2019

AP® CollegeBoard

AP® Physics C: Mechanics

Sample Student Responses and Scoring Commentary Set 1

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General Notes About 2019 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.

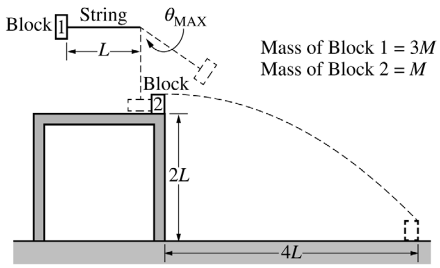
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked 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 2

15 points



Note: Figure not drawn to scale.

A pendulum of length L consists of block 1 of mass $3M$ attached to the end of a string. Block 1 is released from rest with the string horizontal, as shown above. At the bottom of its swing, block 1 collides with block 2 of mass M, which is initially at rest at the edge of a table of height $2L$. Block 1 never touches the table. As a result of the collision, block 2 is launched horizontally from the table, landing on the floor a distance $4L$ from the base of the table. After the collision, block 1 continues forward and swings up. At its highest point, the string makes an angle θ_{MAX} to the vertical. Air resistance and friction are negligible. Express all algebraic answers in terms of M, L, and physical constants, as appropriate.

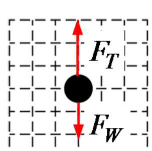
(a) LO CON-2.C.a, SP 5.E
1 point

Determine the speed of block 1 at the bottom of its swing just before it makes contact with block 2.

For correctly calculating the speed of block 1		1 point
$U_{g1} = K_2 \therefore mgh = \frac{1}{2}mv^2 \therefore gL = \frac{1}{2}v^2$		
$v = \sqrt{2gL}$		
Note: Credit is earned even if no work is shown.		

(b) LO INT-2.B.b, SP 3.D
2 points

On the dot below, which represents block 1, draw and label the forces (not components) that act on block 1 just before it makes contact with block 2. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. Forces with greater magnitude should be represented by longer vectors.



For correctly drawing and labeling the weight of the block and the tension in the string		1 point
For drawing the tension longer than the weight of the block		1 point
Note: A maximum of one point can be earned if there are any extraneous vectors.		

Question 2 (continued)

(c) LO INT-2.B.b, SP 5.A, 5.E
2 points

Derive an expression for the tension F_T in the string when the string is vertical just before block 1 makes contact with block 2. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

For using an appropriate equation to calculate the tension in the string		1 point
$F_T = mg + ma_C = mg + \frac{mv^2}{r} = 3Mg + \frac{(3M)\left(\sqrt{2gL}\right)^2}{L}$		
For a correct answer		1 point
$F_T = 9Mg$		

For parts (d)–(g), the value for the length of the pendulum is $L = 75$ cm.

(d) LO CHA-2.C, SP 6.A, 6.C
2 points

Calculate the time between the instant block 2 leaves the table and the instant it first contacts the floor.

For using a correct kinematic equation to calculate the time		1 point
$\Delta y = v_1 t + \frac{1}{2}at^2 = \frac{1}{2}at^2 \therefore t = \sqrt{\frac{2\Delta y}{a}} = \sqrt{\frac{2(2L)}{g}} = \sqrt{\frac{(4)(0.75\text{ m})}{\left(9.8\text{ m/s}^2\right)}}$		
For a correct answer		1 point
$t = 0.55$ s		

(e) LO CHA-2.C, SP 6.A, 6.C
2 points

Calculate the speed of block 2 as it leaves the table.

For using a correct kinematic equation to calculate the speed		1 point
$\Delta x = vt \therefore v = \frac{\Delta x}{t} = \frac{4L}{t}$		
For substituting the time from part (d) into equation above		1 point
$v = \frac{(4)(0.75\text{ m})}{(0.55\text{ s})} = 5.45\text{ m/s}$		

Question 2 (continued)

(f) LO CON-4.E.a, SP 6.B, 6.C
3 points

Calculate the speed of block 1 just after it collides with block 2.

For indicating the use of the correct conservation of momentum to calculate the speed		1 point
$p_i = p_f \therefore m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$		
For correctly substituting the mass into equation above		1 point
$(3M)v_{1i} + 0 = (3M)v_{1f} + (M)v_{2f}$		
For substituting the speeds from parts (a) and (e) into equation above		1 point
$v_{1f} = \dfrac{(3M)v_{1i} - (M)v_{2f}}{(3M)} = \dfrac{(3M)\sqrt{2gL} - (M)v_{2f}}{(3M)}$		
$v_{1f} = \dfrac{(3)\sqrt{(2)\left(9.8\ \text{m/s}^2\right)(0.75\ \text{m})} - (1)(5.45\ \text{m/s})}{(3)} = 2.02\ \text{m/s}$		
($v_{1f} = 2.06\ \text{m/s}$ when using $g = 10\ \text{m/s}^2$)		

(g) LO CON-2.C.a, SP 6.B, 6.C
3 points

Calculate the angle θ_{MAX} that the string makes with the vertical, as shown in the original figure, when block 1 is at its highest point after the collision.

