2018

AP® CollegeBoard

AP Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

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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.

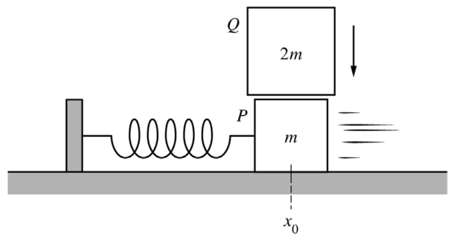
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked 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 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.

Question 5

7 points total **Distribution of points**



Block P of mass m is on a horizontal, frictionless surface and is attached to a spring with spring constant k. The block is oscillating with period T_P and amplitude A_P about the spring's equilibrium position x_0. A second block Q of mass $2m$ is then dropped from rest and lands on block P at the instant it passes through the equilibrium position, as shown above. Block Q immediately sticks to the top of block P, and the two-block system oscillates with period T_{PQ} and amplitude A_{PQ}.

(a) LO / SP: 3.B.3.1 / 6.4
1 point

Determine the numerical value of the ratio T_{PQ}/T_P.

For a correct answer: $\sqrt{3}$		1 point

Question 5 (continued)

Distribution of points

(b) LO / SP: 3.B.3.1 / 6.4, 7.2; 3.B.3.4 / 2.2, 6.2; 4.C.1.1 / 1.4, 2.2; 4.C.1.2 / 6.4;
5.B.3.1/ 2.2, 6.4; 5.B.3.3 / 1.4, 2.2; 5.B.4.1 / 6.4, 7.2; 5.B.4.2 / 1.4, 2.1, 2.2; 5.D.2.1 / 6.4, 7.2
6 points

How does the amplitude of oscillation A_{PQ} of the two-block system compare with the original amplitude A_P of block P alone?

____ $A_{PQ} < A_P$ ____ $A_{PQ} = A_P$ ____ $A_{PQ} > A_P$

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, explain your reasoning.

Correct answer: $A_{PQ} < A_P$. Note: The response is graded even if an incorrect selection is made.		
For applying conservation of momentum to the collision		1 point
For correctly finding that the post-collision speed has decreased (or, for determining that $v_f = \frac{1}{3}v_i$)		1 point
Note: The first 2 points can be earned for stating that the collision is inelastic		
For stating or implying that the system's kinetic energy has decreased (or, for calculating a lower final kinetic energy)		1 point
For stating or implying kinetic energy of blocks right after collision equals maximum potential energy of spring OR For stating or implying that the maximum potential energy equals the total mechanical energy just after the collision (Simply stating that $E_{tot} = \frac{1}{2}kA^2$ is sufficient.)		1 point
For stating or implying that maximum potential energy is reached when the displacement from equilibrium equals the amplitude of oscillation		1 point
Note: The previous 2 points can be earned in a single sentence in which one or both of the points is implicit.		
For a logical, relevant, and internally consistent argument that addresses the required argument or question asked and follows the guidelines described in the published requirements for the paragraph-length response		1 point

Alternate solution for first 2 points in part (b):		
A frictional force is exerted on block P by Q, so it slows down. *Note: The third point can be earned if energy loss is stated.*		*2 points*

Question 5 (continued)

Example: The second block (*Q*) adds mass without changing the horizontal momentum of the two-block system. In effect, block *P* (mass *m*) becomes block *PQ* (mass 3*m*). This reduces the speed at equilibrium from v_{max} to $v_{max}/3$ according to conservation of momentum. To see how this affects amplitude, we must analyze what happens to the maximum kinetic energy (*K*) of the oscillating mass: $K_P = \frac{1}{2}mv_{max}^2$ $\quad K_{PQ} = \frac{1}{2}(3m)\left(\frac{v_{max}}{3}\right)^2 = \frac{1}{6}mv_{max}^2 = \frac{1}{3}K_P$ Because the maximum *K* is reduced, this means the maximum potential energy in the spring is also reduced (to $1/3$ of its former value). Because amplitude is related to maximum potential energy $\left(U_{max} = \frac{1}{2}kA^2\right)$, the amplitude of block *PQ* is less than that of block *P*.	

