Includes
Teacher's Notes
and
Typical
Experiment Results

Instruction Manual and Experiment Guide for the PASCO scientific Model OS-8536

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OPTICS TABLE

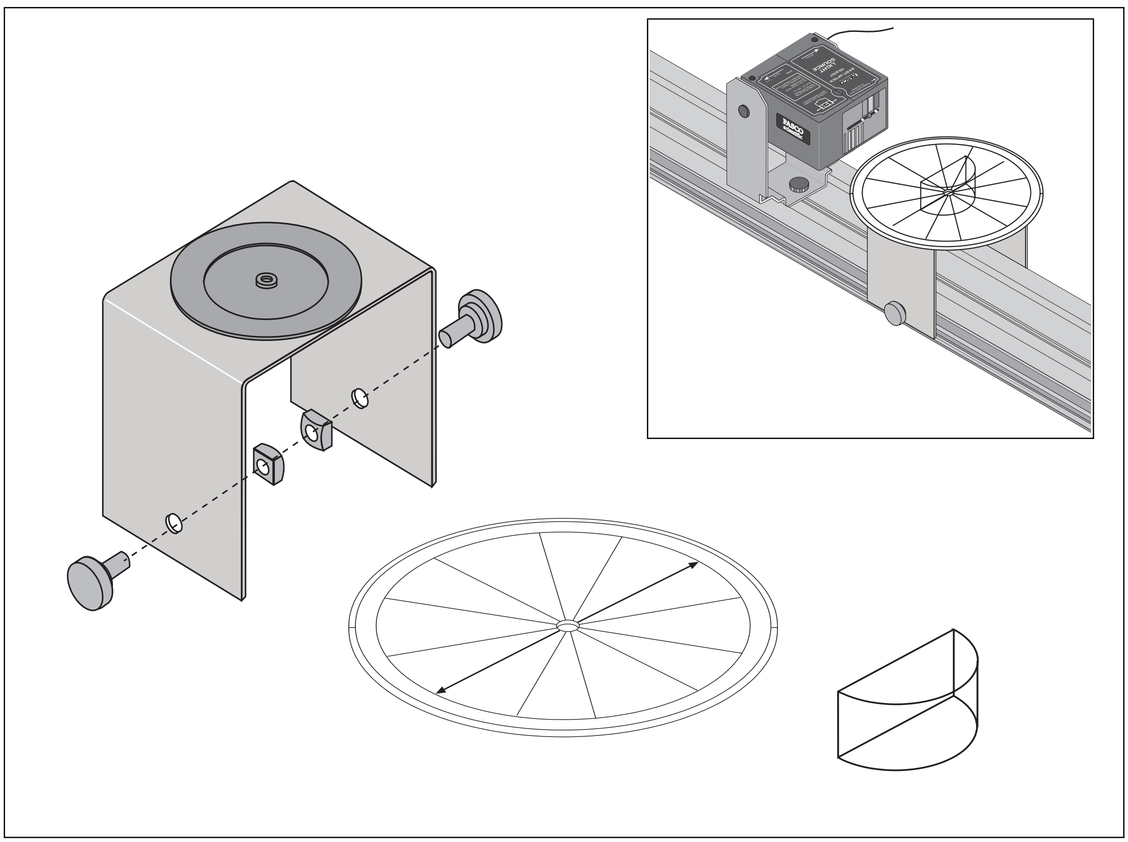

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Table of Contents

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This manual authored by: Dave Griffith

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Introduction

The PASCO OS-8536 Optics Table includes:

- cylindrical lens
- ray table
- ray table base and mounting hardware

The lens, ray table, and ray table base are designed to be used with the Optics Bench, Ray Optics Kit, and Light Source which are included in the OS-8515 Basic Optics System.

Cylindrical Lens

The Cylindrical Lens is a "D"-shaped piece of clear acrylic plastic. The lens is one inch (2.54 cm) thick, and the radius of curvature is one inch (2.54 cm).

Ray Table

The Ray Table is a metal disk six inches (15.24 cm) in diameter with a degree scale printed on both sides. In addition, the center of one side has a Cartesian grid marked in millimeters (mm). The Ray Table has a hole in its center which fits over the post on the top of the Ray Table Base.

Ray Table Base

The top side of the Ray Table Base has a ring of magnetic material that holds the Ray Table in position when the Ray Table is placed on the post on the top of the table.

The mounting hardware on each leg of the Ray Table Base consists of a square nut and a thumbscrew. The square nuts fit into the T-slot on each side of the Optics Bench that is a part of the OS-8515 Basic Optics System. Tightening the thumbscrews holds the Ray Table Base in position when it is mounted on the Optics Bench.

Mounting the Ray Table Base to the Optics Bench

Loosen each thumbscrew by turning counter-clockwise. Leave the square nut on the end of each thumbscrew. Attach the Ray Table Base to the Optics Bench by inserting the square nuts into the T-slots on each side of the track. The base can be moved to any position along the track while the thumbscrews are loose. Tighten the thumbscrews to secure the base in position.

