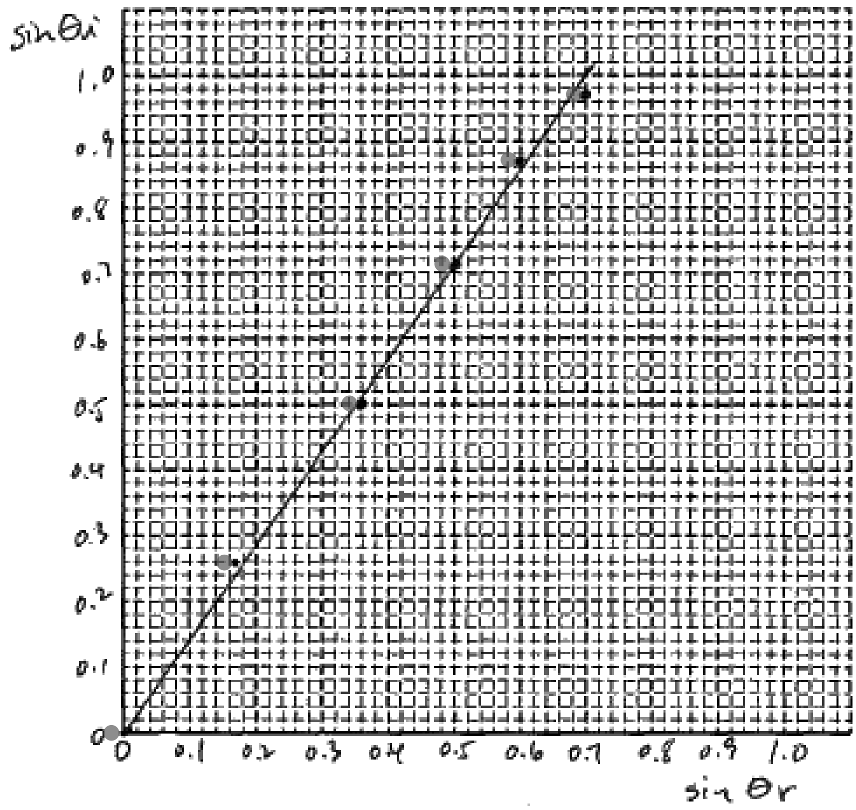
Question 3

10 points total **Distribution of points**

(a) 3 points



For labeling both axes with variables that will yield a straight-line graph	1 point
For correctly scaling both axes	1 point
For correctly plotting the points	1 point

(b) 4 points

For a straight line that best represents the data	1 point
For relating the slope to the index of refraction using Snell's law	1 point
$n =$ slope (or $1/\text{slope}$ if plotting $\sin\theta_r$ as a function of $\sin\theta_i$)	
For substituting two points on the line	1 point
For the example graph shown, $n = \dfrac{(1.00 - 0.20)}{(0.70 - 0.14)}$	
For a calculated index of refraction in the range 1.2 - 1.6	1 point
$n = 1.43$	

Question 3 (continued)

Distribution of points

(c) 3 points

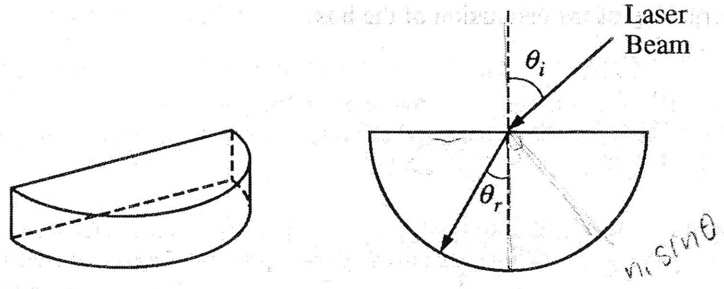
For a new experimental method in which the student aims the laser at the curved side of the block	1 point
For stating that the critical angle is the minimum angle at which no light is refracted or total internal reflection is reached	1 point
For relating the index of refraction to the critical angle and stating that $n_2 = 1$ (the second medium is air)	1 point

Example

Aim the laser through the curved side of the block at normal incidence, so that it emerges from the center of the flat side. Pivot the block about the center of the flat side so that the emerging beam just grazes the flat side (or the beam begins to disappear).