Question 5 (continued)

Learning Objectives (LO)

LO 3.B.3.1: The student is able to predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. [See Science Practices 6.4, 7.2]

LO 3.B.3.4: The student is able to construct a qualitative and/or a quantitative explanation of oscillatory behavior given evidence of a restoring force. [See Science Practices 2.2, 6.2]

LO 4.C.1.1: The student is able to calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy. [See Science Practices 1.4, 2.1, 2.2]

LO 4.C.1.2: The student is able to predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system. [See Science Practice 6.4]

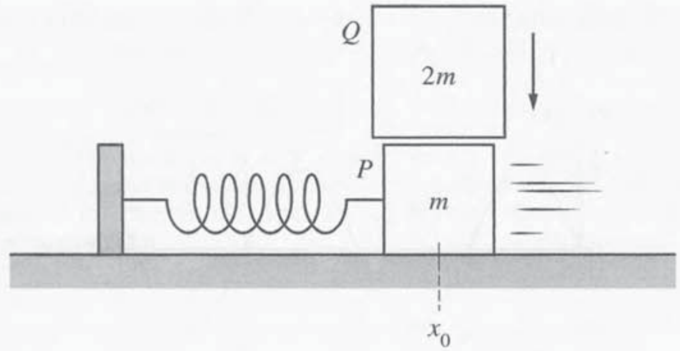
LO 5.B.3.1: The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [See Science Practices 2.2, 6.4, 7.2]

LO 5.B.3.3: The student is able to apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. [See Science Practices 1.4, 2.2]

LO 5.B.4.1: The student is able to describe and make predictions about the internal energy of systems. [See Science Practices 6.4, 7.2]

LO 5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [See Science Practices 1.4, 2.1, 2.2]

LO 5.D.2.1: The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [See Science Practices 6.4, 7.2]



5. (7 points, suggested time 13 minutes)

Block P of mass m is on a horizontal, frictionless surface and is attached to a spring with spring constant k. The block is oscillating with period T_P and amplitude A_P about the spring's equilibrium position x_0. A second block Q of mass $2m$ is then dropped from rest and lands on block P at the instant it passes through the equilibrium position, as shown above. Block Q immediately sticks to the top of block P, and the two-block system oscillates with period T_{PQ} and amplitude A_{PQ}.

(a) Determine the numerical value of the ratio T_{PQ}/T_P.

$$T_P = 2\pi\sqrt{\frac{m}{k}}$$

$$T_{PQ} = 2\pi\sqrt{\frac{3m}{k}}$$

$$\frac{T_{PQ}}{T_P} = \frac{2\pi\sqrt{\frac{3m}{k}}}{2\pi\sqrt{\frac{m}{k}}} = \frac{\sqrt{\frac{3m}{k}}}{\sqrt{\frac{m}{k}}}$$

$$\frac{\sqrt{\frac{3m}{k}}\sqrt{\frac{m}{k}}}{\frac{m}{k}} = \frac{\frac{\sqrt{3}\,m}{k}}{\frac{m}{k}} = \boxed{\sqrt{3}}$$

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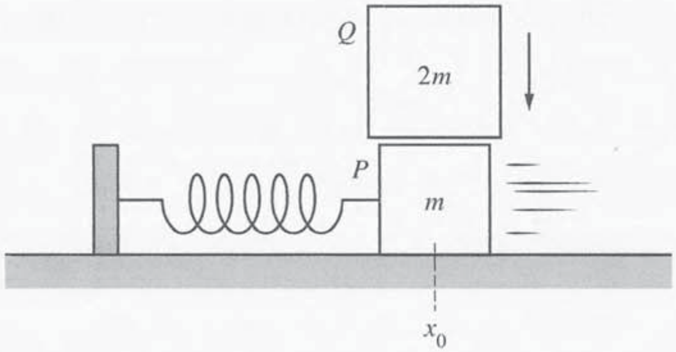

(b) The figure is reproduced above. How does the amplitude of oscillation A_{PQ} of the two-block system compare with the original amplitude A_P of block P alone?

X $A_{PQ} < A_P$ ____ $A_{PQ} = A_P$ ____ $A_{PQ} > A_P$

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, explain your reasoning.

Momentum is conserved during the collision.

$m v_0 = 3m v_f \Rightarrow v_0 = 3v_f \quad v_f = \frac{v_0}{3}$

Final velocity is $\frac{1}{3}$ of the initial velocity.

$KE_{PQ} = \frac{1}{2} 3m \left(\frac{v_0}{3}\right)^2 = \frac{1}{6} m v_0^2$ vs. $\frac{1}{2} m v_0^2 = KE_Q$

KE at the equilibrium of blocks Q and P is less than with only Block P.

$U_s = \frac{1}{2} k x^2 \quad \frac{1}{6} m v_0^2 = \frac{1}{2} k x_1^2$ vs. $\frac{1}{2} m v_0^2 = \frac{1}{2} k x_1^2$

$x_{PQ} = v_0\sqrt{\frac{m}{3k}} \quad x_P = v_0\sqrt{\frac{m}{k}}$

If all KE is converted to spring potential, block P will compress the spring a greater distance. $(x_{PQ} < x_P)$

Therefore $A_{PQ} < A_P$.

