Refraction of Light Rays

Snell's Law and Applications of Snell's Law

January 14, 2014

Print *Your Name*

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Print *Your Partners' Names*

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Instructions

Before lab, read the *Introduction*, and answer the Pre-Lab Questions on the last page of this handout. Hand in your answers as you enter the general physics lab.

You will return this handout to the instructor at the end of the lab period.

Table of Contents

Comprehensive Equipment List

One setup per person *(e.g., three setups per table, if three partners share one table)*

glass plate	wood drawing board*	pins (10 per person)
protractor	ruler	masking tape (one roll per table)
pencil, number 2, sharp!		

One setup shared by the whole lab

Blackboard optics demo showing ray refracting through a rectangular block (and, if possible, the situations in Activity #2).

0. Introduction

0.1 *Bring to the lab*

- A scientific calculator
- This handout

0.2 *Before lab* Read about Snell's Law in your textbook.

- James Walker, 4th edition: sections 26.5.
- Randall Knight, 2nd edition: section 23.3

* In addition to the wood boards, one can also use the cork boards from the electric fields lab, with a few pieces of blank computer paper between the lab worksheet and the cork.

0.3 ***No partners*** Everybody does their own work. There are no groups for this lab.

0.3.1 Even though you work at your usual table with your usual group, you make your own measurements and do your own calculations.

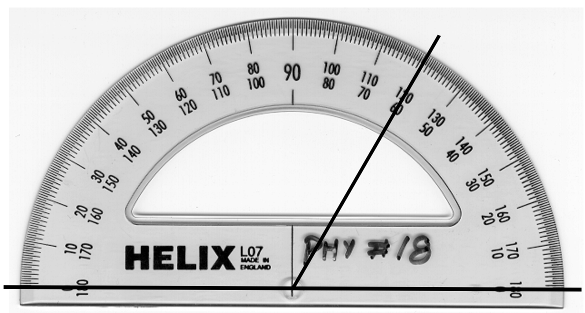
0.3.2 Feel free to discuss answers to questions with others at your or other tables.

0.4 ***Sharp pencils***

In order to obtain good results, it is important to use a sharp pencil. Pencils and a sharpener are in the lab. Quality and accuracy of your work is a component of your grade on this lab.

0.5 ***How to use a protractor***

Figure 1 and Figure 2 show the right way and the wrong way to measure an angle with a protractor.



Right The angle is correctly determined to be 60°

Figure 1

Wrong The angle is ***not*** 58°

Figure 2

0.6 ***Definition of Index of Refraction***

0.6.1 Light travels more slowly in glass and other transparent materials than it does in a vacuum. The index of refraction for a material is the ratio of the speed of light in vacuum to the speed of light in that material. Using glass as the material:

$$n_g \equiv \frac{c}{v_g} \quad \left(\frac{\textit{speed of light in vacuum}}{\textit{speed of light in glass}} \right)$$

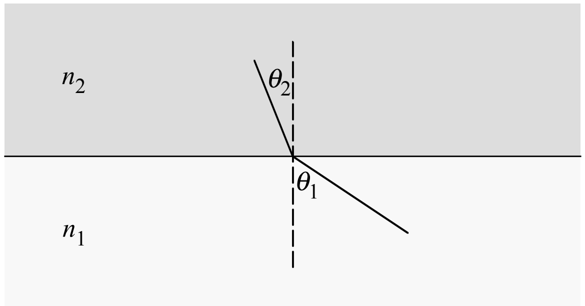
0.6.2 Because the index of refraction is the ratio of two velocities, it has no units.

0.6.3 Since the speed of light is always greatest in vacuum, the index of refraction is always greater than 1.0.

$$n_g > 1$$

0.6.4 For most practical purposes, the speed of light in air can be taken to be the same as the speed of light in vacuum: $n_{air} \approx 1.00$.

