

PHYSICS 2

SECTION II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

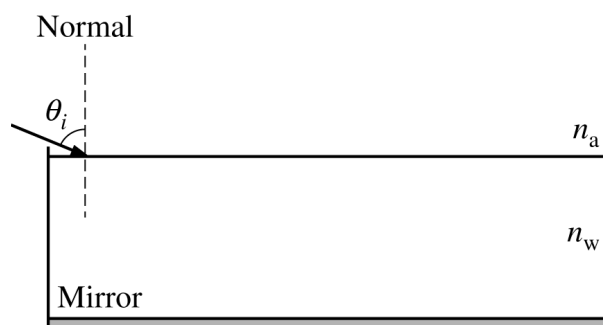
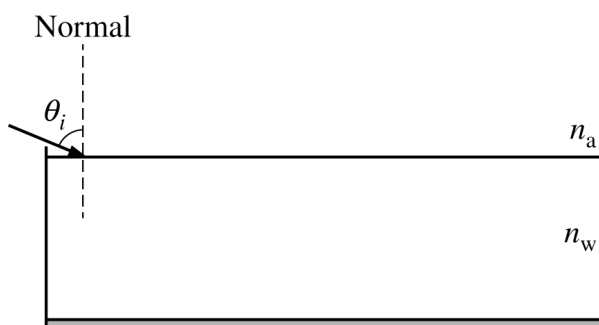


Figure 1

(10 points, suggested time 20 minutes)

A rectangular tank with a mirrored bottom is filled with water (index of refraction n_w). A beam of light passes from air (index of refraction n_a) into the water at angle θ_i from the normal, as shown in Figure 1. Index of refraction n_w is greater than index of refraction n_a .

- (a) On the following diagram, sketch the entire path of the beam as the beam enters, travels through, and then exits the water.

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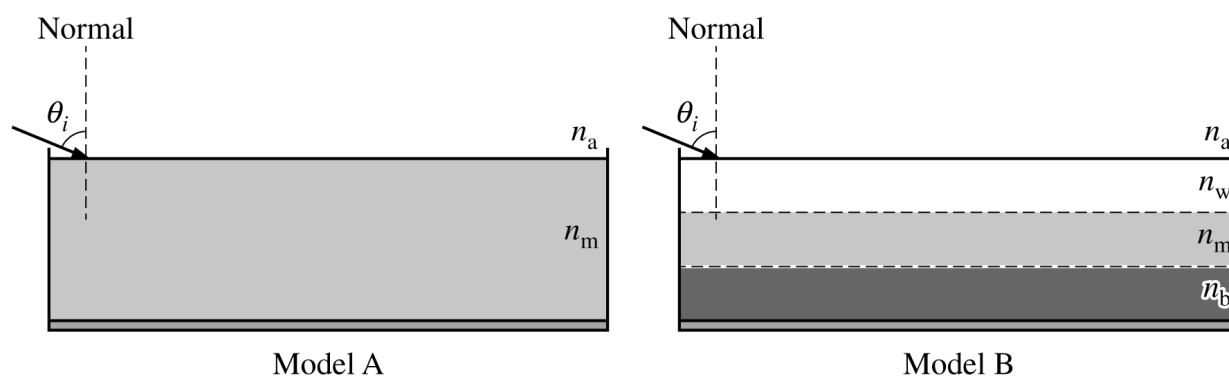
Continue your response to **QUESTION 1** on this page.

Figure 2

Sugar is then added to the water, resulting in a mixture that has a different index of refraction than water. A student considers two models, Model A and Model B, for how the sugar mixes with water. The models are shown in Figure 2.

Model A: The sugar is uniformly mixed throughout the water, resulting in a mixture with index of refraction n_m such that $n_m > n_w$.

Model B: Layers are formed of varying concentrations of sugar in the water. There are three distinct layers of equal volume. The top layer is only water (index of refraction n_w). The middle layer has the same concentration of sugar as the mixture in Model A (index of refraction n_m). The bottom layer has the highest concentration of sugar (index of refraction n_b).

(b) Consider Model A. Briefly describe how the observed wavelength of light changes, if at all, as the beam travels from air into the mixture.

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- (c) Relevant angles between the beam and the normal for the various layers present in models A and B are defined in the following table.