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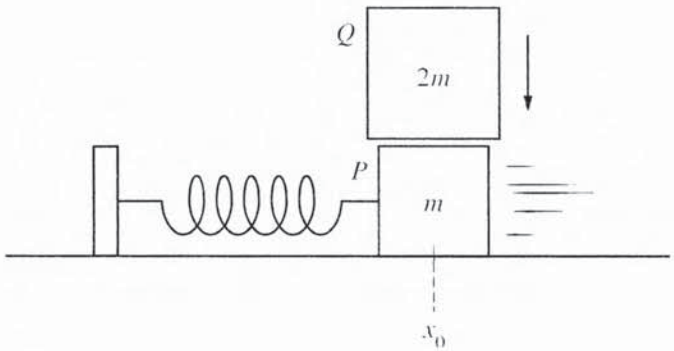

5. (7 points, suggested time 13 minutes)

Block P of mass m is on a horizontal, frictionless surface and is attached to a spring with spring constant k. The block is oscillating with period T_P and amplitude A_P about the spring's equilibrium position x_0. A second block Q of mass $2m$ is then dropped from rest and lands on block P at the instant it passes through the equilibrium position, as shown above. Block Q immediately sticks to the top of block P, and the two-block system oscillates with period T_{PQ} and amplitude A_{PQ}.

(a) Determine the numerical value of the ratio T_{PQ}/T_P.

$$T_s = 2\pi\sqrt{\frac{m}{k}}$$

$$T_s = 2\pi\sqrt{\frac{3m}{k}}$$

$\sqrt{3}$

$$\frac{T_{PQ}}{T_P} = \sqrt{3}$$

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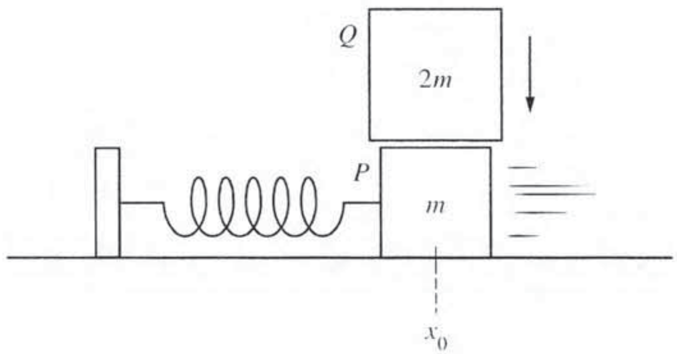

(b) The figure is reproduced above. How does the amplitude of oscillation A_{PQ} of the two-block system compare with the original amplitude A_P of block P alone?

__✓__ $A_{PQ} < A_P$ ____ $A_{PQ} = A_P$ ____ $A_{PQ} > A_P$

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, explain your reasoning.

Because the objects stick together, we know that the total kinetic energy in the system has decreased. If the kinetic energy of the system decreases, that means that the potential energy in the spring also decreases. U_s is less now. Using $U_s = \frac{1}{2}kx^2$, if U_s decreases, x must also decrease because k is a constant. x represents displacement, so the displacement and amplitude decrease for A_{PQ}.

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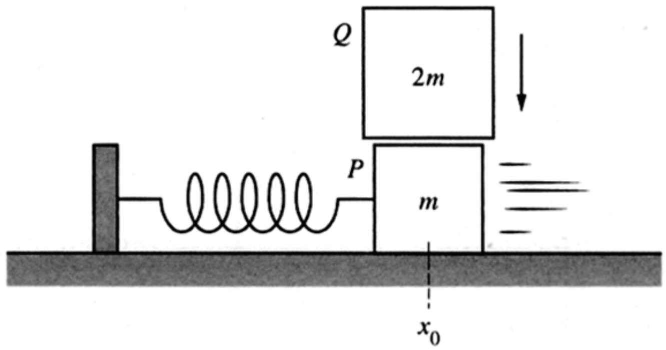

5. (7 points, suggested time 13 minutes)

Block P of mass m is on a horizontal, frictionless surface and is attached to a spring with spring constant k. The block is oscillating with period T_P and amplitude A_P about the spring's equilibrium position x_0. A second block Q of mass $2m$ is then dropped from rest and lands on block P at the instant it passes through the equilibrium position, as shown above. Block Q immediately sticks to the top of block P, and the two-block system oscillates with period T_{PQ} and amplitude A_{PQ}.