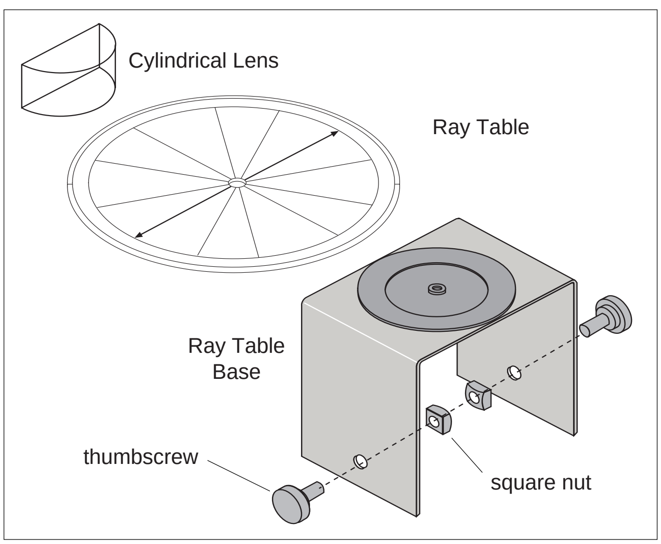


Figure 1: Components

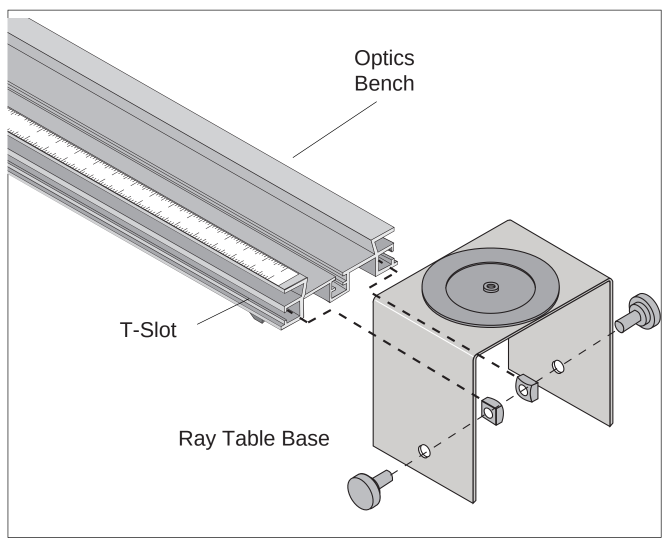


Figure 2: Mounting Ray Table Base

About the Experiments

Experiments 1, 2, and 6 use the OS-8536 (Cylindrical Lens, Ray Table, and Ray Table Base), and the Light Source and Optics Bench from the OS-8515 Basic Optics System.

The other experiments use the Ray Table and Ray Table Base of the OS-8536 and the Light Source and Optics Bench of the OS-8515 and the following additional equipment from the OS-8515 Basic Optics System:

Experiment 3	Prisms	Rhombus
Experiment 4	Reflection	Three-Surface Mirror
Experiment 5	Snell's Law	Rhombus
Experiment 7	Refraction	Convex Lens, Concave Lens
Experiment 8	Lensmaker's Equation	Concave Lens
Experiment 9	Apparent Depth	Convex Lens, Rhombus

Experiment 3 through 9 are described in more detail in the Instruction Manual and Experiment Guide for the OS-8515 Basic Optics System.

Experiment 1: Reversibility

EQUIPMENT NEEDED

– Cylindrical Lens
– Ray Table Base
– Light Source
– Ray Table
– Optics Bench

Purpose

The purpose is to determine the relationship that exists between the angle of incidence and the angle of refraction for light passing from air into a more optically dense medium (the Cylindrical Lens). The second purpose is to determine whether the same relationship holds between the angles of incidence and refraction for light passing out of a more optically dense medium back into air. That is to say, if the light is traveling in the opposite direction through the lens, is the law of refraction the same or different? In this experiment, you will find the answer to this question.

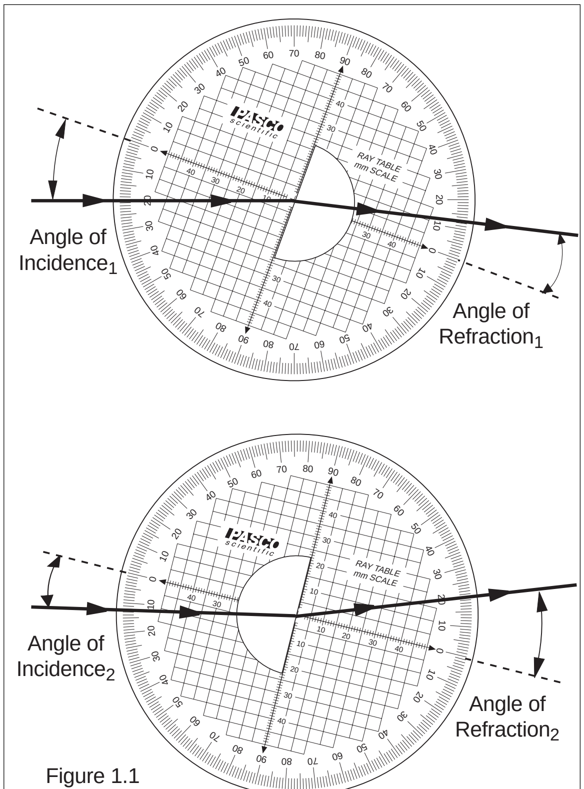


Figure 1.1

Procedure

Mount the Ray Table Base and the Light Source on the Optics Bench.

1. Put the Ray Table on the base with the Cartesian grid (mm SCALE) facing up. Turn the Ray Table so the 0 (zero) degree line points to the Light Source.
2. Put the Light Source on its bracket so that the multiple slits are facing the Ray Table. Position the Light Source so it is about two centimeters from the edge of the Ray Table. Adjust the slit mask on the front of the Light Source so the Light Source projects one ray of light across the middle of the top surface of the Ray Table.
3. For the first trial, put the Cylindrical Lens on the Ray Table so the flat surface of the lens faces the Light Source and the edge of the lens is on the 90 (ninety) degree line with the lens exactly centered on the 0 (zero) degree line.

