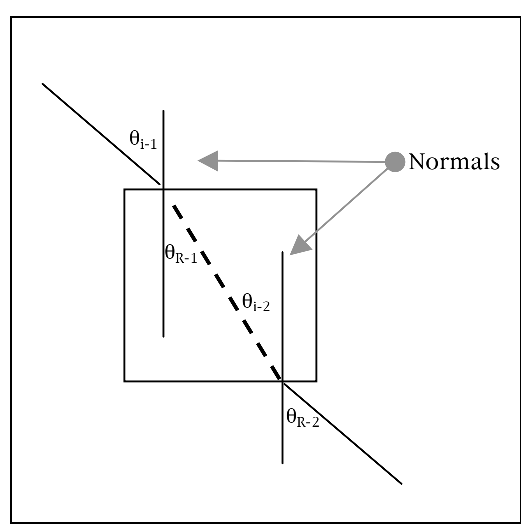

Fig. 13-9: Refraction - Final

28. Draw a line through P_3 and P_4 to the edge of the square, then a line normal to the square through this point.
29. Draw a line inside the square to connect the normals (Fig. 13-9).
30. Measure and record each θ.
31. Consider the law of refraction. As light enters the plexi-glass it bends towards the normal since it enters a medium whose index of refraction is greater than the index of refraction of the medium it is leaving (air). The light then travels through the plexi-glass and exits the other side. The light now bends away from the normal since it enters a medium whose index of refraction is less than the index of refraction of the medium it is leaving.
32. Therefore, $\theta_{i-1}=\theta_{R-2}$ and $\theta_{R-1}=\theta_{i-2}$.
33. Calculate the index of refraction of the plexi-glass using the average values.
34. Calculate the speed of light through the plexi-glass.
35. Your partner will repeat for a different value of θ_i.

Part 5: Total Internal Reflection

36. Place the plexi-glass triangle in the center of a sheet of paper and trace around it. Draw a line normal to the bottom edge (Fig. 13-10), about 1 cm from the corner. Place the paper and triangle on the corkboard; place two white pins on the normal line, with their positions labeled P_1 and P_2.

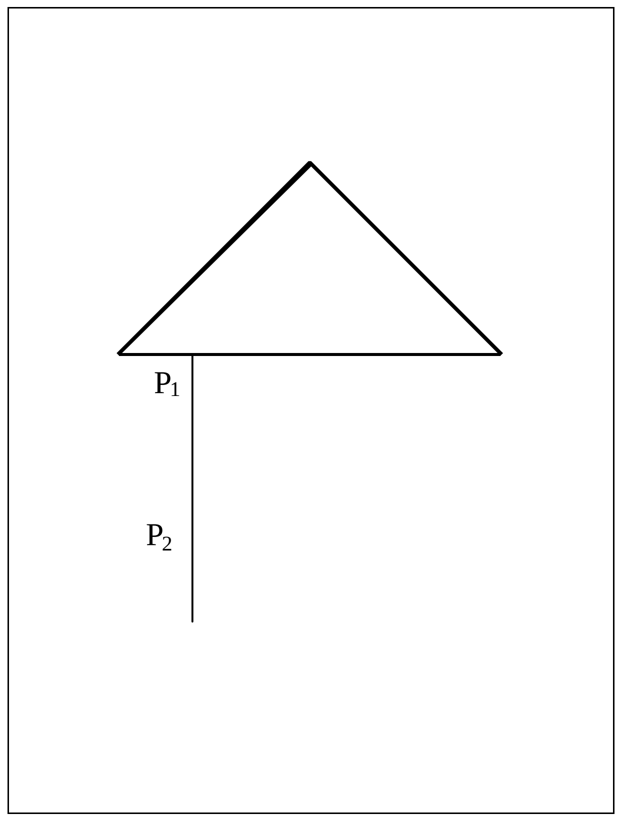

Fig. 13-10: Internal Reflection

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37. Look through the triangle and adjust your position until the two white pins are aligned. Then align two pins with the white pins *as viewed through the plexi-glass*. Label these positions P_3 and P_4.
38. Return the triangle and pins to the kit; place the paper on the table.
39. Draw the path of the light ray by:

- extending the normal to the far side of the triangle
- reflect to the opposite side
- reflect again and exit the bottom edge along a line that should connect P_3 and P_4.

40. Draw normals where the light ray intersects the sides of the triangle.
41. Measure θ_i and θ_R at both sides of the triangle.
42. Calculate θ_c.

Questions

1. What is the shortest height a plane mirror must be so that a person who is 1.5 meters tall is able to see his or her whole body?