2022

AP® | CollegeBoard

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

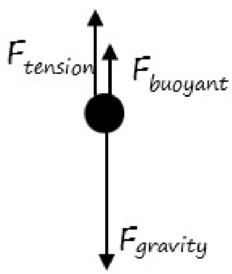
Free-Response Question 1

- ☑ Scoring Guidelines
- ☑ Student Samples
- ☑ Scoring Commentary

Question 1: Short Answer Paragraph Argument — 10 points

(a)(i)	For correctly drawing and labeling the gravitational, buoyant, and tension forces with no extraneous forces	**1 point**

Example Response



(a)(ii)	For an application of Newton's laws that is correct or consistent with the diagram in part (a)(i) and indicates zero net force	**1 point**
	For a correct substitution of the buoyant force into a solution that is consistent with the previous equation	**1 point**

Scoring Note: A correct answer with no supporting work earns this point.

Example Response

$$\Sigma\vec{F} = m\vec{a}$$

$$F_T + F_B - F_g = 0$$

$$F_T + F_B = F_g$$

$$F_T = F_g - F_B$$

$$F_T = m_b g - \rho_w V_b g$$

Total for part (a) 3 points

(b)	For correctly relating the speed of the light in the new medium to the index of refraction	**1 point**
	For indicating that the frequency does not change	**1 point**
	For a correct relationship between speed and wavelength	**1 point**
	For a correct relationship between wavelength and fringe separation	**1 point**
	For a logical, relevant, and internally consistent argument that addresses the question asked and follows the guidelines described in the published requirements for the paragraph-length response	**1 point**

Example Response

The speed of light in the new fluid is less than the speed of light in water because the fluid has a greater index of refraction. This means that the wavelength of the light in the beam will be smaller because the frequency does not change. Since the wavelength is smaller, the angular separation of the bright fringes will decrease, as described by the equation $m\lambda = d\sin\theta$.

Total for part (b) 5 points

(c) For explicitly indicating that the amount of refraction at the fluid-prism interface depends on the ratio of the indices of refraction of the materials **1 point**

Scoring Note: Basing the explanation on the difference in refractive indices is acceptable.

For correctly relating a larger angle of refraction to the beam hitting the screen below point P **1 point**

Example Response

The beam refracts more when the air is present because the difference between the indices of refraction between the prism and the surrounding medium is greater. So, the beam hits the screen below point P.

Total for part (c) 2 points

Total for question 1 10 points

Question 1

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

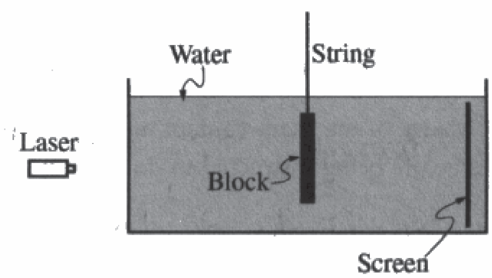
PHYSICS 2

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.



1. (10 points, suggested time 20 minutes)

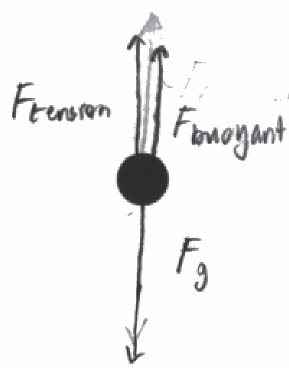
Students are investigating electromagnetic wave phenomena in transparent media. They use a string to support a ~~stationary~~ thin, rectangular block of mass m_b, volume V_b, and density ρ_b. The block has two narrow slits in its center and is submerged in a glass tank containing water with density ρ_w,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

Question 1

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.

Since this block is stationary, there is no net force acting on it. So, $F_{tension} + F_{buoyant} - F_g = 0$. Solving, for the tension in the string yields:

$$F_{tension} = F_g - F_{buoyant}$$

$$\Rightarrow F_{tension} = m_b g - \rho_w V_b g$$

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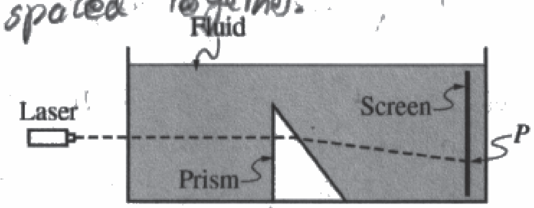
Question 1

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.

