2018

AP CollegeBoard

AP Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

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Free Response Question 4

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AP® PHYSICS
2018 SCORING GUIDELINES

General Notes About 2018 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

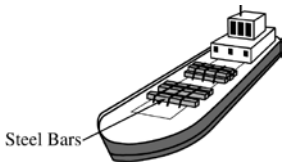
5. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but the use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

AP® PHYSICS 2
2018 SCORING GUIDELINES

Question 4

10 points total **Distribution of points**



A large boat like the one shown above has a mass M_b and can displace a maximum volume V_b. The boat is floating in a river with water of density ρ_{water} and is being loaded with steel beams each of density ρ_{steel} and volume V_{steel}. The boat owners want to be able to carry as many beams as possible.

(a) LO 1.E.1.2, SP 6.4; LO 3.B.2.1, SP 1.1, 1.4, 2.2; LO 5.B.10.1, SP 2.2
4 points

Derive an expression for the maximum number N of steel beams that can be loaded on the boat without exceeding the maximum displaced volume, in terms of the given quantities and physical constants, as appropriate.

For equating the correct forces acting on the boat-steel system: gravity (weight) and the buoyant force		1 point
For correctly calculating the weight of the boat-steel system		1 point
$W_{system} = (M_b + N_{steel}\rho_{steel}V_{steel})g$, where N is the number of steel beams (must clearly use mass of boat)		
For correctly calculating the buoyant force		1 point
$F_b = \rho_{water}gV_b$		
For algebraic manipulation of the equations to get an expression for the number of beams consistent with the equations for weight and buoyant force		1 point
$(M_b + N\rho_{steel}V_{steel})g = \rho_{water}gV_b$		
$N = (\rho_{water}V_b - M_b)/\rho_{steel}V_{steel}$		

(b) LO 6.C.1.1, SP 6.4, 7.2; LO 6.E.1.1, SP 6.4, 7.2; LO 6.E.3.3, SP 6.4, 7.2
4 points

The captain realizes that oil is leaking from the boat, creating a thin film of oil on the water surface. In one area of the oil film the surface looks mostly green. Explain in detail how constructive interference contributes to the green appearance. Assume the index of refraction of the oil is greater than the index of refraction of the water.

The constructive interference is between light reflected from the air-oil interface and light reflected from the oil-water interface.		
For indicating that the green appearance is the result of interference of light from two waves		1 point
For indicating that there is a phase shift due to one of the reflections		1 point
For indicating that the wavelength of the light is different in air and oil		1 point
For indicating that there is a path-length difference of the light reflected from the two surfaces		1 point

Question 4 (continued)

Distribution of points

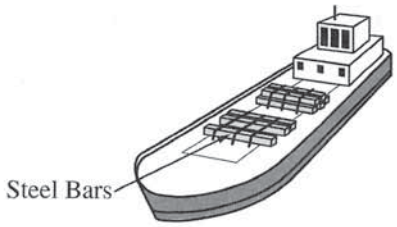
(c) LO 5.F.1.1, SP 2.2, 7.2
2 points

Later the boat is floating down the river with the water current, heading for a town. The river has a width of 60 m and a constant depth and flows at a speed of $5\ \text{km/hr}$. Partway to the town, the river narrows to a width of 30 m while its depth remains the same. Calculate the speed of the water in the narrow section.

For an attempting to apply the principle of continuity		1 point
$A_{wide}v_{wide} = A_{narrow}v_{narrow}$		
$(60\ \text{m})(\text{depth})(5\ \text{km/hr}) = (30\ \text{m})(\text{depth})(v_{narrow})$		
For correctly calculating the speed		1 point
$v_{narrow} = 10\ \text{km/hr}$		

Learning Objectives (LO)

LO 1.E.1.2: The student is able to select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. [See Science Practices 4.1, 6.4]
LO 3.B.2.1: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, 2.2]
LO 5.B.10.1: The student is able to use Bernoulli's equation to make calculations related to a moving fluid. [See Science Practice 2.2]
LO 5.F.1.1: The student is able to make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). [See Science Practices 2.1, 2.2, 7.2]
LO 6.C.1.1: The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves. [See Science Practices 6.4, 7.2]
LO 6.E.1.1: The student is able to make claims using connections across concepts about the behavior of light as the wave travels from one medium into another, as some is transmitted, some is reflected, and some is absorbed. [See Science Practices 6.4, 7.2]
LO 6.E.3.3: The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation. [See Science Practices 6.4, 7.2]



4. (10 points, suggested time 20 minutes)

A large boat like the one shown above has a mass M_b and can displace a maximum volume V_b. The boat is floating in a river with water of density ρ_{water} and is being loaded with steel beams each of density ρ_{steel} and volume V_{steel}. The boat owners want to be able to carry as many beams as possible.