0.7 ***Snell's Law***



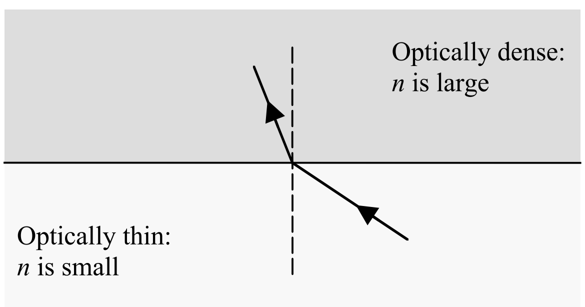
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Snell's Law

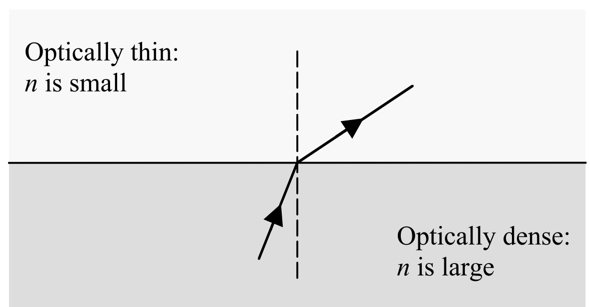
Figure 3

0.7.1 Snell's Law determines how a ray of light bends when it crosses the interface between two different materials (vacuum-glass, air-glass, water-glass). See the diagram and formula in Figure 3.

0.7.2 A transparent material is called *optically dense* if its index of refraction is significantly larger than 1.0, but transparent materials are called *optically thin* if its index of refraction is near to 1.0. Air (n = 1.000293) is optically thin, and diamond (n = 2.419) is optically dense.



(a) From "thin" to "dense"



(b) From "dense" to "thin"

Figure 4

0.7.3 It follows from Snell's Law that a beam going from an optically thin medium to an optically dense medium is bent toward the normal, but a beam going from a dense medium to a thin medium is bent away from the normal. [The "normal" is the dotted line perpendicular to the boundary between the dense and thin materials.] See Figure 4. Use these diagrams when answering some of the questions in this handout.

0.7.4 In Figure 4 part *(a)*, the greater the index of refraction of the dense material, the more the ray bends.

0.8 ***Direct measurement of the index of refraction of glass***

For the situation in Figure 3, Snell's Law is

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

If material 1 is air and material 2 is glass, the above becomes

$$n_{\text{air}} \sin\theta_{\text{air}} = n_{\text{glass}} \sin\theta_{\text{glass}}.$$

Since n_{air} = 1.00, the above simplifies to

$$\sin\theta_{\mathrm{air}} = n_{\mathrm{glass}}\sin\theta_{\mathrm{glass}}.$$

Solving for n_{glass}, you get the following.

$$\boxed{n_{glass} = \frac{\sin\theta_{air}}{\sin\theta_{glass}}}$$

The equipment in the lab will enable you to measure θ_{air} and θ_{glass}. Then you use those values in the above formula to calculate n_{glass}.

1. Activity #1: Measure the index of refraction of a glass plate

Follow the directions below (beginning on page 5) to complete Table 1, and then calculate the average value of the index of refraction and the discrepancy estimate, writing the results of the calculations in the spaces provided below Table 1.

Refer to Figure 5 for the definitions of the angles θ_{air} and θ_{glass} in the following table.

Point	Angle of propagation in air (angle of incidence) θ_{air} (degrees)	Angle of propagation in glass (angle of refraction) θ_{glass} (degrees)	Index of refraction of glass $n_{glass} = \frac{\sin\theta_{air}}{\sin\theta_{glass}}$
P			
Q			
R			

Table 1 Data Table (If measurements could be exact, the three values of n_{glass} would all be the same.)

Average of the n_{glass} values in Table 1 _______________

Discrepancy estimate, $\frac{n_{largest} - n_{smallest}}{n_{average}} \times 100\%$ **:** _______________

Discrepancies around 5% or less are typical.

