Refraction

Physics 102 **Workshop #7** **Mar. 6 – Mar. 7, 2008**

Name: ______________________________ **Instructor: ____________**
Lab Partner(s): _______________________ **Time of Workshop: _____**

General Instructions

- Workshop exercises are to be carried out in **groups of three.**
- **One report per group** is due by the end of the class.
- Each week's workshop session would typically contain **three sections**. The first two sections must be completed in class. The third section should be attempted if there is time.
  1. A pre-lab reading and assignment section
  2. Experiment section
  3. Practice questions and problems

This lab session is devoted to Refraction and applications of Snell's law.

Please make all distance measurements in centimeters and angle measurements in degrees.

Part I: Pre-lab assignment

1. What is the index of refraction?

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

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

4. 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?

5. 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).

6. 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.

Part II: Refraction Experiments

COMPREHENSIVE EQUIPMENT LIST

glass plate	wood drawing board	pins	protractor
ruler	masking tape	pencil(sharp!)	

DEFINITION OF INDEX OF REFRACTION

Light travels slower 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:

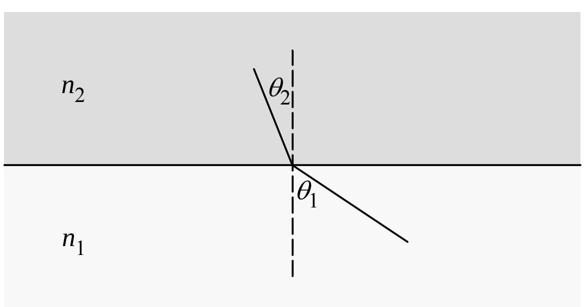
$$n_g \equiv \frac{c}{v_g} \quad \left(\frac{\textit{speed of light in vacuum}}{\textit{speed of light in glass}} \right)$$

The index of refraction is the ratio of two velocities and hence has no units. Since the speed of light is always greatest in vacuum, the index of refraction is always greater than 1.0.

$\mathbf{n_g > 1}$

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

SNELL'S LAW



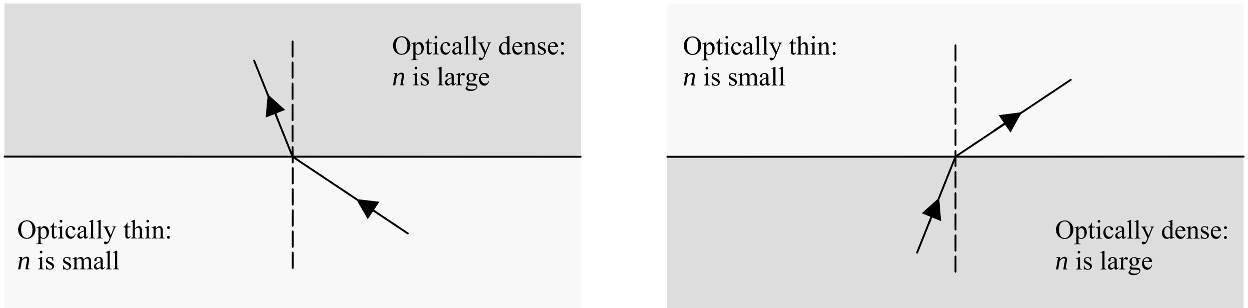
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Snell's Law

Figure 1: Snell's law

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 fig. 1.

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 2: Bending of rays due to refraction

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 2. Use these diagrams when answering some of the questions in this handout.

In Figure 2 part (a), the greater the index of refraction of the dense material, the more the ray bends.

DIRECT MEASUREMENT OF THE INDEX OF REFRACTION OF GLASS

For the situation in Figure 1, Snell's Law is

$$\mathbf{n_1 \sin\theta_1 = n_2 \sin\theta_2.}$$

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

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

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

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

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}.

ACTIVITY 1: MEASURE THE INDEX OF REFRACTION OF A GLASS PLATE

Follow the directions below to complete Table 1.

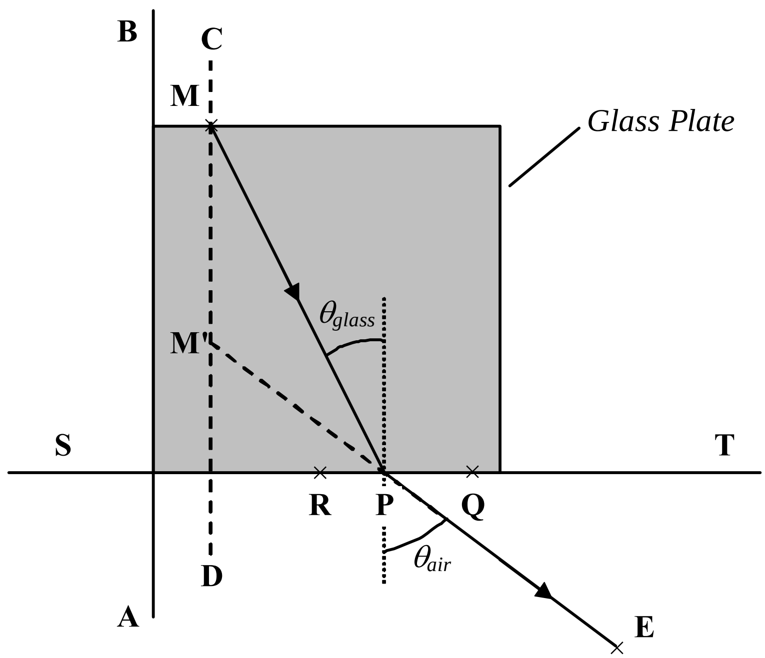


Figure 3: Placement of glass plate and location of first pin (at point P)

