2017

AP CollegeBoard

AP Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

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AP Central is the official online home for the AP Program: apcentral.collegeboard.org

AP® PHYSICS
2017 SCORING GUIDELINES

General Notes About 2017 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 one 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 and 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 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
2017 SCORING GUIDELINES

Question 1

10 points total | **Distribution of points**

(a)

i. 1 point

For indicating that student Y is correct in stating that the water moves faster at point *B*, and not indicating any other aspect — 1 point

ii. 2 points

Student Y's statement that P_B is greater than P_A is not correct.

For a correct indication of how height affects pressure using the Bernoulli equation (i.e., conservation of energy principles) — 1 point

For correct indication of how the speed affects pressure using the Bernoulli equation (i.e., conservation of energy principles) — 1 point

Example: The pressure at point *B* is not greater. Because the water at *B* is moving faster and is higher than at point *A*, the kinetic energy and the gravitational potential energy terms in Bernoulli's equation are both greater. Because the sum of pressure and these energy terms is a constant, the pressure must be less.

iii. 1 point

For indicating one of the following: — 1 point

- Student Z is correct in stating that the potential energy of the water-Earth system has increased.
- Student Z is correct in stating that conservation of energy applies.
- Stating that nothing is correct or giving no response, with a justification in (iv).

iv. 1 point

For indicating that student Z is incorrect in stating that the speed is less at point *B*, not indicating any other aspect, and using continuity or the Bernoulli equation (i.e., conservation of energy principles) to show that it is greater — 1 point

OR

if third bullet for (iii) applies, indicating that work is done on the water due to the pressure difference, so the energy is not constant

Question 1 (continued)

Distribution of points

(b)

i. 2 points

For a correct application of the continuity equation including substitutions 1 point

$A_A v_A = A_B v_B$

$v_B = A_A v_A / A_B = r_A^2 v_A / r_B^2 = (2.5 \text{ cm})^2 (0.5 \text{ m/s}) / (1.5 \text{ cm})^2$

For a correct answer with units 1 point

$v_B = 1.4 \text{ m/s}$

ii. 1 point

For an application of Bernoulli's equation to this situation and substitutions consistent with (b)(i) 1 point

$$P_A + \rho g y_A + \frac{1}{2}\rho v_A^2 = P_B + \rho g y_B + \frac{1}{2}\rho v_B^2$$

$$P_B = P_A + \rho g (y_A - y_B) + \frac{1}{2}\rho \left(v_A^2 - v_B^2\right)$$

$$P_B = 2 \times 10^5 + (1000)(10)(-5) + \frac{1}{2}(1000)\left(0.5^2 - 1.4^2\right) = 2 \times 10^5 - 50000 - 855$$

$$P_B = 1.5 \times 10^5 \text{ Pa}$$

(c)

i. 1 point

For substituting correctly in an appropriate equation for determining the pressure 1 point

$P = P_0 + \rho g h_A = 1 \times 10^5 \text{ Pa} + \left(1000 \text{ kg/m}^3\right)\left(10 \text{ m/s}^2\right)(6 \text{ m})$

$P = 1.6 \times 10^5 \text{ Pa}$

ii. 1 point

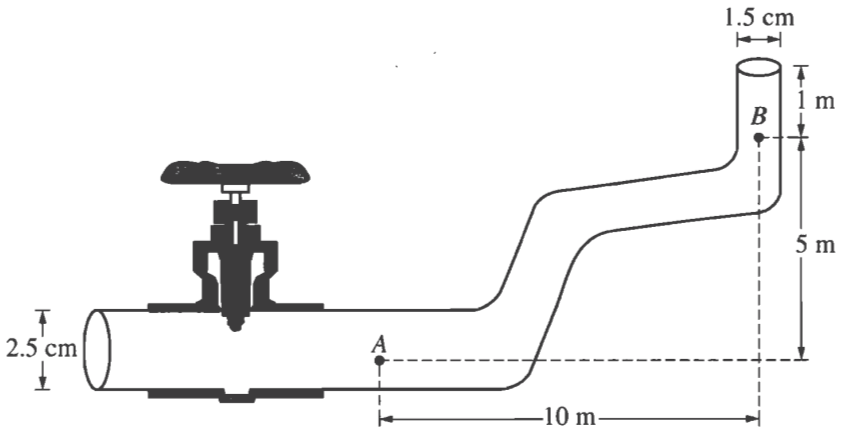
For indicating that the buoyant force is toward the top of the page and gravity is toward the bottom of the page, with the buoyant force longer 1 point