See Figure 1.2

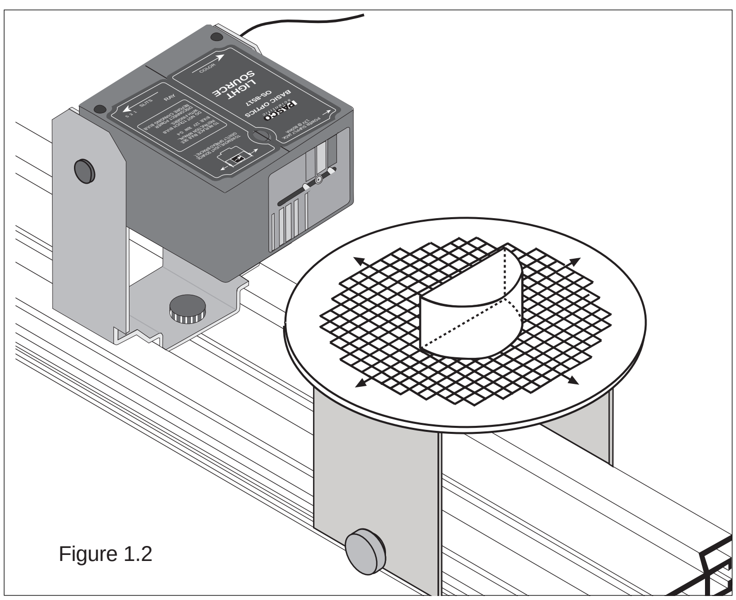


Figure 1.2

Record data.

Without disturbing the alignment of the Cylindrical Lens, rotate the Ray Table and set the angle of incidence to the values listed in Table 1.1. Enter the corresponding angle of Refraction in the table in two columns: Angle of $Refraction_1$ and Angle of $Incidence_2$. (In other words, for the second trial, let Angle of $Incidence_2$ be the value you measured for Angle of $Refraction_1$).

Ray Incident on:	**Flat Surface**		**Curved Surface**	
Angle of:	**$Incidence_1$**	**$Refraction_1$**	**$Incidence_2$**	**$Refraction_2$**
	0°			
	10°			
	20°			
	30°			
	40°			
	50°			
	60°			
	70°			
	80°			

Table 1.1 Data

For the second trail let the single ray from the Light Source strike the *curved* surface of the Cylindrical Lens. (Just rotate the Ray Table 180°.) Start at 0 (zero) degrees. Rotate the Ray Table to each Angle of $Incidence_2$ (the values you listed in Table 1.1 as Angle of $Refraction_1$). Record the corresponding values as the Angle of $Refraction_2$.

1. Using your values for $Incidence_1$ and $Refraction_1$, determine the index of refraction for the acrylic from which the Cylindrical Lens is made. Remember, Snell's Law describes the relationship between the angles of incidence and refraction and the indices of refraction:

   n_{air} sin $Incidence_1$ = $n_{acrylic}$ sin $Refraction_1$. (Assume that the index of refraction for air is 1.0.)

   $n_{acrylic}$ = ____.

2. Using your values for $Incidence_2$ and $Refraction_2$, *redetermine* the index of refraction for the acrylic from which the Cylindrical Lens is made.

   $n_{acrylic}$ = ____.

3. Is the Law of Refraction the same for light rays going in either direction between the two media?

4. Does the principle of optical reversibility hold for Reflection as well as Refraction? Explain.

Experiment 2: Dispersion

EQUIPMENT NEEDED

– Cylindrical Lens
– Ray Table Base
– Light Source
– Ray Table
– Optics Bench
– white paper

Procedure

Mount the Ray Table Base, Ray Table, Cylindrical Lens, and the Light Source on the Optics Bench.

1. Put the Ray Table on the base with the polar grid (DEGREE SCALE) facing up. Turn the Ray Table so the 0 (zero) degree line (NORMAL) points to the Light Source.
2. Set up the equipment as shown in Figure 2.1. Adjust the slit mask on the Light Source so a single light ray is incident on the *curved* surface of the Cylindrical Lens.

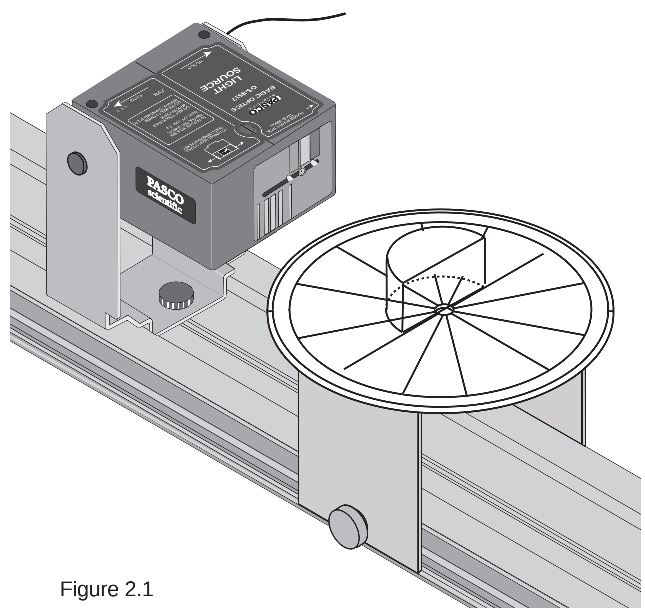


Figure 2.1

Record data

Set the Ray Table so the angle of incidence of the single ray striking the flat surface of the lens (from inside the lens) is zero-degrees. Hold a piece of white paper against the edge of the Ray Table so the refracted ray is visible on the piece of paper.