PROCEDURE

1. Remove the last page from this handout, and tape it to your drawing board. This will be referred to as worksheet for the rest of the procedure.
2. On the worksheet, locate the two solid lines **ST** and **AB**. Place your glass plate on the Lab Worksheet aligned with **ST** and **CD** as shown in fig 3.
3. Stick a pin into the drawing board at the point identified as **M** in fig 3. **M** is on line **CD** at the top of the glass plate.
4. Stick a second pin into the drawing board at point **P** (at the place marked with an ×) on the worksheet.
5. The following steps describe the procedure for locating a third pin on the drawing board.
    a. Bring your eye to the level of the paper, and sight through the glass.
    b. 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**.
    c. Stick a third pin into the drawing board (at point **E** in fig. 3) so that it and the other two pins all lie on a single straight line.
6. Using the pin holes in the 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**.
7. With your protractor, measure $\boldsymbol{\theta_{glass}}$ and $\boldsymbol{\theta_{air}}$. Record the results in Table 1.
8. Show your calculations in the space provided below the table.
9. Repeat steps 1 - 8, but with pins at points **R** and **Q** on the worksheet.

10. 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.
11. Calculate the discrepancy estimate. Discrepancy estimates in the range 2% to 5% are reasonable. If the discrepancy estimate is greater, repeat the experiment.

POSITION	**ANGLE OF PROPAGATION IN AIR (ANGLE OF INCIDENCE) $\Theta_{AIR}°$**	**ANGLE OF PROPAGATION IN GLASS (ANGLE OF REFRACTION) $\Theta_{GLASS}°$**	**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 _______________

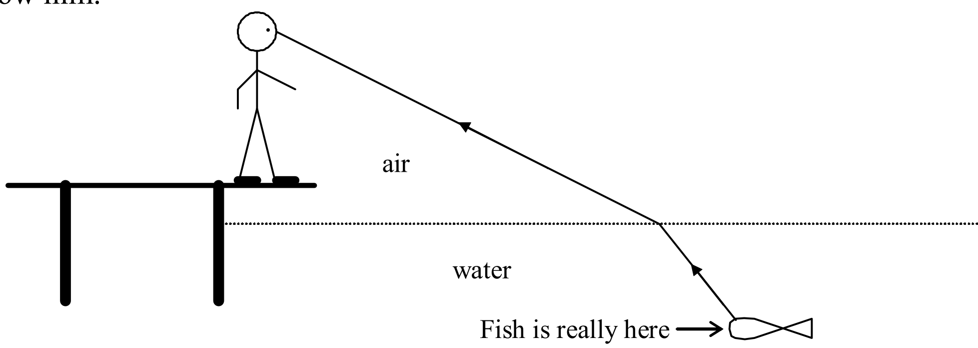
Discrepancy estimate, $\frac{n_{largest} - n_{smallest}}{n_{average}} \times 100\%$ **:** _______________

Discrepancies around 5% or less are typical.

ACTIVITY 2: QUESTIONS

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.

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

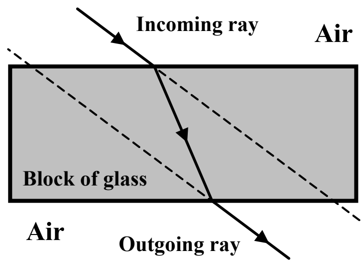


   a. On the diagram for this question, draw the fish in the location where it appears to be, as seen by the person on the dock.

   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.

   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?

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



4. Figure 4 part (a) shows two rays of light that meet at the same point on a screen. In Figure 4 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 2.