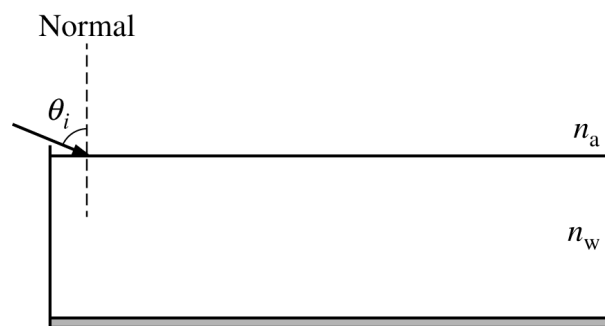
Model A		Model B	
θ_i	Incident angle of the beam in air	θ_i	Incident angle of the beam in air
θ_1	Angle the beam makes with the normal in the mixture in Model A	θ_2	Angle the beam makes with the normal in the top layer in Model B
		θ_3	Angle the beam makes with the normal in the middle layer in Model B
		θ_4	Angle the beam makes with the normal in the bottom layer in Model B

- i. Determine an expression for θ_4 in terms of θ_i , n_a , and n_b .
- ii. Rank the angles from greatest to least, with 1 being greatest. If two angles are the same value, give them the same ranking.

_____ θ_1 _____ θ_2 _____ θ_3 _____ θ_4

Briefly explain your reasoning using appropriate physics principles and/or mathematical models.

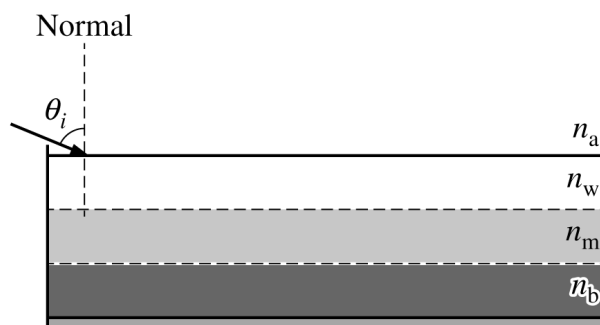
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Continue your response to **QUESTION 1** on this page.

Original Tank



Model A



Model B

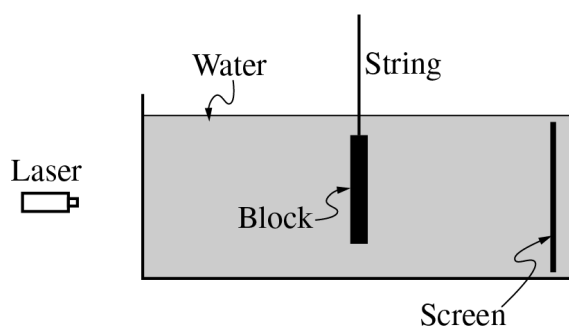
For the original tank filled with water, the beam is observed to exit the surface of the water a horizontal distance d_w from the entry point. For models A and B, the horizontal distances are d_A and d_B , respectively.

- (d) Determine whether d_A and d_B are each greater than, less than, or equal to d_w . It is NOT necessary to compare d_A to d_B . Briefly justify your answer.

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PHYSICS 2**SECTION II****Time—1 hour and 30 minutes****4 Questions**

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1. (10 points, suggested time 20 minutes)

Students are investigating electromagnetic wave phenomena in transparent media. They use a string to support a stationary thin, rectangular block of mass m_b , volume V_b , and density ρ_b . The block has two narrow slits in its center and is submerged in a glass tank containing water with density ρ_w , as shown above.

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Continue your response to **QUESTION 1** on this page.

(a)

- i. On the dot below, which represents the block, draw and label the forces that are exerted on the block. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

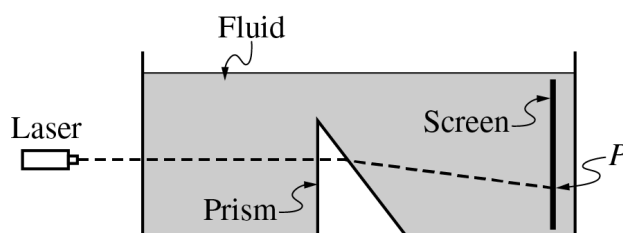


- ii. Derive an expression for the force exerted on the block by the string in terms of the given quantities and physical constants, as appropriate.

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Continue your response to **QUESTION 1** on this page.

- (b) A monochromatic laser beam is incident perpendicular to the wall of the tank. The beam passes through the slits in the block. An interference pattern is formed on the screen inside the tank. The water is then replaced with a clear fluid with a greater index of refraction than that of water. In a coherent, paragraph-length response, describe how the greater index of refraction of the new fluid affects the interference pattern. Explain your reasoning in terms of speed, frequency, and wavelength of the light.



