Name: ______________________________ Section: __________

Lab Partner: ______________________________ Date: ______________

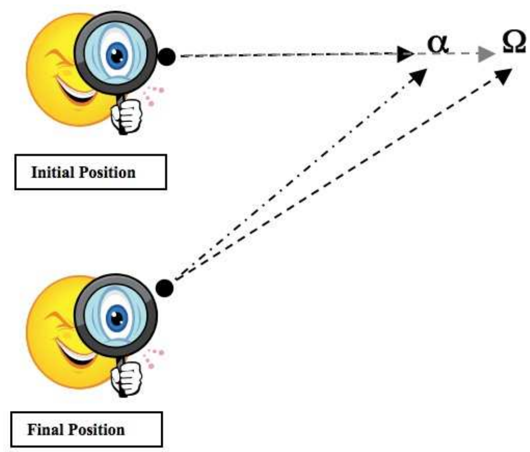
Worksheet - Exp 21: Geometric Optics

(Attach all experimental diagrams to this datasheet.)

Objective: To study the behavior of light using the ray model.

Theory: **Parallax** is *the effect whereby the position or direction of an object appears to differ when viewed from different positions.* This means that the object and the two observations points are not collinear.

Since a virtual image cannot be projected on a screen, it can be difficult to determine its location. Consider an object whose image is observed in a mirror. The image is a virtual image. To determine the position of a virtual object, one can align a real object (pin) with a virtual object (image of a different pin). If the observer changes their position and the two objects do not separate, the real and virtual objects are in the same location.



The **Law of Reflection** states that when light reflects from a smooth, flat surface (*e.g.*, a plane mirror), the angle of incidence equals the angle of reflection: $\theta_i = \theta_r$

The **Law of Refraction (Snell's Law)** describes the behavior of a ray of light that passes from one medium into another: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

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

Total Internal Reflection is a special case in which light is unable to cross the boundary between the two media. Consider Eq. 21.3 and a specific combination of media, such as glass and air, with light passing through a medium of higher n (n_1) into a medium of lower n (n_2). As θ_1 increases, θ_2 increases more rapidly. θ_1 can reach a value that results in θ_2 being equal to 90°. When this happens, the light will not exit the medium. It will be totally internally reflected. This θ_1 angle is called the *critical angle*, θ_C: $\theta_1 = \theta_C \quad \text{when} \quad \theta_2 = 90°$

Mirror Placement: The "Plexi-Ray Kit" contains a small piece of cork or plastic to stabilize the mirror during your experiment. The mirror must sit on the paper, not on the stabilizer.

PROCEDURE

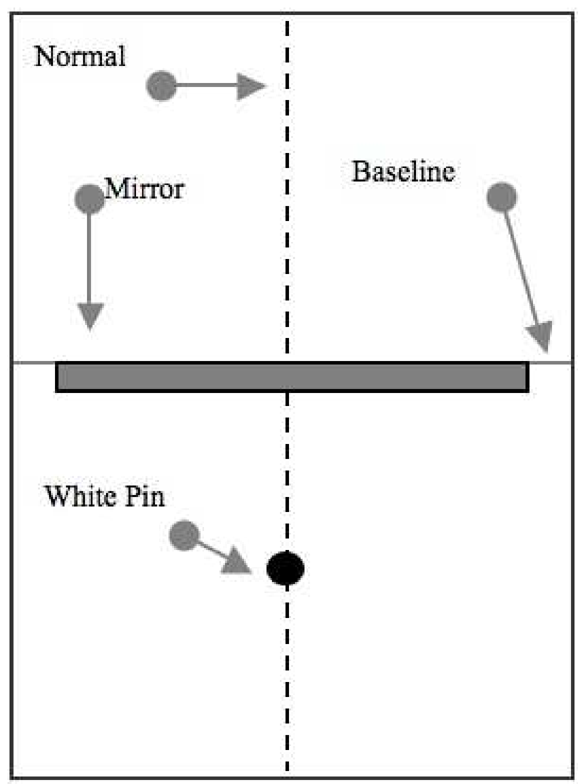
1. Read through *Step 6* before beginning. All arrangements (paper) should be aligned with the edge of the table.
2. Measure all normal lines with a protractor to ensure they are 90°; do not estimate. Draw the lines long enough to allow accurate measurements using the protractor. Do not fold the paper!
3. 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). This will increase accuracy and improve your results. When aligning objects and images, close one eye.

