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Geometrical Optics

Theory

Refer to your Lab Manual, pages 291 – 294.

Equipment Needed

Light Source	Optics Bench
Ray Table and Base	Cylindrical Lens
Three-surface Mirror	Concave Lens
Convex Lens	Rhombus
Ruler	Compass

Procedure:

PART 1: Plane Mirror

Determine how rays are reflected in a plane mirror.

1. Mount the Ray Table and the Light Source on the Optics Bench.
2. Place the ray table on the base with the degree scale facing up.
3. Position the light source near the edge of the ray table. Adjust the slit mask on the light source so that only one light ray shines across the top of the ray table, along the Normal line.
4. Place the three-surface mirror on the component line of the ray table with the plane surface of the mirror facing the light source.
5. On a white sheet of paper draw to scale your arrangement of the plane mirror, incident ray and reflected rays.
6. Without disturbing the alignment of the plane mirror rotate the ray table and set the angle of incidence to 15^o. Record the corresponding angle of refraction on Data Table 1. Both angles should be measured from the normal line.
7. Draw the incident and reflected rays on your paper, use arrowheads to indicate the direction of propagation and record the angles for each.
8. Repeat step #6 - #7, set the angle of incidence to 30^o, 45^o, 60^o, 75^o and 90^o, record the angle of refraction for each on Data Table 1 and draw the incident and reflected rays on your paper.
9. Adjust the ray box so it produces the three primary color rays. Shine the colored rays at an angle to the plane mirror. On another sheet of paper mark the position of the surface of the plane mirror and trace the incident and reflected rays. Indicate the colors of the incoming and the outgoing rays and mark them with arrows in the appropriate directions.

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PART 2: Concave and Convex Mirror

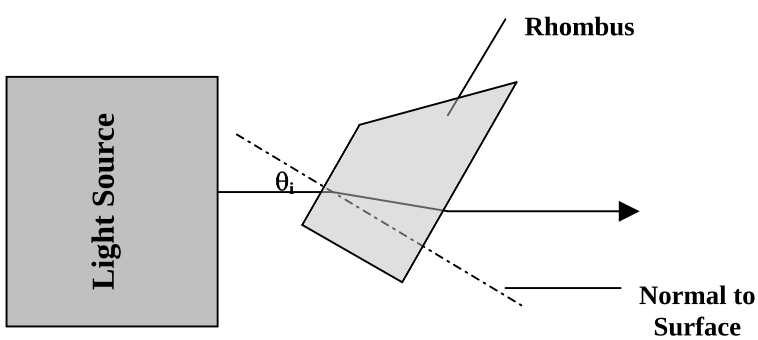
Determine the focal length and curvature of a concave mirror and a convex mirror.

1. Adjust the slit mask so that five light rays shine across the top of the ray table, along the normal line.
2. Place the three-surface mirror with its concave surface facing the light source and the center light ray shining on the center of the concave mirror.
3. Place a white sheet of paper on the ray table under the concave mirror, trace the outline of the mirror and trace the incident and reflected rays.
4. Remove the sheet of paper from the ray table. Use arrows to indicate the incoming and outgoing rays.
5. Determine the *focal point* of the mirror, this is the place where the five reflected rays cross each other.
5. Measure the focal length from the center of the concave mirror to the focal point. Record in Data Table 2.
6. Use a compass to draw a circle that matches the curvature of the mirror. Measure the radius of curvature using a ruler and compare it to the focal length.
7. Repeat steps #2 - #8 for the convex surface of the mirror. Note that the reflected rays are diverging and will not cross. Use a ruler to extend the reflected rays back behind the mirror's surface. The focal point is where these extended rays cross.

PART 3: Snell's Law

Use Snell's Law to determine the index of refraction of the acrylic rhombus.

1. Position the light source near the edge of the ray table. Adjust the slit mask until one light ray shines across.
2. Place a white sheet of paper on top of the ray table. Place the rhombus on the center of the table, position it so that the single ray light passes through the parallel sides of the rhombus, as shown below.