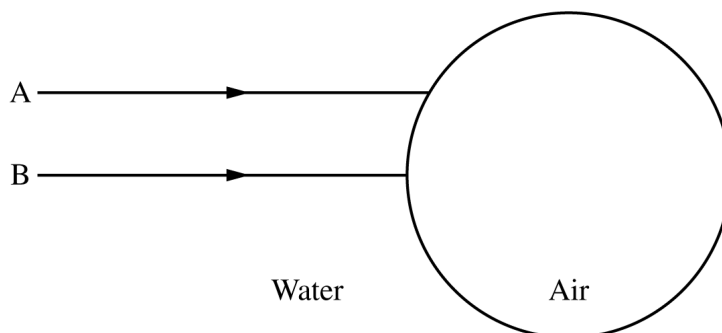
- (c) The block is replaced by a triangular prism, as shown above. The path of the beam is indicated by the dotted line, and the beam reaches the screen at point P . The fluid is then removed from the tank, and the prism is surrounded by air. Predict whether the beam will reach the side of the tank above point P , at point P , or below point P when the prism is surrounded by air. Support your answer using physics principles.

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4. (10 points, suggested time 20 minutes)

A student notices many air bubbles rising through the water in a large fish tank at an aquarium.

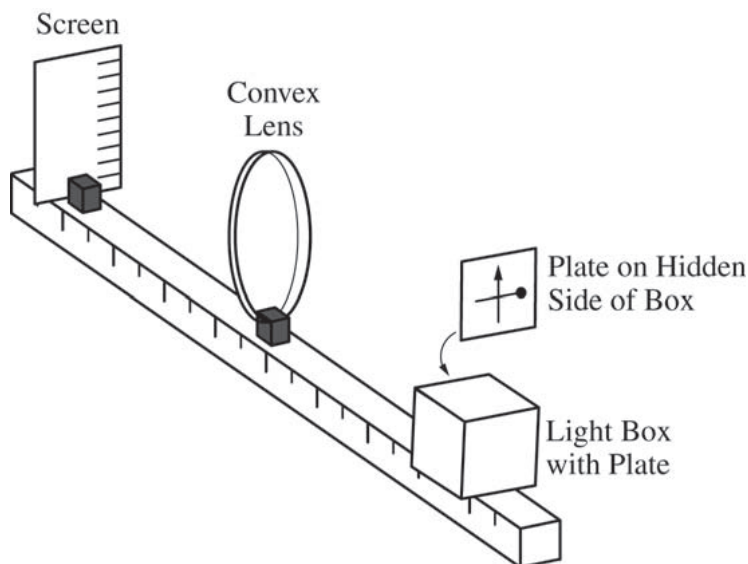
- (a) In the figure below, the circle represents one such air bubble, and two incoming rays of light, A and B, are shown. Ray B points toward the center of the circle. On the diagram, draw the paths of rays A and B as they go through the bubble and back into the water. Your diagram should clearly show what happens to the rays at each interface.



- (b) The bubble has a volume V_1 , the air inside it has density ρ_A , and the water around it has density ρ_W . The bubble starts at rest and has a speed v_f when it has risen a height h . Assume that the change in the bubble's volume is negligible. Derive an expression for the mechanical energy dissipated by drag forces as the bubble rises this distance. Express your answer in terms of the given quantities and fundamental constants, as appropriate.
- (c) At a particular instant, one bubble is 4.5 m below the water's surface. The surface of the water is at sea level, and the density of the water is 1000 kg/m^3 .
- Determine the absolute pressure in the bubble at this location.
 - The bubble has a volume V_1 when it is 4.5 m below the water's surface. Assume that the temperature of the air in the bubble remains constant as it rises. In terms of V_1 , calculate the volume of the bubble when it is just below the surface of the water.
 - If the air in the bubble cooled as it rose, the volume of the bubble would be less than the value calculated in part (c)(ii). Use physics principles to briefly explain why.

STOP

END OF EXAM



3. (12 points, suggested time 25 minutes)

Some students are asked to determine the focal length of a convex lens. They have the equipment shown above, which includes a waterproof light box with a plate on one side, a lens, and a screen. The box has a bright light inside, and the plate on the side has shapes cut out of it through which the light shines to create a bright object. This particular plate has a cutout that is a vertical arrow and a horizontal bar with a circle at one end. In the view shown above, the circle is near the right edge of the plate.

With the screen and light box on opposite sides of the lens, the box is aligned so that the plate is 20 cm from the center of the lens, and an image of the arrow and bar is formed on the screen. The students find that the image is clear on the screen when the screen is 30 cm from the center of the lens.

(a) On the figure below, sketch how the image on the screen appears to the students.