Part 1: Parallax

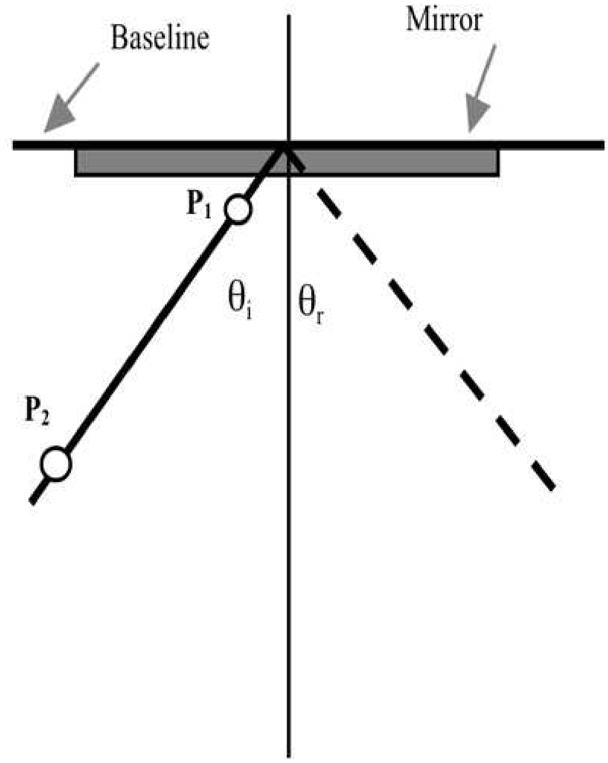
4. For *Part 1*, you will use a *virtual image* (the mirror image of a pin); use the image of the white pin as the first object and *a real object* (a color pin) as a second object. If the second object is placed at a location other than the location of the first object, note that when you change your position there is a shift in the apparent position of the two objects. You will see two images; they will not be aligned.
5. When parallax occurs, there are two possibilities:
   - The pin is in front of the virtual image. Parallax is larger for the pin.
   - The pin is behind the virtual image. Parallax is smaller for the pin.
6. If the pin is placed at the same location as the virtual image and you change your position, there will be no change in the apparent position of the two objects (*i.e.*, there will be no separation of the objects). You will see only one image, thus eliminating parallax.
7. Refer to Fig. 21.6. Draw a line across the center of a sheet of paper (baseline) and a line normal to the baseline down the center of the paper.
8. Place the paper on the corkboard and place the back of the mirror on the baseline. Place a white pin mid-way on the normal in front of the mirror. The image of this pin will be *object 1*.
9. Place a color pin on the normal behind the mirror. This pin will be *object 2*.
10. 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. (Your partner will help you stay on the normal.)
11. Measure and record the distance from the mirror to the white pin, d_0, and the distance from the mirror to the second pin, d_i.

Distance	Value
d_o	
d_i	
% Diff.	

Table 1: Parallax (10 pts)



Part 2: Reflection



12. Refer to the figure to the right. Draw a baseline across a sheet of paper, near the top. Draw a line normal to the baseline down the center of the paper. Draw a line to the left of the normal (incident line) with angle θ_i between 25° and 35°.
13. Place the two white pins on the incident line. Label these positions P_1 and P_2.
14. Look at the mirror from the right side of the normal so that you can see the image of the first two pins. Adjust your position so that the *images* of the white pins are aligned; align two color pins with them.
15. Label these two points P_3 and P_4.
16. Draw a line connecting point P_3 and P_4 to the baseline. Measure and record θ_i and θ_r.

Angle	Value
θ_i	
θ_r	
% Diff.	

Table 3: Reflection (10 pts)

17. What is the shortest height a mirror must be so that a person who is 1.4 meters tall is able to see his or her entire body? Draw a ray diagram to support your answer. (4 pts)

Part 3: Refraction

18. Place the plexiglass square at the center of a sheet of paper and trace around it.

19. In the upper-left corner of the traced square, draw a line normal to the square, about 2 cm from the corner (Fig. 21.9).