Slowly rotate the Ray Table to increase the angle of incidence. As you do, watch the refracted ray on the piece of paper.

1. At what angle of refraction do you begin to notice *color separation* in the refracted ray?
   ____________________________________.
2. At what angle of refraction is the color separation a maximum?
   ____..
3. What colors are present in the refracted ray? (Write them in the order of minimum to maximum angle of refraction.)
4. Measure the index of refraction of acrylic for red and blue light:

   (Remember, n_{air} sin $Incidence_{air}$ = $n_{acrylic}$ sin $Refraction_{acrylic}$)

   Note: The index of refraction of a given material is usually expressed as a constant. However, different colors of light refract to slightly different angles, and therefore have slightly different indices of refraction.

n_{red} = ____________________

n_{blue} = ___________________

Experiment 3: Prism

EQUIPMENT NEEDED

– Light Source
– Ray Table and Base
– white paper
– Optics Bench
– Rhombus

Purpose

To show how a prism separates white light into its component colors and to show that different colors are refracted at different angles through a prism.

Theory

Snell's Law states that the angle of refraction depends on the angle of incidence and the index of refraction of the material. Because the index of refraction for light varies with the frequency of the light, white light which enters the material at a given angle of incidence will separate out into its component colors as each frequency is bent a different amount.

Procedure for Separating White Light

Mount the Light Source and the Ray Table Base on the Optics Bench. Put the Ray Table on the base. Position the Light Source near the edge of the Ray Table. Adjust the slit mask on the Light Source so one light ray shines across the middle of the top of the Ray Table.

Position the Rhombus on the Ray Table as shown in the diagram. The triangular end of the Rhombus is used as a prism in this experiment. Keep the light ray near the point of the rhombus for maximum transmission of the light.

Rotate the rhombus until the angle (θ) of the emerging ray is as large as possible and the ray separates into colors.

(a) What colors are seen and in what order are they?

(b) Which color is refracted at the largest angle?

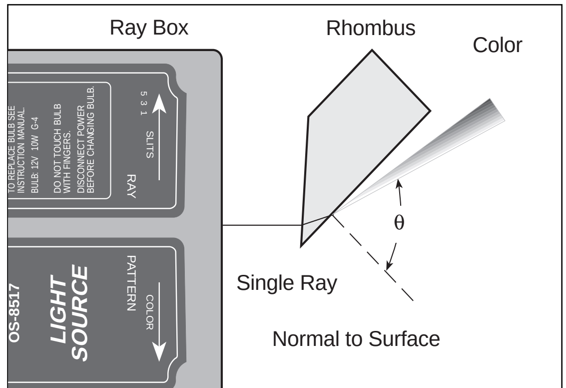


Figure 3

Experiment 4: Reflection – Plane and Curved Mirrors

EQUIPMENT NEEDED

– Light Source
– Three-Surface Mirror
– metric rule
– Optics Bench
– Drawing compass (SE-8733)
– pencil

Purpose

To study how rays are reflected and to determine the focal length and radius of curvature of different types of mirrors.

Part I: Plane Mirror

Procedure

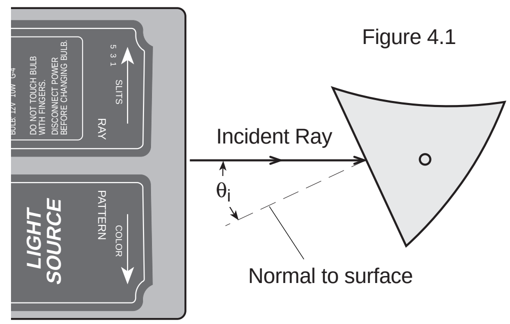


Figure 4.1

Mount the Light Source and the Ray Table Base on the Optics Bench. Put the Ray Table on the base with the DEGREE SCALE facing up. Position the Light Source near the edge of the Ray Table. Adjust the slit mask on the Light Source so one light ray shines across the middle of the top of the Ray Table. Rotate the table so the light ray shines along the NORMAL line on the table.

Place the Three-Surface mirror on the COMPONENT line on the Ray Table with the plane surface facing the light source.

Rotate the Ray Table a few degrees. Measure the angle of incidence (θ_i) and the angle of reflection. Both these angles should be measured from the NORMAL line.

Change the angle of incidence and measure the incident and reflected angles again.

Part II: Cylindrical Mirrors

Theory

A concave cylindrical mirror will focus parallel rays of light at a *focal point*. The *focal length* is the distance from the focal point to the center of the mirror surface. The *radius of curvature* of the mirror is twice the focal length. See the diagram.

Procedure

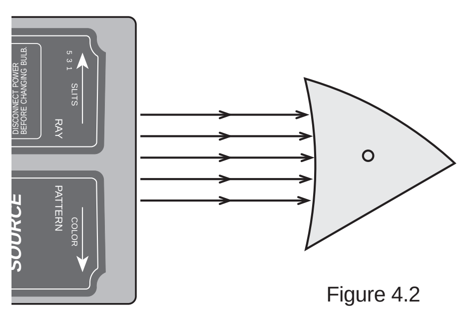


Figure 4.2

Adjust the slit mask on the front of the Light Source so that *five* light rays from the Light Source shine across the top of the Ray Table. Rotate the table so the center light ray shines along the NORMAL line. Turn the Three-Surface mirror so the concave surface faces the Light Source and the center light ray shines on the center of the curved surface.