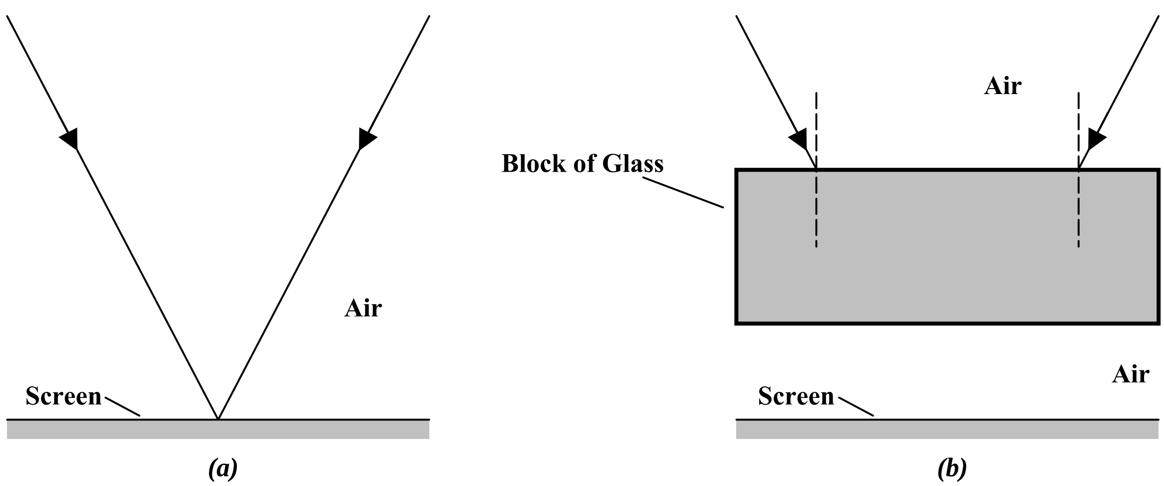
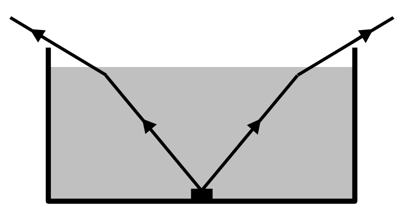
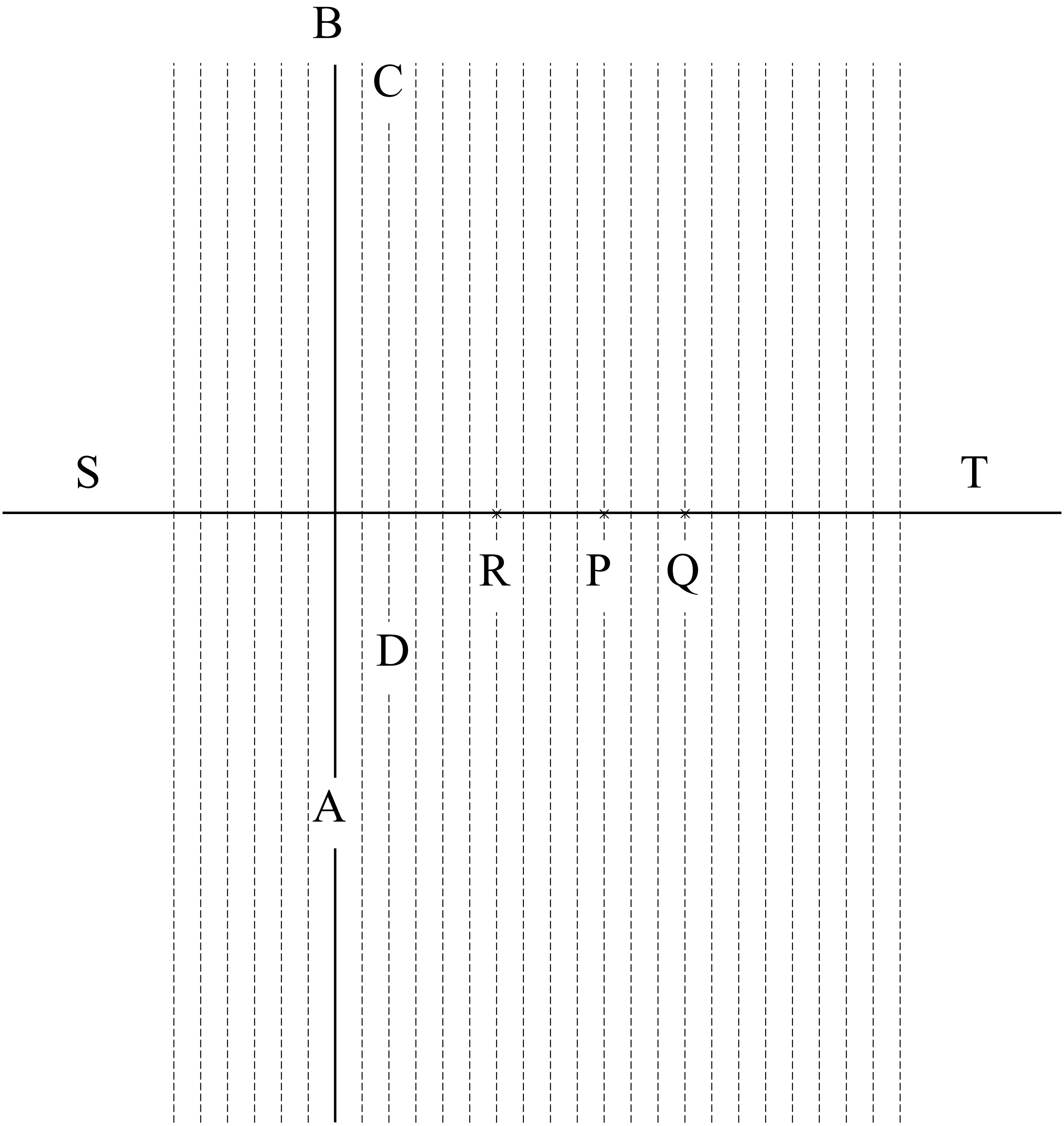


Figure 6

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 2.

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