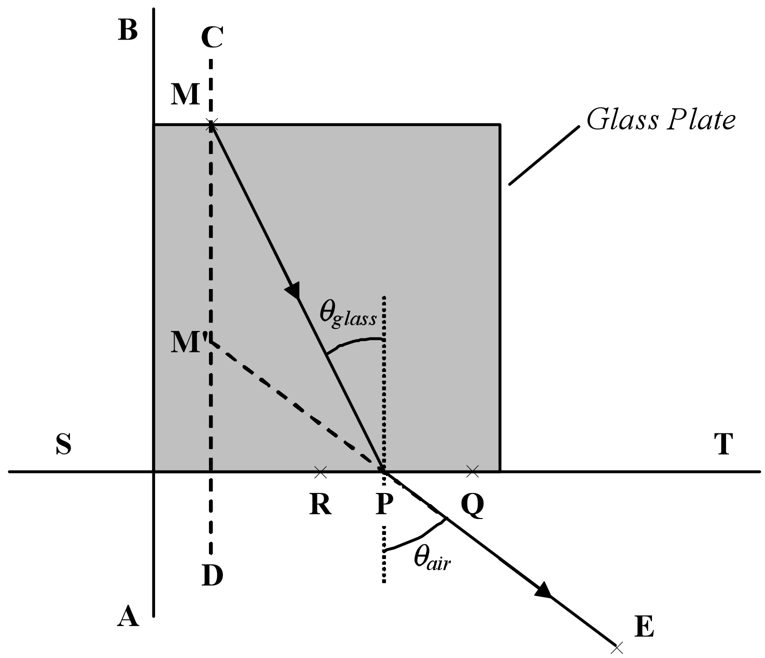


Figure 5 Placement of glass plate and location of first pin (at point P)

1.1 Remove the Lab Worksheet (page 11) from this handout, and tape it to your drawing board.

1.2 On the Lab Worksheet, locate the two solid lines **ST** and **AB**. Place your glass plate on the Lab Worksheet aligned with **ST** and **AB** as shown in Figure 5.

1.3 Use masking tape to tape the glass plate firmly in place. Putting tape on the left, right, and top of the glass plate is sufficient - it is better not to put tape on the bottom of the glass.

1.4 Stick a pin into the drawing board at the point identified as **M** in Figure 5. **M** is on line **CD** at the top of the glass plate.

1.5 Stick a second pin into the drawing board at point **P** (at the place marked with an ×) on the Lab Worksheet.

1.6 The following steps describe the procedure for locating a third pin on the drawing board.

1.6.1 Bring your eye to the level of the paper, and sight through the glass.

1.6.2 You will see two pins: the pin at point **P**, and an image, located at point **M'** in Figure 5, of the pin at **M**.

1.6.3 Stick a third pin into the drawing board (at point **E** in Figure 5) so that it, the pin at **P**, and the image at **M'** all lie on a single straight line. ***Place the third pin as close to the edge of the paper as possible.***

1.6.4 Have your instructor check the location of your pin at **E**. He or she will initial your lab report when the pin at **E** is correctly located.

Instructor's initials ___________

1.7 Using the pin holes in the Lab Worksheet as guides, carefully and accurately draw a solid line from point **M** to point **P** and another solid line from point **P** to point **E**.

1.8 With your protractor, measure θ_{glass} and θ_{air}. Record the results in Table 1.

1.9 Use the sheet in this handout titled *Calculations* (page 10) to show the calculation of the index of refraction of glass from the angles θ_{glass} and θ_{air}, and enter the result of the calculation into Table 1.

1.10 Repeat 1.4 - 1.9, but with pins at points **R** and **Q** on the Lab Worksheet.

1.11 Calculate the average of the three values of the index of refraction of the glass plate, and record the result in the space provided beneath Table 1.