Trace the outline of the mirror and trace the incident and reflected rays. Indicate the incoming and the outgoing rays with arrows in the appropriate directions.

The place where the five reflected rays cross each other is the *focal point* of the mirror. Measure the *focal length* from the center of the concave mirror surface to the focal point. Use the compass to draw a circle that matches the curvature of the mirror. Measure the radius of curvature using a rule and compare it to the focal length.

Repeat the procedure for the convex surface of the mirror. Note that the reflected rays are diverging for a convex mirror and they will not cross. After you trace the outline of the mirror and the incident and reflected rays, use a rule to extend the reflected rays back behind the mirror's surface.

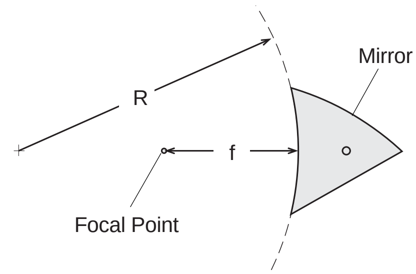


Figure 4.3

Experiment 5: Snell's Law

EQUIPMENT NEEDED

– Light Source
– Ray Table and Base
– protractor
– Optics Bench
– Rhombus
– pencil

Purpose

To use Snell's Law to determine the index of refraction of the Acrylic rhombus.

Theory

Snell's Law states

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

where θ_1 is the angle of incidence, θ_2 is the angle of refraction, and n_1 and n_2 are the respective indices of refraction of the materials.

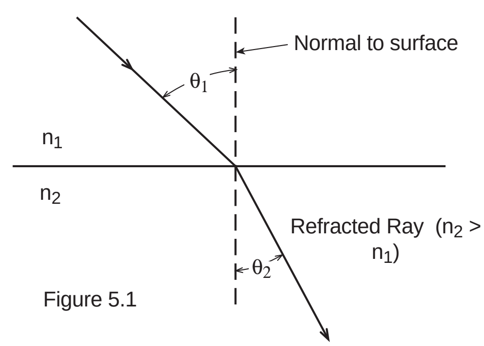


Figure 5.1

Procedure

Mount the Light Source, Ray Table Base, and Ray Table on the Optics Bench. Position the Light Box near the edge of the Ray Table. Adjust the slit mask on the front of the Light Source so that one light ray shines across the middle of the top of the Ray Table.

Place the Rhombus on the center of the table and position it so the single light ray passes through the parallel sides of the Rhombus as shown in Figure 5.2. Use a pencil to trace the outline of the parallel surfaces of the Rhombus onto the Ray table. Trace the incident and transmitted rays. Indicate the incoming and the outgoing rays with arrows in the appropriate directions.

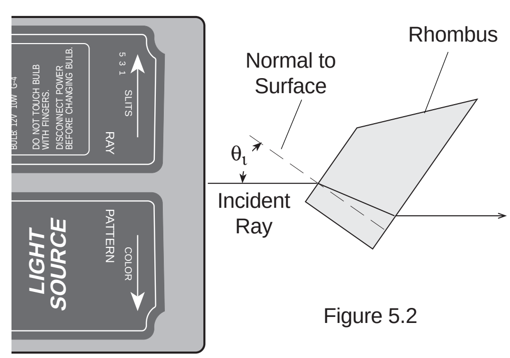


Figure 5.2

Remove the Rhombus and draw a line on the Ray Table connecting the points where the ray entered and left the Rhombus.

Choose either the point where the ray enters the Rhombus or the point where the ray leaves the Rhombus. At this point, draw the *normal* to the surface. Measure the angle of incidence (θ_i) and the angle of refraction. Measure both angles from the normal.

Change the angle of incidence and measure the incident and refracted angles again.

Experiment 6: Total Internal Reflection

EQUIPMENT NEEDED

– Light Source
– Ray Table and Base
– protractor
– white paper
– Optics Bench
– Cylindrical Lens
– pencil

Purpose

To determine the critical angle at which total internal reflection occurs.

Theory

Snell's Law states that the angle of an incident light ray relative to the normal of a boundary between two substances is related to the angle of the refracted light ray.

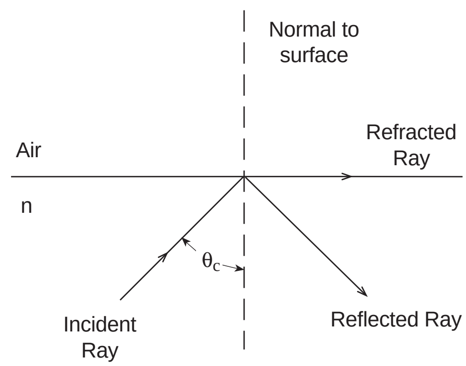


Figure 6.1

If a ray of light traveling from a medium of greater index of refraction to a medium of lesser index of refraction is incident with an angle greater than the critical angle (θ_c), there is no refracted ray and total internal reflection occurs. If the angle of incidence is exactly the critical angle, the angle of the refracted ray is 90 degrees. In this case, using Snell's Law,

$$n\sin\theta_c = (1)\sin(90°)$$

assuming the medium of lesser index of refraction is air with $n_2 = 1$ and the medium of greater index of refraction is the acrylic Rhombus with $n_1 = n = 1.5$. Solving for the critical angle gives

$$\sin\theta_c = \frac{1}{n}$$

Procedure

Mount the Light Source and Ray Table Base on the Optics Bench. Put the Ray Table on the base with the DEGREE SCALE facing up. Position the Light Box near the Ray Table. Adjust the slit mask on the front of the Light Source so one light ray shines across the across the top of the Ray Table. Turn the Ray Table so the light ray shines along the NORMAL (zero degrees) line of the table.