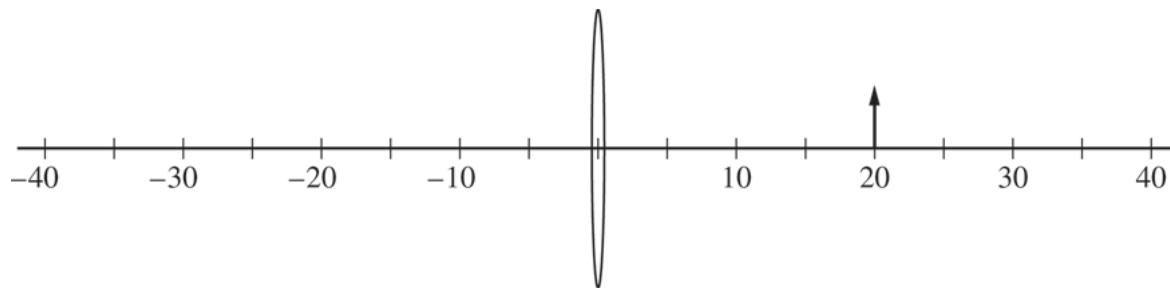


(b)

- i. Calculate the focal length of the lens.
- ii. Calculate the magnitude of the magnification of the image.

(c)

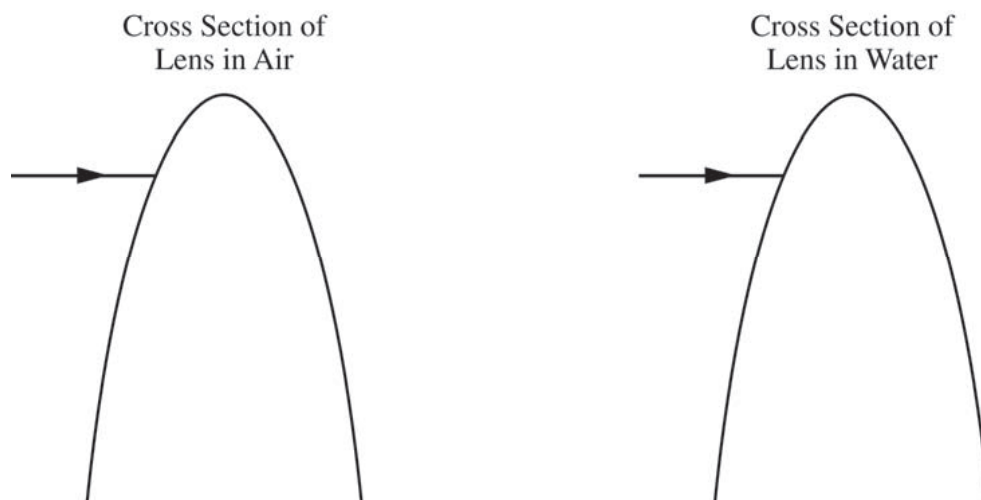
- i. In the side view below, the arrow represents the bright object created by the plate. Draw a ray diagram on the figure below that is consistent with your calculations in parts (b)(i) and (ii). Show at least two rays, as well as the location and orientation of the image.



- ii. Explain how your diagram is consistent with your calculated focal length and magnification in parts (b)(i) and (ii).

- (d) The entire apparatus is now submerged in water, whose index of refraction is greater than that of air but less than that of the lens.

- i. The figures below show cross sections of the top portion of the convex lens in air and the convex lens in water. An incident ray is shown in both cases. On each figure, draw the ray as it passes through the lens and back into the air or water.



- ii. Describe how the focal length of the lens and the position and size of the image formed by the lens when it is in the water compare to when the lens is in air. Explain how the rays drawn in the figures in part (d)(i) support your answer.

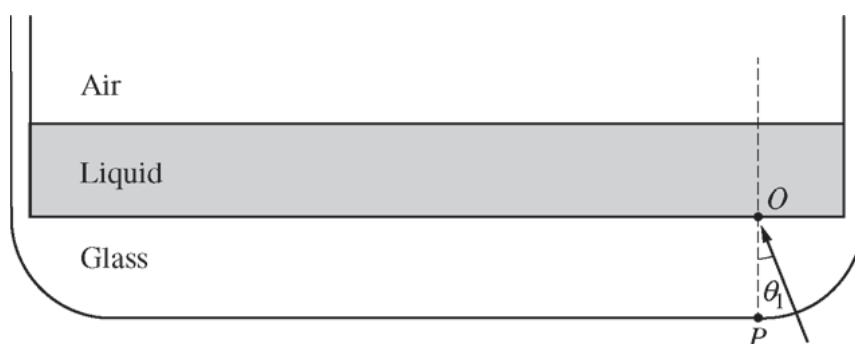
2. (12 points, suggested time 25 minutes)

A student is given a glass block that has been specially treated so that the path of light can be seen as the light travels through the glass. The student is asked to design an experiment to measure the index of refraction of the glass. The light source available in the laboratory is a hydrogen lamp that emits red light of a known wavelength.