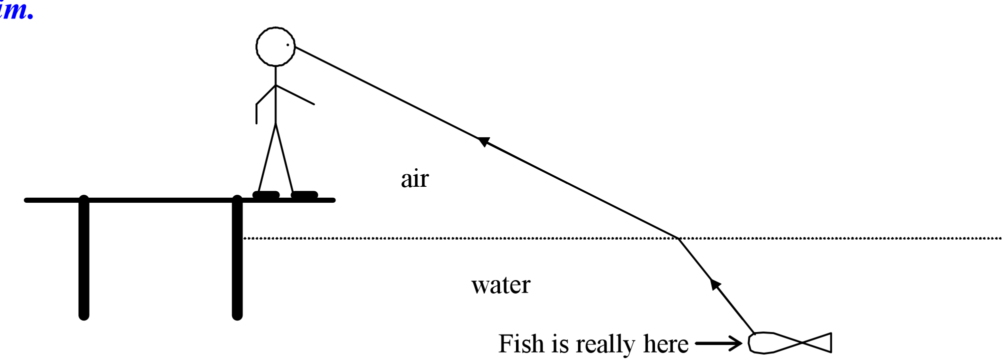
1.12 Calculate the discrepancy estimate according to the formula on page 4 (under Table 1), and enter the result in the space provided beneath Table 1. Discrepancy estimates in the range 2% to 5% are reasonable.

2. Activity #2: Questions

Have you lab instructor check and initial all questions except *Q 1*.

Q 1 Using 3.00 × 10 ^{8} m/s for the speed of light in air, determine the speed of light in the glass you used in this experiment. Show your calculations.

Q 2 A man is fishing from a dock, but not with a pole and line. He sees a fish in the water below him.



a) On the diagram for this question, draw the fish in the location where it appears to be, as seen by the person on the dock.

Instructor's Initials

b) Assume he is fishing with a bow and arrow. Should he shoot the arrow directly at where the fish appears to be, or in front or behind where the fish appears to be? Method: Draw the path taken by a light ray that leaves the fish and enters the man's eye. Then extend that light ray back into the water to see where the arrow will go if the man aims where the fish appears to be.

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c) Suppose that, instead of using a bow and arrow to shoot the fish, he uses a laser that projects an intense beam of red light. How should the man aim the laser in order that the laser beam will hit the fish? Directly at where the fish appears to be, or in front or behind where the fish appears to be?

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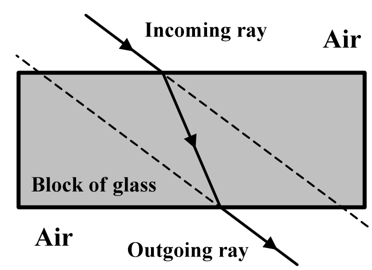
Q 3 Refer to the diagram for this question, and explain why the incoming ray and the outgoing ray are parallel.



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Q 4 Figure 6 part (a) shows two rays of light that meet at the same point on a screen. In Figure 6 part (b) a block of glass lies in the path of the same light rays. Trace the light rays in part (b) through the glass, taking into account how they bend at the edges of the glass, and determine whether the meeting point is on the screen, in front of the screen, or behind the screen. Refer to Figure 4.