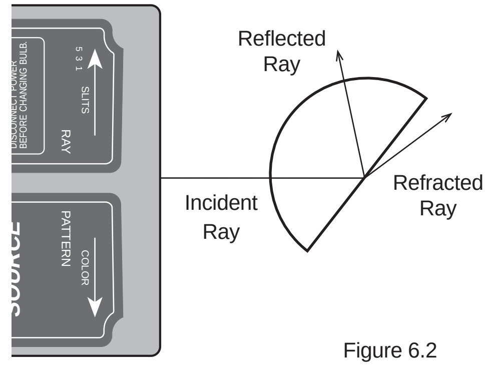


Figure 6.2

Place the Cylindrical Lens on the Ray Table so the curved side of the lens faces the Light Source and the flat side of the lens is on the COMPONENT line.

Rotate the Ray Table until the light ray emerging from the Cylindrical Lens just barely disappears. Hold a piece of white paper next to the edge of the Ray Table so you can see the light ray.

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

Use the pencil to trace the edges of the Cylindrical Lens onto the Ray Table. Mark the point on the table where the light ray is internally reflected. Also mark the entrance point of the incident ray and the exit point of the reflected ray.

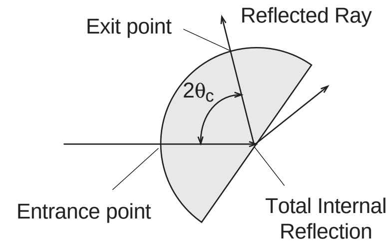


Figure 6.3

Remove the Cylindrical Lens and draw the rays that are *incident upon and reflect off* the inside flat surface of the Cylindrical Lens. Measure the total angle between these rays using a protractor. Note that this total angle is *twice* the critical angle because the angle of incidence equals the angle of reflection.

Experiment 7: Refraction – Convex and Concave Lenses

EQUIPMENT NEEDED

– Light Source
– Ray Table and Base
– Concave Lens
– Optics Bench
– Convex Lens
– ruler

Purpose

To explore the difference between convex and concave lenses and to determine their focal lengths.

Theory

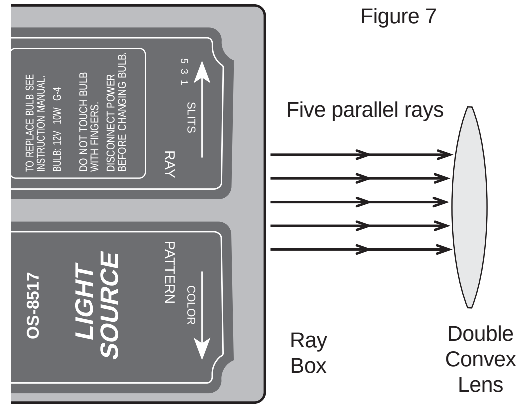
Parallel rays of light passing through a thin convex lens cross at the focal point of the lens. The focal length is measured from the center of the lens to the focal point.

Procedure

Mount the Light Source, Ray Table Base, and Ray Table on the Optics Bench. Place the Convex Lens on the edge of the Ray Table nearest to the Light Source. Shine five light rays from the Light Source straight into the convex lens. Trace the outline of the lens and trace the incident and transmitted rays. Indicate the incoming and the outgoing rays with arrows in the appropriate directions.

The place where the five refracted rays cross each other is the *focal point* of the lens. Measure the *focal length* from the center of the convex lens to the focal point.

Figure 7



Repeat the procedure for the concave lens. Put the concave lens about two-thirds of the way across the Ray Table from the Light Source. Note that the rays leaving the lens are diverging and they will not cross. After you trace the outline of the lens and the incident and refracted rays, use a ruler to extend the outgoing rays straight back through the outline of the lens. The focal point is where these extended rays cross.

Nest the convex and concave lenses together and place them in the path of the parallel rays. Trace the rays. What does this tell you about the relationship between the focal lengths of these two lenses?

Slide the convex and concave lenses apart to observe the effect of a combination of two lenses. Then reverse the order of the lenses. Trace the patterns.

Place the convex lens in the path of the five light rays. Put a finger in front of the slit mask to block out the center three rays and mark the focal point for the outer two rays. Next, adjust the slit mask on the fron t of the Light Source so three light rays shine across the middle of the Ray Table and mark the focal point for the three rays. Are the two focal points the same?

Experiment 8: Lensmaker's Equation

EQUIPMENT NEEDED

– Light Source
– Ray Table and Base
– metric ruler
– Optics Bench
– Concave lens
– pencil

Purpose

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

Theory

The lensmaker's equation is used to calculate the focal length of a lens based on the radii of curvature of its surfaces and the index of refraction of the lens material.

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

where f is the *focal length*, n is the *relative index of refraction* of the lens material, and R_1 and R_2 are the *radii of curvature* of the lens surfaces.