(a) Derive an expression for the maximum number N of steel beams that can be loaded on the boat without exceeding the maximum displaced volume, in terms of the given quantities and physical constants, as appropriate.

$F_b = F_{W_{boat}} + F_{steel}$

$\rho_{water} V_b g = M_b g + \rho_{steel} V_{steel} N g$

$$N = \frac{\rho_{water} V_b - M_b}{\rho_{steel} V_{steel}}$$

(b) The captain realizes that oil is leaking from the boat, creating a thin film of oil on the water surface. In one area of the oil film the surface looks mostly green. Explain in detail how constructive interference contributes to the green appearance. Assume the index of refraction of the oil is greater than the index of refraction of the water.

The oil floats on the water and because its index of refraction is greater than air, light that reflects off of the oil is phase shifted by half a wavelength. Some light travels into the oil and is refracted more downward due to higher index of refraction than air. This light reflects off of the bottom of the oil layer and is not phase shifted as the water has a higher index of refraction than the oil, the light then travels back up and reflects out of the oil at the same angle as the light was reflected off the top of the oil. The light reflected from both processes is constructive at the green wavelength because the distance it took the light to travel considering its lessened wavelength through the oil phase shifted it half a green light wavelength to match the green light reflected off the oil.

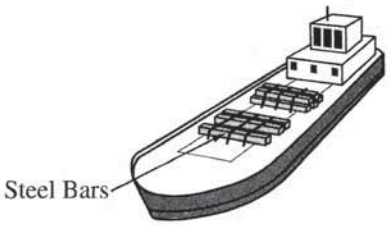
GO ON TO THE NEXT PAGE.

(c) Later the boat is floating down the river with the water current, heading for a town. The river has a width of 60 m and a constant depth and flows at a speed of 5 km/hr. Partway to the town, the river narrows to a width of 30 m while its depth remains the same. Calculate the speed of the water in the narrow section.

d = depth (m)

$V_1 A_1 = V_2 A_2$

$V_2 = \frac{V_1 A_1}{A_2} = \frac{(5)(d)(60)}{d\,(30)} = 10 \text{ km/hr}$



4. (10 points, suggested time 20 minutes)

A large boat like the one shown above has a mass M_b and can displace a maximum volume V_b. The boat is floating in a river with water of density ρ_{water} and is being loaded with steel beams each of density ρ_{steel} and volume V_{steel}. The boat owners want to be able to carry as many beams as possible.

(a) Derive an expression for the maximum number N of steel beams that can be loaded on the boat without exceeding the maximum displaced volume, in terms of the given quantities and physical constants, as appropriate.

$F_b = \rho_w V_b g = (m_s g) N$

$\rho_{steel} = \frac{m_{steel}}{V_{steel}}$

$\rho_w V_b g = (\rho_{steel} \cdot V_{steel}) g N$

$m_{steel} = \rho_s V_s$

$N = \frac{\rho_{water} V_{boat}}{\rho_{steel} \cdot V_{steel}}$

(b) The captain realizes that oil is leaking from the boat, creating a thin film of oil on the water surface. In one area of the oil film the surface looks mostly green. Explain in detail how constructive interference contributes to the green appearance. Assume the index of refraction of the oil is greater than the index of refraction of the water.

When the light is traveling in oil, some of the light reflects instead of going into water + interference patterns occur at the surface which gives it a green color. Since $n_{oil} > n_w$, the constructive interference occurs at $\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}$ & so on.

GO ON TO THE NEXT PAGE.

1.382 mls

P2 Q4 B p2

(c) Later the boat is floating down the river with the water current, heading for a town. The river has a width of 60 m and a constant depth and flows at a speed of 5 km/hr . Partway to the town, the river narrows to a width of 30 m while its depth remains the same. Calculate the speed of the water in the narrow section.