Measure the angle between the incident beam and the normal to the flat side. This is the critical angle θ_c .The index of refraction is given by $n = 1/\sin\theta_c$.

B3 A1



Side View Top View

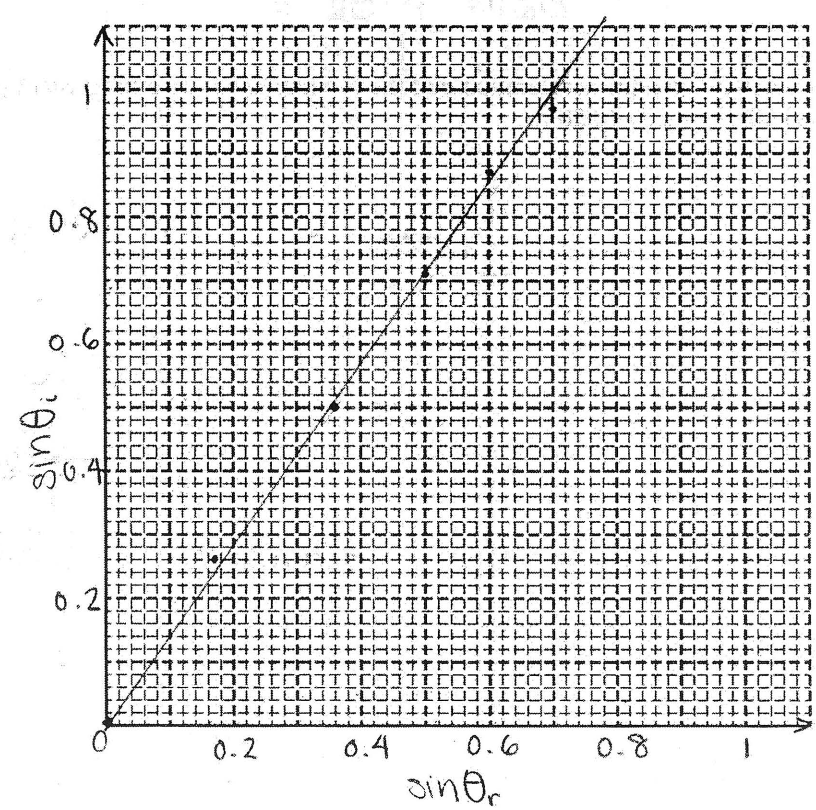
3. (10 points)

A student is asked to experimentally determine the index of refraction of the semicircular block of transparent plastic shown in the figure above. The student aims a red laser beam of wavelength $\lambda = 632$ nm at the center of the flat side of the block, as shown. The ray is refracted from air into the plastic and strikes the semicircular side of the block perpendicularly. The student uses a protractor to aim the laser at several different angles of incidence θ_i between $0°$ and $90°$ and to measure the angles of refraction θ_r. The student's data are given in the table below.

n

θ_i	0°	15°	30°	45°	60°	75°
θ_r	0°	10°	21°	30°	37°	44°
$\sin\theta_i$	0	0.26	0.50	0.71	0.87	0.97
$\sin\theta_r$	0	0.17	0.36	0.50	0.60	0.70

(a) On the grid below, plot data that will allow the index of refraction of the plastic to be calculated from a straight line that represents the data. Clearly label the axes, including the scales.



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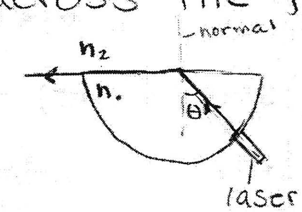
(b) On your graph, draw a straight line that best represents the data. Use the slope of the line to determine the index of refraction of the plastic.

slope = n

$n = \dfrac{0.8 - 0.4}{0.56 - 0.28} = \boxed{1.43}$

(c) The student now wants to confirm the result obtained in part (b) by using the critical angle for the plastic. Describe one experimental method the student can use to measure the critical angle. Indicate how the index of refraction can be determined from this measurement.