If the index of refraction of this clear liquid is greater than that of water, the speed of light in this fluid must be less than the speed of light in water. This will cause a decrease in the wavelength of light in this liquid according to the equation $\lambda = \frac{v}{f}$, since the frequency of a beam of light is constant regardless of the medium. Lastly, according to the equation $d\sin\theta = m\lambda$ this decrease in wavelength will cause a decrease in $\sin\theta$, since the separation d is kept constant. Because $\sin\theta \approx \theta$ for small values of θ, this will cause the angle of diffraction to be reduced. This will result in an interference patten that is more closely spaced together.



(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.

Since the light in this diagram bends away from the normal when it exits the prism, the index of refraction of the prism must be greater than that of the fluid. When the fluid is replaced by air, which has an index of refraction near 1 (smaller than the fluid), the relative difference in indexes of refraction between the prism and air will be even greater, causing light to bend further away from the normal vector as it exits the prism due to Snell's Law. This will result in a greater angle of refraction and will lead to the beam reaching the screen at a point below P.

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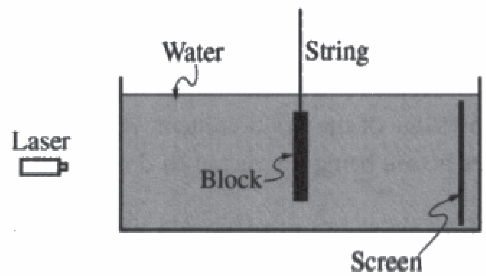

1. (10 points, suggested time 20 minutes)

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.

Question 1

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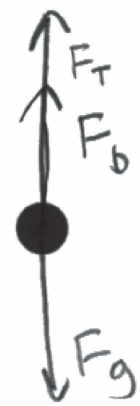


ii. Derive an expression for the force exerted on the block by the string in terms of the given quantities and physical constants, as appropriate.

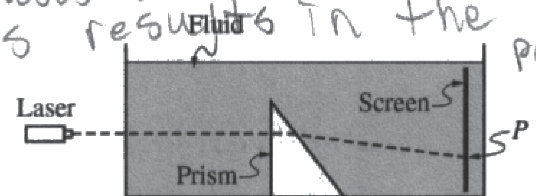
$$F_T = m_b \cdot g - \rho_b \cdot V_b \cdot g$$

Question 1

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.

The Interference Pattern will be decrease in width. Since the new fluid has a greater index of refraction, the speed of light in it will decrease, $\lambda = \frac{v}{f}$ ∴ the v has decreased and f is always the same during changes in medium so the λ decreases. In the formula $d \sin\theta = m\lambda$ d stays constant as the slit width doesn't change, m is constant as it determines brights or darks, and λ decreases. This results in sinθ also decreasing. $\sin\theta = \frac{x}{L}$ where x = width of the pattern and L is the length b/w the pattern and the slit. if sin θ decreases and L is constant, x must decrease. This results in the width of the pattern decreasing



fluid n<x prism n=2x

(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.

The beam will go to a Point below Point P as air's index of refraction < the fluids. The reason the beam bends in the first case is b/c light rays leave the prism and travel faster in the fluid than in the prism so they bend down. If the Δn is increased and the nprism is greater than nsurroundings, the beam will reflect more down. $n_{air} < n_{fluid} < n_{prism}$.

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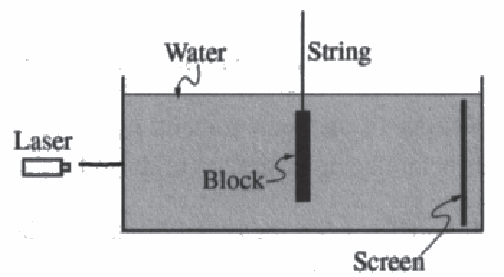

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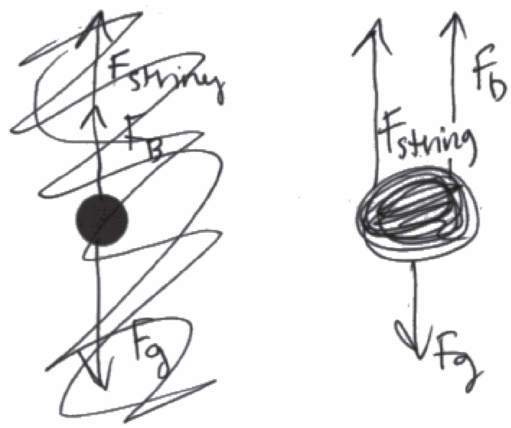


ii. Derive an expression for the force exerted on the block by the string in terms of the given quantities and physical constants, as appropriate.

$F_{string} + F_b = F_g$

$F_{string} + (\rho_b g V_b) = F_g$

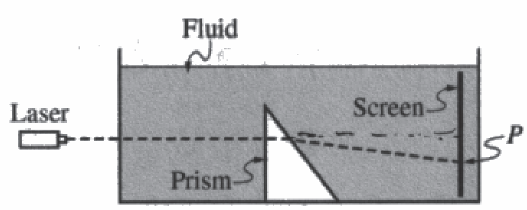
$F_{string} = F_g - (\rho_b g V_b)$

Question 1

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.