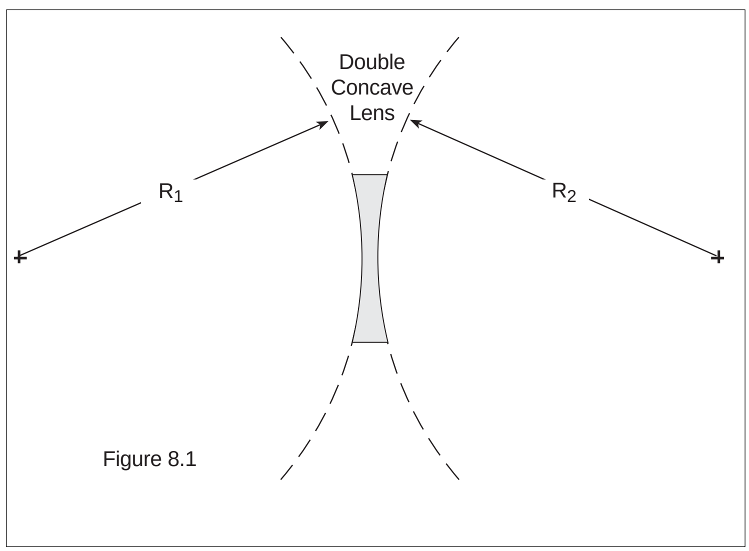


Figure 8.1

➤ NOTE: In this notation, R is *positive* for a convex surface (as viewed from outside the lens) and R is *negative* for a concave surface.

Procedure

Mount the Light Source, Ray Table Base, and Ray Table on the Optics Bench. Place the Concave Lens on the Ray Table. Shine five light rays from the Light Source straight into the lens. Trace the outline of the lens and trace the incident and transmitted rays. Indicate the incoming and the outgoing rays with arrows in the appropriate directions.

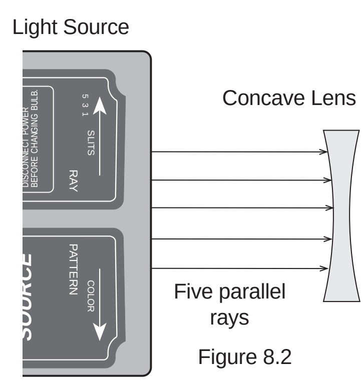


Figure 8.2

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Remove the lens. To measure the focal length, use a ruler to extend the outgoing diverging rays straight back through the outline of the lens. The focal point is where these extended rays cross. Measure the distance from the center of the lens to the focal point.

To 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 incident rays and the faint reflected rays. 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.

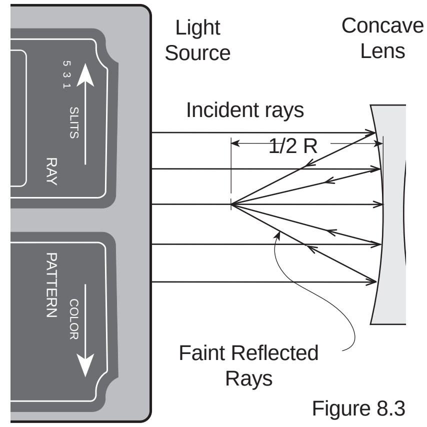


Figure 8.3

Note that the lens is symmetrical and it is not necessary to measure the curvature of both sides of the lens because R is the same for both. Calculate the focal length of the lens using the lensmaker's equation. The index of refraction is 1.5 for the lens. Remember that a concave surface has a *negative* radius of curvature.

Experiment 9: Apparent Depth

EQUIPMENT NEEDED

- – Light Source
- – Convex lens
- – masking tape
- – Optics Bench
- – Rhombus
- – metric ruler– pencil

PART I

Purpose

To determine the index of refraction using apparent depth.

Theory

Light rays originating from the bottom surface of a block of material refract at the top surface as the rays emerge from the material into the air. When viewed from above, the apparent depth, d, of the bottom surface of the block is less than the actual thickness, t, of the block. The apparent depth is given by

$d = t/n$, where n is the index of refraction of the material.

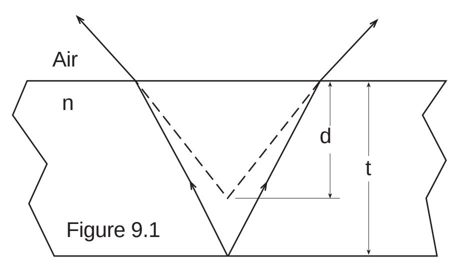


Figure 9.1

Procedure

Mount the Light Source, Ray Table Base, and Ray Table on the Optics Bench. Place the Convex Lens on the edge of the Ray Table nearest to the Light Source. Adjust the slit mask on the front of the Light Source so five light rays shine straight into the Convex Lens. Use a strip of masking tape to block the center three light rays.

Mark the place where the two outer light rays cross each other.

Next, place the Rhombus as shown in Figure 9.2. The surface of the Rhombus facing the Light Source must be exactly at the point where the two rays cross. The crossed rays simulate the rays that emerge from the bottom of the Rhombus block discussed in the theory.

Trace the outline of the of the Rhombus and trace the rays diverging from the surface facing away from the Light Source.

Remove the Rhombus, turn off the light source, and trace the diverging rays back into the outline of the Rhombus. The place where these rays cross (inside the outline of the Rhombus) is the apparent position of the "bottom" of the Rhombus when viewed from the "top".

Measure the apparent depth, d, and the thickness, t. Calculate the index of refraction of the material using n = t/d. Compare the measured value to the accepted value (n = 1.5).