Student can draw lots of pressure forces around the dot instead of one buoyant force, as long as there is no buoyant force labeled and they add up to a net buoyant force that is longer than the gravitational force.

P2 Q1 A1

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.



Note: Figure not drawn to scale.

1. (10 points, suggested time 20 minutes)

Two students observe water flowing from left to right through the section of pipe shown above, which decreases in diameter and increases in elevation. The pipe ends on the right, where the water exits vertically. At point A the water is known to have a speed of $0.50\ \text{m/s}$ and a pressure of $2.0 \times 10^5\ \text{Pa}$. The density of water is $1000\ \text{kg/m}^3$.

(a) The students disagree about the water pressure and speed at point B. They make the following claims.
Student Y claims that the pressure at point B is greater than that at point A because the water is moving faster at point B.
Student Z claims the speed of the water is less at point B than that at point A because by conservation of energy, some of the water's kinetic energy has been converted to potential energy of the Earth-water system.

i. Indicate any aspects of student Y's claim that are correct.

The water is moving faster at point B

ii. Indicate any aspects of student *Y*'s claim that are incorrect. Support your answer using appropriate physics principles.

The pressure at point B is less than the pressure at point A because the water is moving faster and there is less water above point B. These principles can be quantified by Bernoulli's equation

$$P_A + \rho g h_A + \frac{1}{2}\rho v_A^2 = P_B + \rho g h_B + \frac{1}{2}\rho v_B^2$$

iii. Indicate any aspects of student *Z*'s claim that are correct.

None of his claim is correct except that conservation of energy does occur.

iv. Indicate any aspects of student *Z*'s claim that are incorrect. Support your answer using appropriate physics principles.

The speed of the water at point B is greater than the speed at point A.

$$A_A v_A = A_B v_B$$

A larger area @ point A means a lower speed @ point A

Also, the kinetic energy isn't transferred to potential energy. Rather, work is done on the system when the volume of the pipe decreases, and both E_K & U_g increase.

(b) Calculate the following at point *B*.

i. The speed of the water

$$A_A v_A = A_B v_B$$

$$(1.5625\pi)(.5) = (.5625\pi)v_B$$

$$v_B = 1.39 \text{ m/s}$$

ii. The pressure in the pipe

$$P_B = P_A + \rho g h_A + \frac{1}{2}\rho v_A^2 - \rho g h_B - \frac{1}{2}\rho v_B^2$$

$$P_B = (2E5) + \frac{1}{2}(1000)(.25) - (1000)(10)(5) - \frac{1}{2}(1000)(1.39)^2$$

$$P_B = 1.4E5 \text{ Pa}$$

Question 1 continues on the next page.

GO ON TO THE NEXT PAGE.

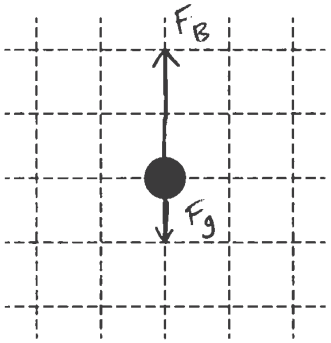
(c) A valve to the left of point *A* now closes off that end of the pipe. The section of pipe shown is still full of water, but the water is no longer flowing.

i. Calculate the absolute pressure at point *A* (the pressure that includes the effect of the atmosphere).