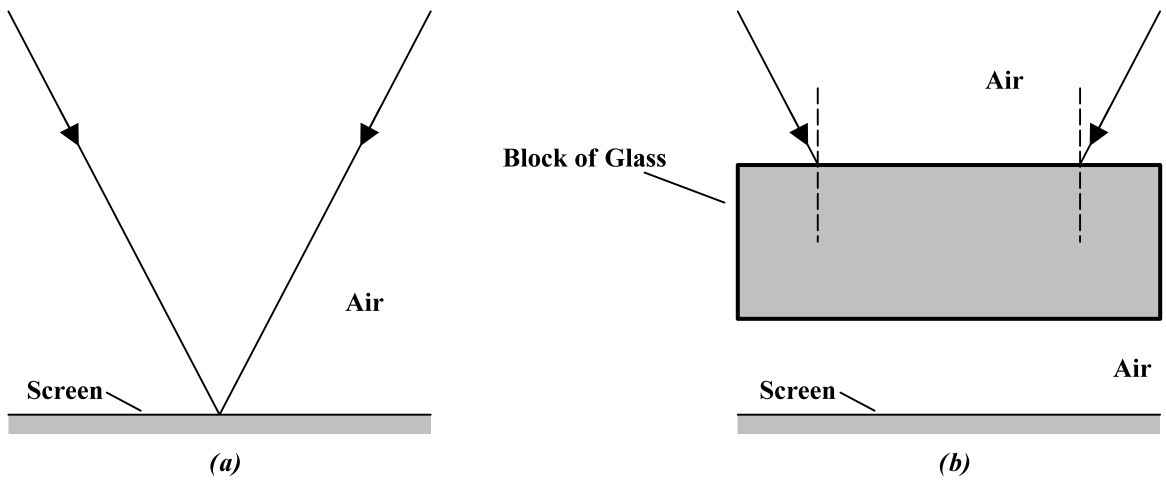
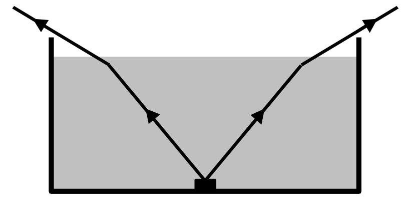


Figure 6

Instructor's Initials

Q 5 One of two identical containers is filled with water, while the other container is filled with ethyl alcohol. The index of refraction of water is less than the index of refraction of ethyl alcohol. When viewed from directly above, one container appears deeper than the other. Which appears deeper, and why? Method: Draw both containers as seen from the side. Place a small dot at the bottom of each. In both containers, draw two identical light rays that travel from the dot up into the air, bending them correctly to show the effect of the index of refraction of the liquid, like the rays in the diagram that accompanies this question. Trace the rays in air back into the liquid to see where they appear to have come from. Then answer the question. Refer also to Figure 4.



Instructor Initials

3. When you are done ...

Hand in this lab handout, including all the following.