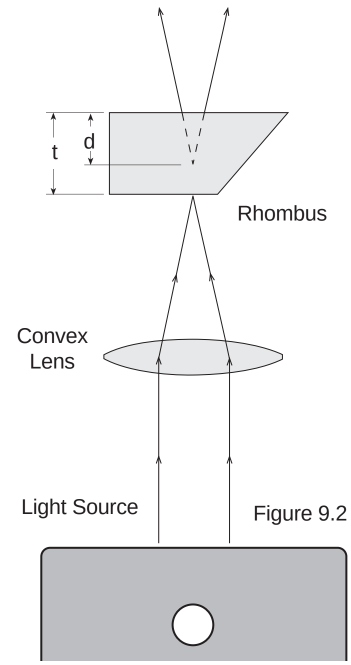


Figure 9.2

PART II

Theory

Parallel rays passing through a Convex Lens cross at the focal point of the lens.If a block with parallel sides is placed between the lens and the focal point, the point where the rays cross moves further from the lens.Since the thickness, t, of the block has an apparent depth, d, that is less than the thickness (d = t/n), the point where the rays cross must move by an amount equal to the difference between the actual thickness of the block and the apparent thickness of the block. Thus the distance, x, that the focal point moves is given by x = t - t/n, where n is the index of refraction of the block.

Procedure

Mark the place where the two light rays cross. Place the Rhombus between the lens and the place where the rays cross. Mark the *new* place where the rays cross. Move the Rhombus to a new position, closer to the lens. Does the position of the focal point change?

Turn off the light source and measure the distance, x, between the marks.

Using the thickness, t, of the Rhombus from Part I and the distance x, calculate the index of refraction using

$$n = \frac{1}{1 - \frac{x}{t}}$$

Compare the measured value to the accepted value (n = 1.5).

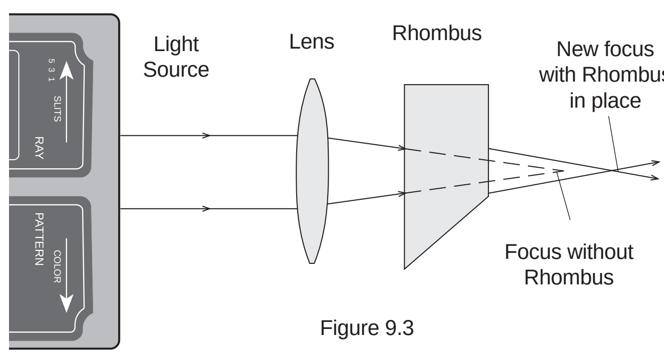


Figure 9.3

Teacher's Guide

Experiment 1: Reversibility

Suggestions on Procedure

For best results, make sure that the Cylindrical Lens is aligned exactly with the Ray Table.

The index of refraction is equal to the slope of the "Refraction 1" graph. n = 1.498

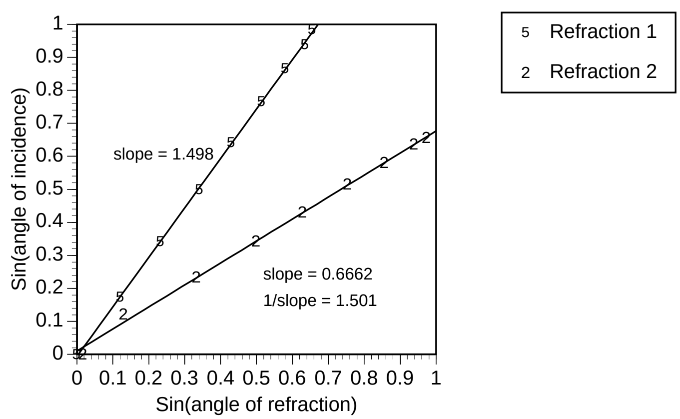
The slope of data set 2 is 1/n. Thus, n = 1.501.

Yes, the Law of Refraction is the same for light rays going in either direction between the two media..

Yes, the principle of optical reversibility holds for reflection as well as refraction.. The angle of incidence equals the angle of reflection regardless of which side the light is coming from.

Angle of:

Incidence1	Refraction1	Incidence2	Refraction2
0	0.0	0.0	1.0
10	7.0	7.0	7.5
20	13.5	13.5	19.5
30	20.0	20.0	30.0
40	25.5	25.5	39.0
50	31.0	31.0	49.0
60	35.5	35.5	59.0
70	39.5	39.5	70.0
80	41.0	41.0	77.0



Experiment 2: Dispersion

Color separation was first noted at about 40°, although it may be noticeable before then depending on the light in the room.

Maximum separation occurs at about 85°; beyond that the violet is totally internally reflected.

In order: (although not all colors may be resolvable depending on the room light) red, orange, yellow, green, cyan, blue, violet.

With an incident angle of 40°, the violet was at 76° and the red was at 73°.

$n_{red} = 1.488$

$n_{violet} = 1.510$

Experiments 3 through 9

Please refer to the Instruction Manual and Experiment Guide for the OS-8515 Basic Optics System.

Notes

Technical Support

Feedback

If you have any comments about the product or manual, please let us know. If you have any suggestions on alternate experiments or find a problem in the manual, please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For technical support, call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

fax: (916) 786-3292

e-mail: techsupp@pasco.com

web: www.pasco.com

Contacting Technical Support

Before you call the PASCO Technical Support staff, it would be helpful to prepare the following information:

- If your problem is with the PASCO apparatus, note:

  Title and model number (usually listed on the label);

  Approximate age of apparatus;

  A detailed description of the problem/sequence of events (in case you can't call PASCO right away, you won't lose valuable data);

  If possible, have the apparatus within reach when calling to facilitate description of individual parts.

- If your problem relates to the instruction manual, note:

  Part number and revision (listed by month and year on the front cover);

  Have the manual at hand to discuss your questions.