$P_A = P_0 + \rho g h$

$P_A = 10^5 + (1000)(10)(6) = 160000$ Pa

ii. An air bubble forms at point *A*. On the figure below, where the dot represents the air bubble, draw a free-body diagram showing and labeling the forces (not components) exerted on the bubble. Draw the relative lengths of all vectors to reflect the relative magnitudes of the forces.



Since the density of air is less than H_2O, the buoyant force is stronger than the gravitational force

P2 Q1 B1

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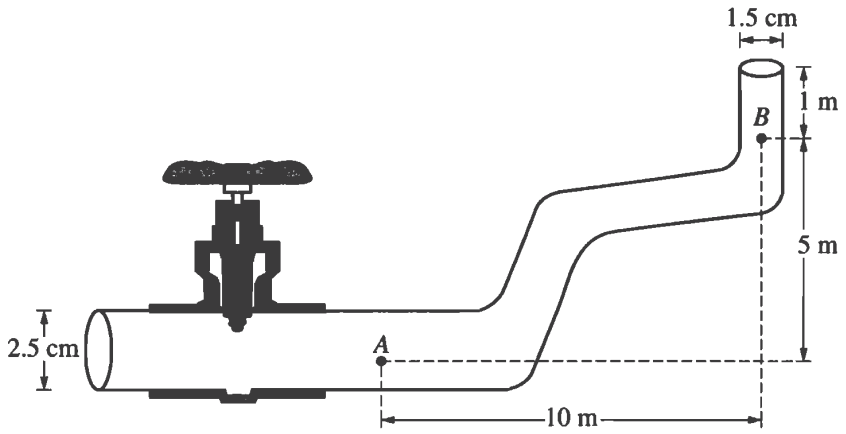


Note: Figure not drawn to scale.

1. (10 points, suggested time 20 minutes)

$A v_A = A v_B$ $A_B < A_A$ so $v_B > v_A$

Two students observe water flowing from left to right through the section of pipe shown above, which decreases in diameter and increases in elevation. The pipe ends on the right, where the water exits vertically. At point *A* the water is known to have a speed of 0.50 m/s and a pressure of 2.0×10^5 Pa. The density of water is 1000 kg/m^3.

(a) The students disagree about the water pressure and speed at point *B*. They make the following claims.
Student *Y* claims that the pressure at point *B* is greater than that at point *A* because the water is moving faster at point *B*.
Student *Z* claims the speed of the water is less at point *B* than that at point *A* because by conservation of energy, some of the water's kinetic energy has been converted to potential energy of the Earth-water system.

i. Indicate any aspects of student *Y*'s claim that are correct.

The water is moving faster at point B

ii. Indicate any aspects of student *Y*'s claim that are incorrect. Support your answer using appropriate physics principles.

Pressure at Point B isn't necessarily greater because $P = \frac{F}{A}$ and while $A_B < A_A$ we don't know the difference in forces if any.

iii. Indicate any aspects of student *Z*'s claim that are correct.

Some of the waters kinetic energy has become potential energy

iv. Indicate any aspects of student *Z*'s claim that are incorrect. Support your answer using appropriate physics principles.

$A_A v_A = A_B v_B$ and $A_B < A_A$ so $v_B > v_A$

The water's speed is not less at point B

(b) Calculate the following at point *B*.

i. The speed of the water

$$\frac{A_A v_A}{A_B} \quad \frac{\pi\left(\left(\frac{1}{2}\right)2.5\right)^2 \cdot .50\ m/s}{\pi\left(\left(\frac{1}{2}\right)1.5\right)^2} = 1.39\ m/s$$

ii. The pressure in the pipe

$$P_1 + \rho g y + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y + \frac{1}{2}\rho v_2^2$$

$$2.0\times10^5\ Pa + \frac{1}{2}(1{,}000)(.50)^2 - (1{,}000)(10)(5) - \frac{1}{2}(1{,}000)(1.39)^2$$