20. Draw an incident line (θ between 25° and 35°). 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.

21. Look *through* the plexiglass square from the edge opposite the pins and close your left eye. (It will help if your partner holds a piece of paper behind the square to block images of other objects in the room.)

22. Adjust your position until the two white pins are aligned, then place two sighting pins (color pins) that align with the image of the two white pins. Label these points P_3 and P_4.

23. Draw a line connecting P_3 and P_4 to the edge of the square. Draw a line normal to the square through this intersection (see top figure).

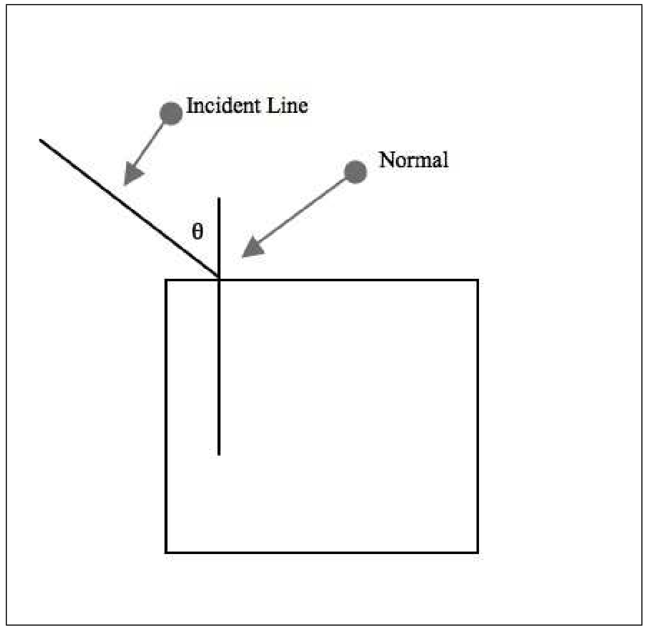
24. Draw a line inside the square to connect the normals (see bottom figure).

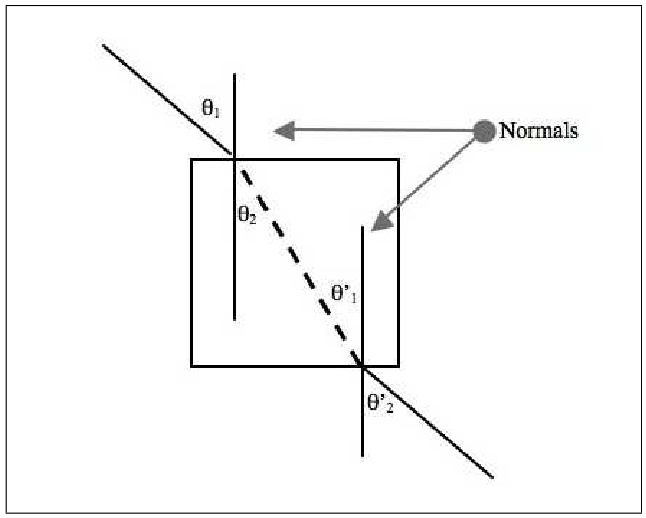
25. Measure and record each θ. You have 2 sets of data, A and A' (top and bottom).

26. Consider the law of refraction and the bottom figure.

    - *Situation A*: As light enters the plexiglass from the air, it bends towards the normal, since it enters a medium with an index of refraction greater than the index of refraction of the medium it is leaving.
    - *Situation B*: As light enters the air from the plexiglass, it bends away from the normal, since it enters a medium with an index of refraction lower than the index of refraction of the medium it is leaving.