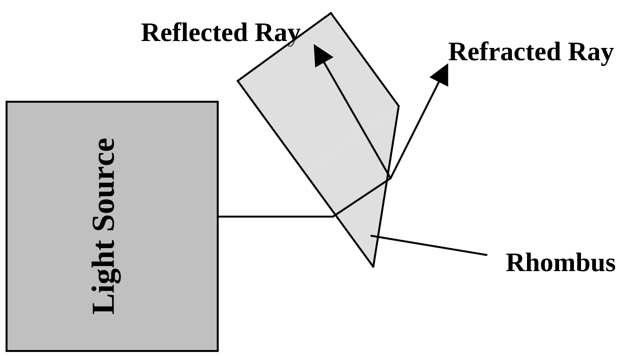
3. Mark the position of the parallel surfaces of the rhombus and trace the incident and transmitted rays. Indicate the incoming and the outgoing rays with arrows in the appropriate directions. Mark carefully where the ray enters and leaves the rhombus.
4. Remove the rhombus and on the paper draw a line connecting the points where the ray entered and left the rhombus. You should also extend the refracted ray in the rhombus for easier measurement.
5. Choose the point where the ray enters the rhombus. At this point, draw the normal to the surface.
6. Measure the angle of incidence (θ_i) and the angle of refraction (θ_r) with a protractor. Both these angles should be measured from the normal. Record the angles in Data Table #3.
7. Change the angle of incidence and measure the incident and refracted angles again. Repeat this procedure for a total of three different incident angles.
8. Using Snell's Law, calculate the index of refraction for the acrylic rhombus and record in Data Table #3.
9. Obtain the average value for the index of refraction and compare to the accepted value of $n = 1.5$ by calculating the percent error.

PART 4: Total Internal Reflection

Determine the critical angle at which total internal reflection occurs.

1. Position the light source near the edge of the ray table. Adjust the slit mask until one light ray shines across.

2. Place a white sheet of paper on the ray table, place the rhombus as shown below. Do not shine the ray through the rhombus too near the triangular tip.



3. Rotate the ray table until the emerging ray just barely disappears. Just as it disappears, the ray separates into colors. The table is rotated far enough if the red color has just disappeared.

4. Trace the surfaces of the rhombus. Mark exactly the point on the surface where the ray is internally reflected. Also mark the entrance point of the incident ray and mark the exit point of the reflected ray.

5. Remove the rhombus and the paper from the ray table. Draw the rays that are incident upon and that reflect off the inside surface of the rhombus.

6. Measure the total angle between the rays using a protractor. If necessary, extend these rays to make the protractor easier to use. Note that this total angle is twice the critical angle because the angle of incidence equals the angle of reflection. Record the measured critical angle in Data Table #4.

7. Calculate the critical angle using Snell's Law and the given index of refraction for acrylic. Record as the theoretical value in Data Table #4.

8. Calculate the percent difference between the measured and theoretical values.

PART 5: Refraction

Explore the difference between convex and concave lenses and determine its focal length.

Convex Lens

1. Adjust the slit mask in front of the light source so that five light rays shine across the top of the ray table. Place a sheet of paper on the ray table, place the convex lens on top of the paper on the edge of the ray table nearest to the light source.
2. Trace the outline of the lens and trace the incident and transmitted rays. Use arrows to indicate the incoming and outgoing rays.
3. Identify the focal point of the lens, this is where the five retracted rays cross each other.
4. Measure the focal length from the center of the convex lens to the focal point. Record in Data Table 5.

Concave Lens

1. Place a sheet of paper on the ray table, place the concave lens on top of the paper about two-thirds of the way across the ray table from the light source.
2. Shine five light rays from the light source straight into the concave lens. Note that the rays leaving the lens are diverging and will not cross.
3. Trace the outline of the lens, the incident rays and the refracted rays. Use a ruler to extend the outgoing rays straight back through the outline of the lens.
4. Identify the focal point of the lens, this is where the extended rays cross.
5. Measure the focal length from the center of the convex lens to the focal point. Record in Data Table 5.