Shine the laser through the semicircular side, and adjust it so that the light leaves the plastic across the flat side (see diagram).



Use a protracter to measure θ, the angle to the normal where light hits the flat side. This is the critical angle.

The critical angle can be caluculated by using $\sin\theta_c = \frac{n_2}{n_1}$, where n_1 = index of refraction for glass and $n_2 = 1$ (index of refraction for air). So $n_2 = \sin\theta_c$

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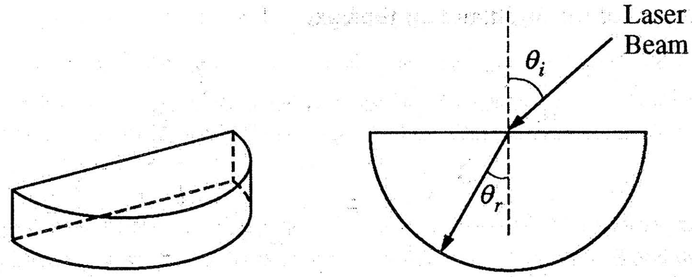


Side View

Top View

$n_1 \sin\theta = n_2 \sin\theta_2$

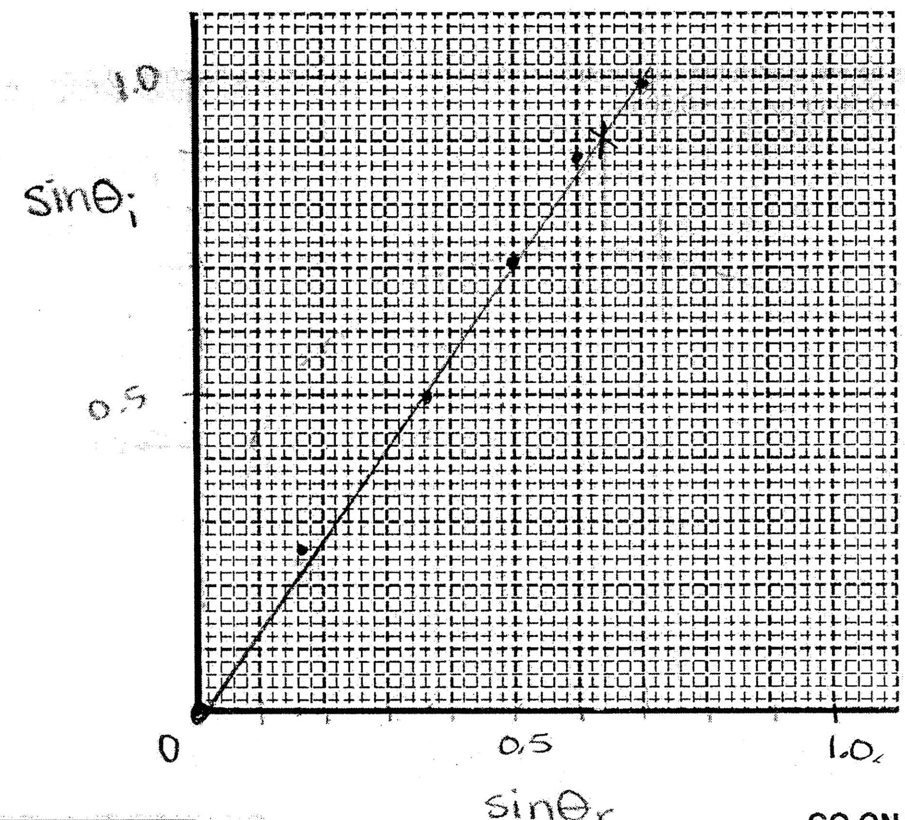
$n_2 = \frac{n_1 \sin\theta_i}{\sin\theta_r}$

3. (10 points)

A student is asked to experimentally determine the index of refraction of the semicircular block of transparent plastic shown in the figure above. The student aims a red laser beam of wavelength $\lambda = 632$ nm at the center of the flat side of the block, as shown. The ray is refracted from air into the plastic and strikes the semicircular side of the block perpendicularly. The student uses a protractor to aim the laser at several different angles of incidence θ_i between 0° and 90° and to measure the angles of refraction θ_r. The student's data are given in the table below.