- (a) A linear graph is to be used to determine the index of refraction of the glass. Indicate the quantities that should be graphed and describe how the graph could be used to determine the index of refraction of the glass.
- (b) Outline an experimental procedure that could gather the necessary data. Include sufficient detail so that another student could follow your procedure. In addition to the glass block and the hydrogen lamp, the equipment in a typical classroom laboratory is available.
- (c) Predict how the path of the light will change as it enters the glass. Support your prediction using a qualitative comparison of the speed of light in glass and the speed of light in air.
- (d) Describe the process(es) by which red light from the lamp is produced by hydrogen atoms that are initially in the ground state. Draw and label an energy level diagram that supports the atomic process(es) you describe.

PHYSICS 2**Section II****4 Questions****Time—90 minutes**

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



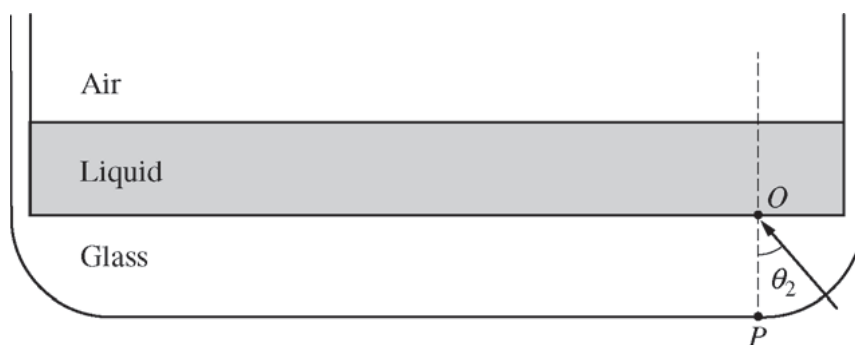
1. (10 points - suggested time 20 minutes)

The figure above shows a cross section of a drinking glass (index of refraction 1.52) filled with a thin layer of liquid (index of refraction 1.33). The bottom corners of the glass are circular arcs, with the bottom right arc centered at point O . A monochromatic light source placed to the right of point P shines a beam aimed at point O at an angle of incidence θ . The flat bottom surface of the glass containing point P is frosted so that bright spots appear where light from the beam strikes the bottom surface and does not reflect. When $\theta = \theta_1$, two bright spots appear on the bottom surface of the glass. The spot closer to point P will be referred to as X ; the spot farther from P will be referred to as Y . The location of spot X and that of spot Y both change as θ is increased.

- (a) In a coherent paragraph-length answer, describe the processes involved in the formation of spots X and Y when $\theta = \theta_1$. Include an explanation of why spot Y is located farther from point P than spot X is and what factors affect the brightness of the spots.

(b) When θ is increased to θ_2 , one of the spots becomes brighter than it was before, due to total internal reflection.

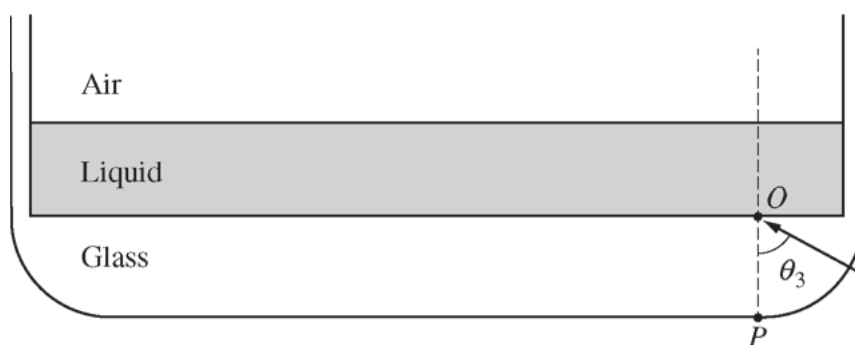
- i. On the figure below, draw a ray diagram that clearly and accurately shows the formation of spots X and Y when $\theta = \theta_2$.



- ii. Which spot, X or Y , becomes brighter than it was before due to total internal reflection? Explain your reasoning.

(c) When θ is further increased to θ_3 , one of the spots disappears entirely.

- i. On the figure below, draw a ray diagram that clearly and accurately shows the formation of the remaining spot, X or Y , when $\theta = \theta_3$.



- ii. Indicate which spot, X or Y , disappears. Explain your reasoning in terms of total internal reflection.