(125 Pa; 50000; 966)

$$\approx 1.5\times10^5\ Pa$$

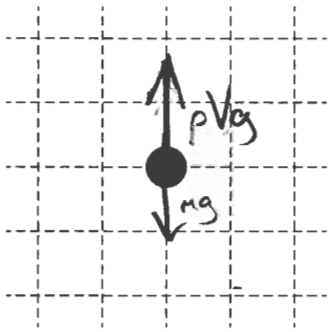
Question 1 continues on the next page.

(c) A valve to the left of point *A* now closes off that end of the pipe. The section of pipe shown is still full of water, but the water is no longer flowing.

i. Calculate the absolute pressure at point *A* (the pressure that includes the effect of the atmosphere).

$2.0\times10^5 + 1.0\times10^5 = 3.0\times10^5\ Pa$

ii. An air bubble forms at point *A*. On the figure below, where the dot represents the air bubble, draw a free-body diagram showing and labeling the forces (not components) exerted on the bubble. Draw the relative lengths of all vectors to reflect the relative magnitudes of the forces.



P2 Q1 C1

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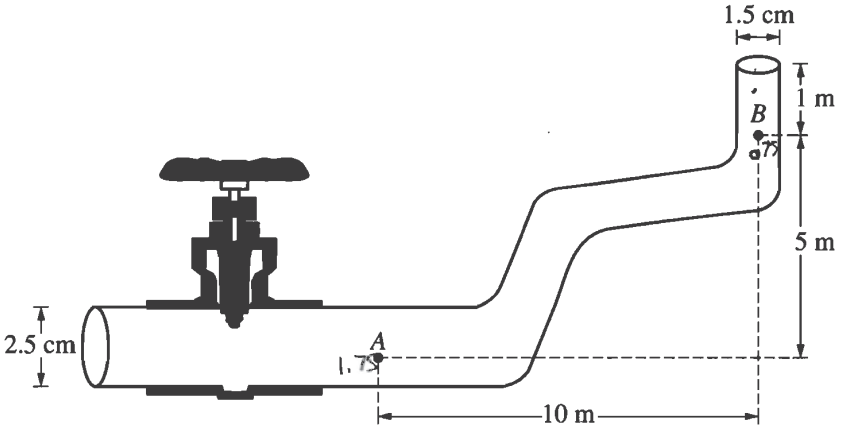

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i. Indicate any aspects of student *Y*'s claim that are correct.

$P = \frac{F}{A}$ $a_a v_a = a_b v_b$ $\pi 1.75^2 v_a = \pi (.75^2) v_b$

Velocity is greater $\frac{5}{3} = \frac{1.75}{.75} = \frac{v_b}{v_a}$

Velocity b = $\frac{5}{3}$ x faster than velocity A

ii. Indicate any aspects of student *Y*'s claim that are incorrect. Support your answer using appropriate physics principles.

Pressure doesn't depend on velocity. $P=\frac{F}{a}$ Force and area are the variables

iii. Indicate any aspects of student *Z*'s claim that are correct.

Some kinetic energy was converted to potential energy

iv. Indicate any aspects of student *Z*'s claim that are incorrect. Support your answer using appropriate physics principles.

speed at B is less.

$av = av$

(b) Calculate the following at point *B*.

i. The speed of the water

$av = av$

$1.75^2(.5) = (.75^2)x$

$1.53 = .5625x$

2.72 m/s

ii. The pressure in the pipe

$P = \frac{F}{a}$

$2\times10^5 = \frac{1.92\times10^6}{9.62}$

1.92

$P = \rho g h$

$P = 1000(10)(6)$

$P = 60000$ Psi

Question 1 continues on the next page.