$A_1 v_1 = A_2 v_2$

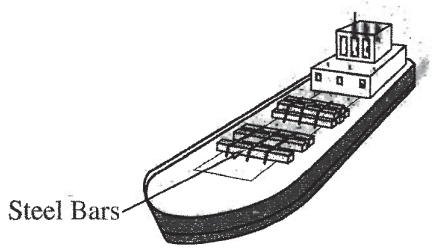
$A = \frac{1}{2} A_{circle}$

$A_1 = \frac{1}{2}(\pi(30)^2) = 1413.72\ m^2$

$1413.72(5) = 353.43\ v_2$

$A_2 = \frac{1}{2}(\pi(15)^2) = 353.43\ m^2$

$v_2 = 20\ km/hr$



4. (10 points, suggested time 20 minutes)

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(a) Derive an expression for the maximum number N of steel beams that can be loaded on the boat without exceeding the maximum displaced volume, in terms of the given quantities and physical constants, as appropriate.

~~$V_b + V_{steel} = V_{total}$~~ $V_{steel} < V_{boat}$

$P_{water} > P_{steel}$

In order to hold N steel beams, the volume of steel must be less than the volume of the boat and the total density must be less than the density of water.

(b) The captain realizes that oil is leaking from the boat, creating a thin film of oil on the water surface. In one area of the oil film the surface looks mostly green. Explain in detail how constructive interference contributes to the green appearance. Assume the index of refraction of the oil is greater than the index of refraction of the water.

Due to a greater index of refraction in oil than in water, light will have a harder time getting through and therefore will make it have a green appearance.

(c) Later the boat is floating down the river with the water current, heading for a town. The river has a width of 60 m and a constant depth and flows at a speed of 5 km/hr. Partway to the town, the river narrows to a width of ~~30 m~~ while its depth remains the same. Calculate the speed of the water in the narrow section.

$A_1 V_1 = A_2 V_2$

$A_1 = 60\ m$

$V_1 = 5\ km/hr$

$A_2 = 30\ m$

$60\ m \times 5\ km/hr = 30\ m\ V_2$

$\frac{300}{30m} = \frac{30m}{30m} V_2$

$V_2 = 10\ km/hr$

The speed of water in the narrow section is 10 km/hr.

AP® PHYSICS 2
2018 SCORING COMMENTARY

Question 4

Overview

This question assessed learning objectives 1.E.1.2, 3.B.2.1, 5.B.10.1, 5.F.1.1, 6.C.1.1, 6.E.1.1, and 6.E.3.3.

The responses to this question were expected to demonstrate the following:

- An understanding of buoyant force.
- An understanding of thin-film interference.
- An understanding of the equation of continuity.
- The ability to manipulate variables.
- The ability to solve an equation.

Sample: P2 Q4 A
Score: 10

Part (a) earned 4 points. The response clearly starts with the fundamental concept of force, equating the correct forces acting on the boat-steel system (force due to gravity on the boat and steel and the buoyant force). It uses correct expressions for the buoyant force and the weight of the boat-steel system and manipulates the equations to get an expression for *N*. Part (b) earned 4 points. It describes the two relevant reflections and indicates that the green appearance is the result of interference of light from these two waves. It says that there is a phase shift due to one of the reflections. In the last few lines it mentions the distance traveled in the oil and the "lessened" wavelength of the light oil. Part (c) earned 2 points. The response shows the application of the principle of continuity and correct calculation of the speed in km/hr.

Sample: P2 Q4 B
Score: 5

Part (a) earned 3 points. The response starts with an equation relating gravity on the system and the buoyant force that earned credit. However, it does not include the weight of the boat, so the point for the correct weight was not earned. The buoyant force on the system is correct, and the resulting equation is correctly manipulated to get an expression for *N*. Part (b) earned 1 point for indicating that the green appearance is the result of interference of light from two different waves. It does not explicitly indicate that there is a phase shift due to one of the reflections. The values in the second sentence imply a phase shift, but it is not clear whether the student has applied that fact or simply recalls appropriate conditions. The response does not indicate any difference in wavelength in the materials or any path length difference of the light reflected from the two surfaces. Part (c) earned 1 point for attempting to apply continuity. The calculation uses the two river widths but in the formula for the area of a circle instead of a rectangle.

Sample: P2 Q4 C
Score: 2

Part (a) earned no points because no appropriate relationship between forces or densities is shown that would allow determination of the number of steel beams. Part (b) earned no points for an explanation that shows no understanding that the situation involves reflections and interference. Part (c) earned 2 points. The response shows the application of the principle of continuity and correct calculation of the speed in km/hr.