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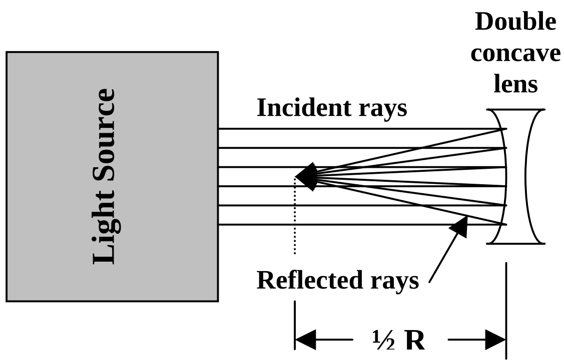
6. Place a sheet of paper on the ray table, nest the convex and concave lenses together and place them in the path of the parallel rays.
7. Trace the rays. What does this tell you about the relationship between the focal lengths of these two lenses?

PART 6: Lensmaker's Equation

Determine the focal length of a convex lens by direct measurement and by using the lensmaker's equation.

1. Place a sheet of paper on the ray table, place the concave lens on top of the paper.
2. Shine five light rays from the light source straight into the concave lens.
3. Trace the outline of the lens, the incident rays and the refracted rays. Indicate the incoming and outgoing rays with arrows.
4. Remove the lens. Use a ruler to extend the outgoing diverging rays straight back through the lens. Determine the focal point, this is where these extended rays cross. Measure the distance from the center of the lens to the focal point. Record in Data Table 6 as experimental focal length.
5. Determine the radius of curvature, put the concave lens back in the path of the rays and observe the faint reflected rays off the first surface of the lens. The front of the lens can be treated as a concave mirror having a radius of curvature equal to twice the focal length of the effective mirror. Trace the surface of the lens, the incident rays and the faint reflected rays.
6. Measure the distance from the center of the front curved surface to the point where the faint reflected rays cross. The radius of curvature of the surface is twice this distance. Record in Data Table 6.
7. Calculate the focal length of the lens using the lensmaker's equation. Record as theoretical focal length.
8. Calculate the percent difference between the two values of the focal length of the concave lens.



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Lab Report

Geometrical Optics

Attach your traces for each.

Data Table 1: Plane Mirror

Angle of Incidence	Angle of Reflection
15^o	
30^o	
45^o	
60^o	
75^o	
90^o	

Data Table 2: Cylindrical Mirrors

	Concave Mirror	Convex Mirror
Focal Length		
Radius of Curvature		

Data Table 3: Snell's Law

Angle of Incidence	Angle of Refraction	*n* Rhombus
Average Index of Refraction		
Percent Error		

Data Table 4: Total Internal Reflection

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	Rhombus
Measured Critical Angle	
Theoretical Critical Angle	
Percent Difference	

Data Table 5: Cylindrical Lenses

	Convex Lens	Concave Lens
Focal Length		

Data Table 6: Lensmaker's Equation

	Concave Lens
Experimental Focal Length	
Radius of Curvature	
Theoretical Focal Length	
Percent Difference	

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Questions:

1. For the plane mirror, what is the relationship between the angle of incidence and the angle of reflection?

2. For the plane mirror, are the three colored rays reversed left-to-right by the plane mirror?

3. What is the relationship between the focal length of a cylindrical mirror and its radius of curvature? Do your results confirm your answer?

4. What is the radius of curvature of a plane mirror?

5. For part 3, what is the angle of the ray that leaves the rhombus relative to the ray that enters the rhombus?

6. How does the brightness of the internally reflected ray change when the incident angle changes from less than θ_c to greater than θ_c?

7. Is the focal length of a concave lens positive or negative?

8. For part 6, how might the thickness of the lens affect the results of this experiment?