(c) A valve to the left of point *A* now closes off that end of the pipe. The section of pipe shown is still full of water, but the water is no longer flowing.

i. Calculate the absolute pressure at point *A* (the pressure that includes the effect of the atmosphere).

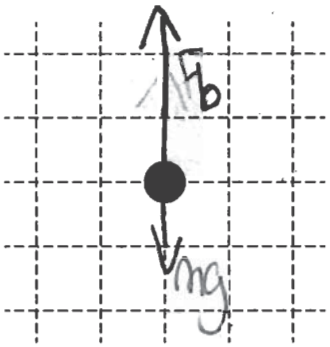
$P = 101300 + \rho g h$

$P = 101300 + 1000 \cdot 10 \cdot 6$

$P = 101300 + 6000$

$P = 95300 \text{ psi}$

ii. An air bubble forms at point *A*. On the figure below, where the dot represents the air bubble, draw a free-body diagram showing and labeling the forces (not components) exerted on the bubble. Draw the relative lengths of all vectors to reflect the relative magnitudes of the forces.



AP® PHYSICS 2
2017 SCORING COMMENTARY

Question 1

Overview

This question assessed learning objectives 3.A.2.1, 3.B.1.4, 5.B.10.1, 5.B.10.3, 5.B.10.4, and 5.F.1.1. The responses to this question were expected to demonstrate the following:

- Understanding of the equation of continuity for fluids.
- The ability to reason about how fluid pressure depends on both speed and height, according to Bernoulli's equation.
- The understanding that kinetic energy increases if work is done on a system, and can do so even when the gravitational potential energy of the system also increases.
- The ability to calculate fluid pressure and fluid speed using correct principles and correct substitution.
- The understanding that pressure for a static fluid depends on depth and external atmospheric pressure.
- The understanding that the buoyant force is the net force exerted by the fluid and is directed upwards.
- The understanding that the buoyant force equals the weight of the displaced fluid.

Sample: P2 Q1 A
Score: 10

The response to part (a)(i) is short and to the point. In part (a)(ii) the response begins by giving the correct relationship between pressures, which student Y described incorrectly. The point for referring to the height correctly is earned by a reference to there being less water above point *B*. Both speed and height dependence are supported with Bernoulli's equation. Part (a)(iii) correctly refers to conservation of energy. In part (a)(iv) two incorrect aspects are correctly discussed. Part (b)(i) has a correct calculation and answer. Although part (b)(ii) has an arithmetic error, credit only depended on the correct application of Bernoulli's equation and substitutions. Part (c) has a correct calculation and force diagram and includes an explanation of the forces that was not required.

Sample: P2 Q1 B
Score: 6

Part (a) (i) earned full credit of 1 point. Although part (a)(ii) correctly refers to the pressure at point B being less, reasoning with the force per area rather than Bernoulli's equation is not correct. Part (a)(iii) gives the common incorrect response indicating potential energy increases because of the loss of kinetic energy. In part (a)(iv) the increase in speed is correctly supported by the continuity equation, so 1 point was earned. Part (b) contains correct calculations and earned 3 points. The response in (c)(i) is not clear about the relationship used and has an incorrect answer, so no credit was earned. The force diagram in (c)(ii) is correct and earned 1 point.

Sample: P2 Q1 C
Score: 4

Part (a) (i) contains calculations that were not required but does write the correct conclusion about student Y's speed statement and earned 1 point. Part (a)(ii) makes an incorrect statement and refers to the wrong principle for the situation, so no credit was earned. Part (a)(iii) does not refer to a correct aspect of student Z's statement. In (a)(iv) an incorrect aspect of student Z's statement is noted, and the continuity equation is given as support, earning 1 point. Part (b)(i) has an incorrect substitution and answer, and (b)(ii) applies the wrong concept, with no credit earned. Part (c)(i) uses the correct relationship and has correct substitutions. The force diagram is correct and earned 1 point.