Therefore, $\theta_1 = \theta_2'$ and $\theta_2 = \theta_1'$. ($n_{air} = 1.0003$)





Air-to-Plexiglass	Plexiglass-to-Air	% Difference
$\theta_1 =$	$\theta_2' =$	
$\theta_2 =$	$\theta_1' =$	
n =	n =	

Table 4: Refraction (18 pts)

Worksheet - Geometric Optics (continued)

27. Calculate the index of refraction of plexiglass using Snell's Law. Our modeled light ray interacts with the air/glass boundary twice, allowing two separate calculations of n for the plexiglass. Assume $n_{air} = 1.0003$. Show your work. (8 pts)

28. Average your two values of $n_{plexiglass}$ (2 pts)

29. Use your average value of $n_{plexiglass}$ to find the speed of light through the plexiglass. Show your work. (5 pts)

30. Calculate the critical angle, θ_C, of the air-plexiglass boundary using your average $n_{plexiglass}$. Show your work. (5 pts)

Part 4: Total Internal Reflection

31. Place the plexiglass triangle in the center of a sheet of paper and trace around it. Draw a line normal to the bottom edge (the long side), about 1 cm from the left corner (see figure). 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.

32. Look *through* the right side of the bottom edge of the triangle and adjust your position until the two white pins are aligned. (It will help if your partner holds a piece of paper behind the triangle to block images of other objects in the room.) Now align two color pins with the white pins *as viewed through the plexiglass.* Label these position P_3 and P_4.

33. Return the triangle and pins to the kit; place the paper on the table.

34. Draw the path of the light ray by:
    - Extending the normal ($\overline{P_1 P_2}$) to the far edge of the triangle
    - Connecting P_3 and P_4, extending the line to the far edge of the triangle
    - Connecting the line segments ($\overline{P_1 P_2}$ to $\overline{P_3 P_4}$) at the top (far edges of the triangle)

35. Draw a line normal to the edge of the triangle where each light ray ($\overline{P_1 P_2}$ and $\overline{P_3 P_4}$) intersects the far edge of the triangle.

36. Measure θ_1 and θ_2 at each location where the light reflects internally. You have two sets of data, A and A' (right and left).

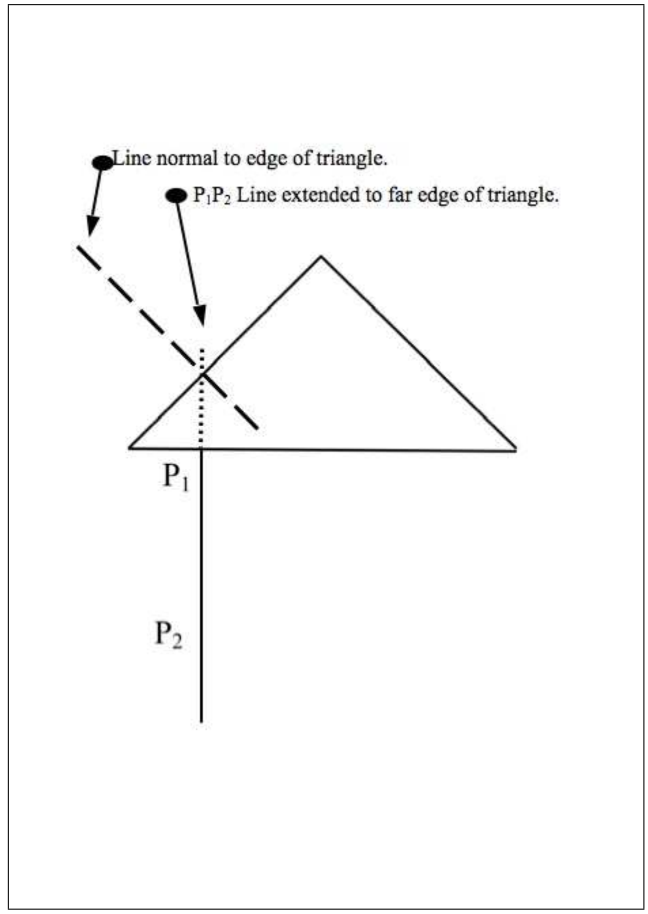


Table 5: Total Internal Reflection (14 pts)

Incident	Reflected	%Difference
$\theta_i =$	$\theta_r =$	
$\theta_i' =$	$\theta_r' =$	

37. Consider the incident and reflected angles for each internal reflection [Table 5]. Are these values greater than θ_C for the air-plexiglass boundary? Should they be? Explain. (6 pts)