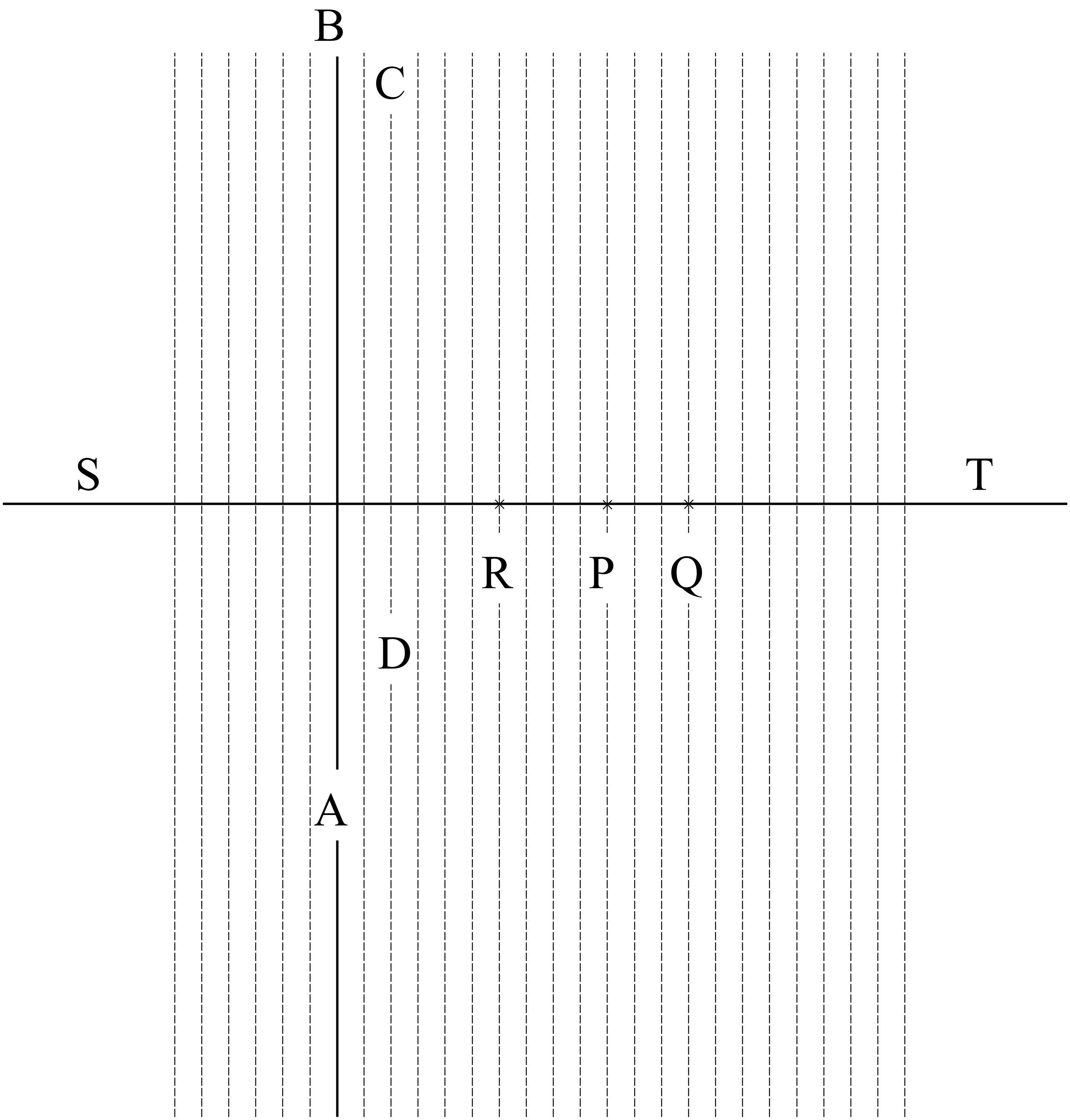
- All entries in Table 1 filled in
- The average of your three values of the index of refraction in the space provided
- The discrepancy estimate in the space provided
- Answers to all the questions
- The page in this handout titled *Calculations*, showing your calculations for Activity #1
- The *Lab Worksheet* you used in lab to draw ray trajectories through glass into air

Calculations

Name ______________________________________

Lab Worksheet

Name ______________________________________



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Pre-Lab Questions

Print *Your Name*

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Read the *Introduction* to this handout, and answer the following questions before you come to General Physics Lab. Write your answers directly on this page. When you enter the lab, tear off this page and hand it in.

1. In this lab, does everyone at each table share their data, or does everyone create his/her own data?

2. What do you bring to lab with you?

3. In measuring a 60º angle, by about how much might your result differ from the correct value if you use your protractor incorrectly?

4. Explain the correct way of using a protractor to measure an angle.

5. What is the index of refraction?

Continued on the next page ...

6. Two materials are both transparent, but one is optically dense and the other is optically thin. Explain the difference between them.

7. State Snell's Law. Include a diagram to explain the terms.

8. A ray of light passes from water into diamond. Water is the optically "thinner" material and diamond is the optically "denser" material. Is the angle the ray makes (with respect to the vertical) greater in the water or in the diamond?

9. A light beam travels from medium 1 to medium 2. Medium 1 has index of refraction 1.2, and medium 2 has index of refraction 1.6. The angle of incidence (in medium 1) is 68°. Find the angle of refraction (in medium 2).

10. A ray of light passes from glass into air. The angle the ray makes (with respect to the vertical) is 22° in the glass and 35° in air. Find the index of refraction of the glass. Show your calculations.