$|\vec{F}_s| = k|x|$

(a) Determine the numerical value of the ratio T_{PQ}/T_P.

$$\frac{T_{PQ}}{T_P} = 1$$

because mass + speed stay proportional, so period doesn't change

same T, but b moves slower than a due to heightened mass

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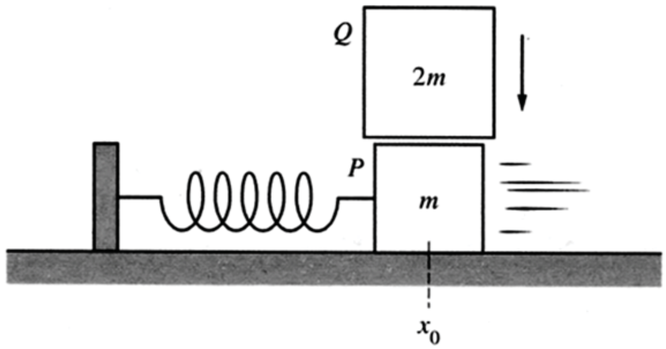
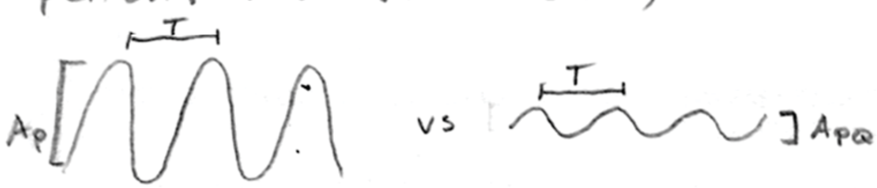


(b) The figure is reproduced above. How does the amplitude of oscillation A_{PQ} of the two-block system compare with the original amplitude A_P of block P alone?

X $A_{PQ} < A_P$ ____ $A_{PQ} = A_P$ ____ $A_{PQ} > A_P$

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, explain your reasoning.

Because the mass of P + Q is greater than that of P alone, the speed of the oscillation PQ decreases. But, taking spring constant k into account, the amplitude of the oscillation would also decrease in order to retain a constant period. (as shown below)



The difference in mass doesn't affect the period, but it does affect the amplitude and speed of the oscillations.

AP® PHYSICS 1
2018 SCORING COMMENTARY

Question 5

Overview

This question assessed learning objectives 3.B.3.1, 3.B.3.4, 4.C.1.1, 4.C.1.2, 5.B.3.1, 5.B.3.3, 5.B.4.1, 5.B.4.2, and 5.D.2.1.

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

- The ability to determine a numeric ratio of the periods of two oscillating systems of different mass.
- Recognition that mechanical energy is lost during an inelastic collision.
- Recognition that total mechanical energy in a system is conserved in the presence of conservative forces.
- The ability to write a logical, relevant, and coherent paragraph-length response to explain what happens to the amplitude of an oscillating system after a collision.

Sample: P1 Q5 A
Score: 7

Part (a) earned 1 point for the correct answer of $\sqrt{3}$. Part (b) earned 6 points. The response earned 2 points for applying conservation of momentum to the collision and finding that the post-collision speed is one third of the initial speed of block *P*. The response earned 1 point for calculating a lower kinetic energy immediately after the collision. The response earned 1 point for implicitly relating the kinetic energy of the combined block system at the equilibrium position to the spring potential energy. The response earned 1 point for implicitly stating that all of the kinetic energy of the combined block system at the equilibrium position is all converted to spring potential energy when the spring is compressed its maximum distance. The response earned 1 point because the response has a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Sample: P1 Q5 B
Score: 5

Part (a) earned 1 point for the correct answer of $\sqrt{3}$. Part (b) earned 4 of 6 points. Two points were not earned because the response does not apply conservation of momentum to the collision, and it does not find that the post-collision speed has decreased. The response earned 1 point for explicitly stating that the kinetic energy after the collision is less than the kinetic energy before the collision. The response earned 1 point for implicitly relating the kinetic energy of the combined block system at the equilibrium position to the spring potential energy. The response earned 1 point for implicitly stating that all of the kinetic energy of the combined block system at the equilibrium position is all converted to spring potential energy when the spring is compressed its maximum distance or amplitude. The response earned 1 point because the response has a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and it follows the guidelines described in the published requirements for the paragraph-length response.

Sample: P1 Q5 C
Score: 1

Part (a) earned no points because the response indicates an incorrect answer of 1. Part (b) earned 1 of 6 points for stating that the velocity of the two-block system is less than the velocity of the single-block system due to the increase in mass. Although the paragraph goes on to draw a correct conclusion, the argument being made is not relevant for the motion of a simple harmonic oscillator, so no additional points were earned.