	θ_i	0°	15°	30°	45°	60°	75°
	θ_r	0°	10°	21°	30°	37°	44°
y	$\sin\theta_i$	0	0.26	0.50	0.71	0.87	0.97
x	$\sin\theta_r$	0	0.17	0.36	0.50	0.60	0.70

(a) On the grid below, plot data that will allow the index of refraction of the plastic to be calculated from a straight line that represents the data. Clearly label the axes, including the scales.



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(b) On your graph, draw a straight line that best represents the data. Use the slope of the line to determine the index of refraction of the plastic.

$$\frac{\Delta y}{\Delta x} = \frac{0.9}{0.64} = \boxed{1.4}$$

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

$$1 \sin\theta_1 = n_2 \sin\theta_2$$

$$n_2 = \frac{\sin\theta_1}{\sin\theta_2} = \frac{\sin\theta_i}{\sin\theta_r}$$

(c) The student now wants to confirm the result obtained in part (b) by using the critical angle for the plastic. Describe one experimental method the student can use to measure the critical angle. Indicate how the index of refraction can be determined from this measurement.

Shine the laser beam at the plastic block until $\theta_r = 90°$ (measured using protractor). The θ_i that produces $\theta_r = 90°$ is the critical angle.

The $\sin\theta_c = \frac{n_2}{n_1}$

Since the first medium is air, $n_1 = 1.00$

Therefore, the $\sin\theta_c = n_2$

Plug in θ_c and solve for n_2

(which was the result in part b and can now be confirmed)

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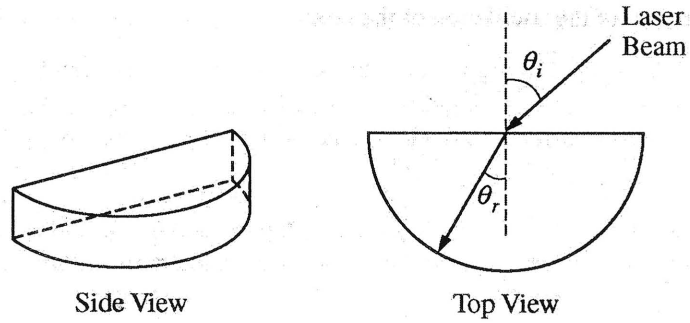
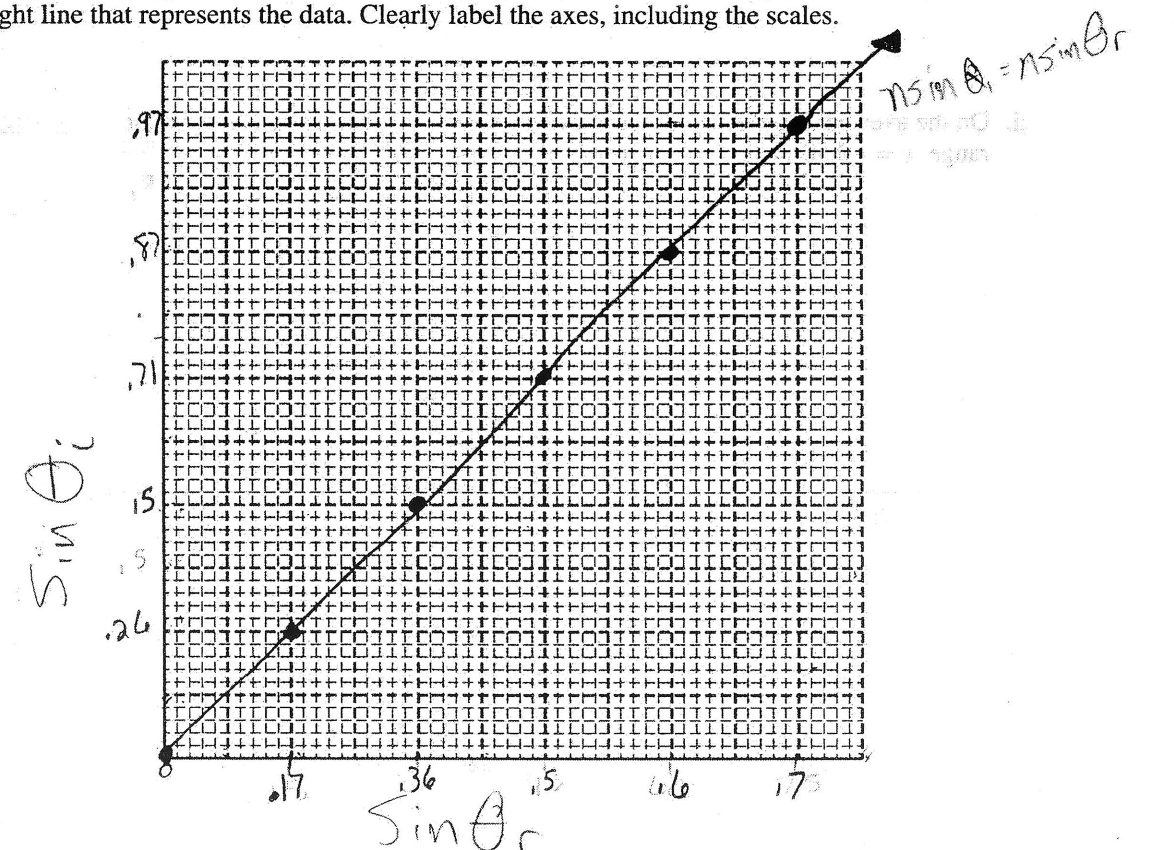