The distance between the light will be greater because the wavelength is larger. The index of refraction is greater so the refracted beams are farther from the normal and thus more spread out.



(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.

$n_{water} > n_{air}$

The beam will reach the side of the tank above point P because the refracted angle in air is less than the refracted angle in water so the beam is refracted closer to the normal.

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Question 1

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses were expected to demonstrate the ability to:

- Apply Newton's laws to a situation involving buoyancy.
- Relate the index of refraction of a medium, the speed of light in the medium, and the wavelength of the light in the medium.
- Demonstrate that when light travels from one medium to another, the frequency of the light does not change.
- Describe the relationship between the wavelength of light and the interference pattern it produces when going through a double slit.
- Use Snell's law at an interface between two optical media, including the meaning of the normal line.
- Create a free-body diagram.
- Perform a mathematical derivation.
- Write a coherent paragraph presenting a scientific analysis of a situation.

Sample: 1A
Score: 10

Part (a)(i) earned 1 point by drawing two distinct upward arrows labeled as the buoyant and tension forces and one downward arrow as the gravitational force. There are no extraneous forces. Part (a)(ii) earned 2 points. The first point was earned because the response states that the net force on the block is zero. The second point was earned because the correct substitution for the buoyant force, including the correct subscript for density, is clearly shown in the response. Part (b) earned 5 points. The first point was earned because the response explicitly states that the index of refraction decreases the speed of the light. The second point was earned because the response explicitly states that the frequency of the light is the same in both materials. The third point was earned because the response connects a decrease in speed with a decrease in wavelength. The fourth point was earned by relating the decreased wavelength with a decrease in the separation between maxima. The fifth point was earned because the response is relevant, internally consistent, and in paragraph form. Part (c) earned 2 points. The first point was earned because the response makes an explicit connection between the angle of refraction at the prism-fluid boundary and the angle of refraction at the prism-air boundary. The second point was earned because the response correctly connects a larger angle of refraction in air to the light hitting the screen below point P.

Sample: 1B
Score: 7

Part (a)(i) earned 0 points because on the free body diagram, the arrows must be separate and distinct; in the response, the arrows are drawn to be coincident and, thus, did not earn this point. Part (a)(ii) earned 0 points. The first point was not earned because the prompt asks for a derivation, which must begin with a fundamental property or relationship. By only stating the derived solution, the response did not earn the point for starting the derivation with a fundamental principle. The second point was not earned because, while a substitution is made for the buoyant force, the subscript identifies the density of the block instead of the density of the fluid. Part (b) earned 5 points. The first point was earned because the response connects the greater index of refraction with the slower speed of light through the fluid. The second point was earned because the response explicitly states that frequency is consistent from medium to medium. The third point was earned because the response connects a decrease in speed with a decrease in wavelength. The fourth point was earned because the response connects the decreased wavelength with the decreased width between maxima. The fifth point was earned because the response is relevant, internally consistent, and in paragraph form. Part (c) earned 2 points. The first point was earned because the response discusses the change in angle of refraction as the ray transitions from the prism to the water as compared to the transition from the prism to the air. The second point was earned because the response states that the increased angle of refraction will cause the beam to intersect the screen below point P.

Question 1 (continued)

Sample: 1C
Score: 4

Part (a)(i) earned 1 point by including two upward arrows labeled as tension and buoyant force and one downward arrow representing the gravitational force. There are no extraneous arrows drawn in the free body diagram.
Part (a)(ii) earned 1 point. The first point was earned by creating equality between the upward and downward forces consistent with the free-body diagram drawn in part (a)(i); the response implies that the net force is zero. The second point was not earned because even though there is a substitution for the buoyant force, the incorrect density is identified. Part (b) earned 2 points. The first point was not earned because the speed of light is not addressed, particularly relative to the increased index of refraction. The second point was not earned because the frequency of the beam is not addressed. The third point was not earned because while wavelength is addressed, the response does not explicitly or implicitly relate the wavelength and the speed of the wave in the medium. The fourth point was earned because the response correctly relates the increased distance between maxima to the increased wavelength. This relationship is consistent with the other statements in the response, even though the wavelength would decrease. The fifth point was earned because the response is relevant, internally consistent, and in paragraph form. Part (c) earned 0 points. The first point was not earned because the response does not discuss the relative change in indices of refraction between the prism and water versus the prism and air. The second point was not earned because the response indicates that the beam will strike the screen above point P instead of below point P.