3. (10 points)

A student is asked to experimentally determine the index of refraction of the semicircular block of transparent plastic shown in the figure above. The student aims a red laser beam of wavelength $\lambda = 632$ nm at the center of the flat side of the block, as shown. The ray is refracted from air into the plastic and strikes the semicircular side of the block perpendicularly. The student uses a protractor to aim the laser at several different angles of incidence θ_i between 0° and 90° and to measure the angles of refraction θ_r. The student's data are given in the table below.

θ_i	0°	15°	30°	45°	60°	75°
θ_r	0°	10°	21°	30°	37°	44°
$\sin\theta_i$	0	0.26	0.50	0.71	0.87	0.97
$\sin\theta_r$	0	0.17	0.36	0.50	0.60	0.70

(a) On the grid below, plot data that will allow the index of refraction of the plastic to be calculated from a straight line that represents the data. Clearly label the axes, including the scales.



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(b) On your graph, draw a straight line that best represents the data. Use the slope of the line to determine the index of refraction of the plastic.

slope $= \frac{y}{x}$ $\quad \frac{.26}{.17} = 1,53 =$ index of refraction (Plastic)

(c) The student now wants to confirm the result obtained in part (b) by using the critical angle for the plastic. Describe one experimental method the student can use to measure the critical angle. Indicate how the index of refraction can be determined from this measurement.

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Question 3

Overview

This question assessed students' data analysis and graphing skills, understanding of refraction in general and total internal reflection specifically, and ability to design a lab using the critical angle.

Sample: B3-A
Score: 9

This is an excellent response. Part (a) has correct labels, scaling, and plotting. One point was lost in part (b) for not directly connecting the slope to Snell's Law, but it does have a good best fit line, shows points selected from the line (not data points), and an answer in the acceptable range. Part (c) had the laser starting on the curved side, finding the critical angle, and using it to find the index of refraction.

Sample: B3-B
Score: 7

Full credit was earned in part (a). In part (b) 1 point was lost for not directly connecting the slope to the index of refraction. One point was earned in part (c) for the definition of critical angle. It was not said that the laser beam enters the curved side of the plastic, and it was incorrectly stated that the first medium was air.

Sample: B3-C
Score: 4

In part (a) 1 point was lost for the incorrect scaling of the data. Credit was earned in part (b) for the best fit line and the index value. Points were lost for not showing two points used in the slope calculation and for not connecting the index of refraction and Snell's law to the slope. No credit was earned in part (c).