For using conservation of energy to calculate the angle		1 point
$K_1 = U_{g2}$		
$\frac{1}{2}mv^2 = mgh$		
For correctly substituting $h = L(1 - \cos\theta)$ into the equation above		1 point
For correctly substituting the speed from part (f) into the equation above		1 point
$\frac{1}{2}mv^2 = mgL(1 - \cos\theta) \therefore \dfrac{v^2}{2gL} = 1 - \cos\theta$		
$\theta = \cos^{-1}\left(1 - \dfrac{v^2}{2gL}\right) = \cos^{-1}\left(1 - \dfrac{(2.02\ \text{m/s})^2}{(2)\left(9.8\ \text{m/s}^2\right)(0.75\ \text{m})}\right) = 43.5°$		
($\theta = 44.1°$ when using $g = 10\ \text{m/s}^2$)		

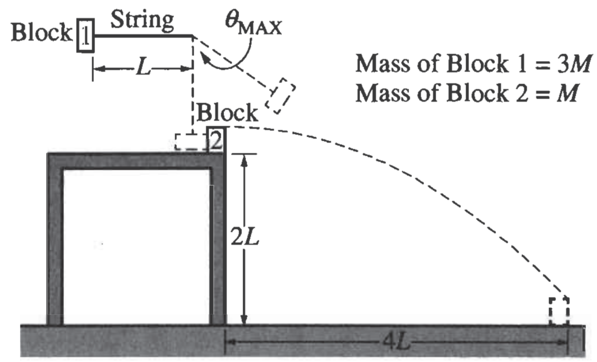
Question 2 (continued)

Learning Objectives

CHA-2.C: Calculate kinematic quantities of an object in projectile motion, such as displacement, velocity, speed, acceleration, and time, given initial conditions of various launch angles, including a horizontal launch at some point in its trajectory.
INT-2.B.b: Describe forces that are exerted on objects undergoing horizontal circular motion, vertical circular motion, or horizontal circular motion on a banked curve.
CON-2.C.a: Calculate unknown quantities (e.g., speed or positions of an object) that are in a conservative system of connected objects, such as the masses in an Atwood machine, masses connected with pulley/string combinations, or the masses in a modified Atwood machine.
CON-4.E.a: Calculate the changes in speeds, changes in velocities, changes in kinetic energy, or changes in momenta of objects in all types of collisions (elastic or inelastic) in one dimension, given the initial conditions of the objects.

Science Practices

3.D: Create appropriate diagrams to represent physical situations.
5.A: Select an appropriate law, definition, or mathematical relationship or model to describe a physical situation.
5.E: Derive a symbolic expression from known quantities by selecting and following a logical algebraic pathway.
6.A: Extract quantities from narratives or mathematical relationships to solve problems.
6.B: Apply an appropriate law, definition, or mathematical relationship to solve a problem.
6.C: Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.



Note: Figure not drawn to scale.

2. A pendulum of length L consists of block 1 of mass $3M$ attached to the end of a string. Block 1 is released from rest with the string horizontal, as shown above. At the bottom of its swing, block 1 collides with block 2 of mass M, which is initially at rest at the edge of a table of height $2L$. Block 1 never touches the table. As a result of the collision, block 2 is launched horizontally from the table, landing on the floor a distance $4L$ from the base of the table. After the collision, block 1 continues forward and swings up. At its highest point, the string makes an angle θ_{MAX} to the vertical. Air resistance and friction are negligible. Express all algebraic answers in terms of M, L, and physical constants, as appropriate.

(a) Determine the speed of block 1 at the bottom of its swing just before it makes contact with block 2.

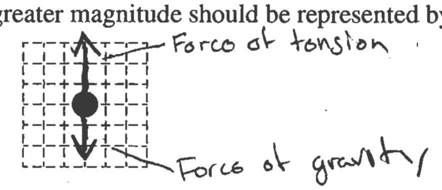
$mgh = \frac{1}{2}mv^2$

$10(L) = .5\ v^2$

$v^2 = 20L$

$v = \sqrt{20L} = 2\sqrt{5L}$

(b) On the dot below, which represents block 1, draw and label the forces (not components) that act on block 1 just before it makes contact with block 2. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. Forces with greater magnitude should be represented by longer vectors.



(c) Derive an expression for the tension F_T in the string when the string is vertical just before block 1 makes contact with block 2. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

$F_T = ma$

$F_T - F_g = 3M\cdot$

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For parts (d)–(g), the value for the length of the pendulum is $L = 75$ cm.

(d) Calculate the time between the instant block 2 leaves the table and the instant it first contacts the floor.

$x_y = x_{oy} + V_{oy}t + \frac{1}{2}at^2$

$-2L = 0 + 0 + \frac{1}{2}(-10)t^2$

$-1.5m = -5t^2$

$3 = t^2$

$t = \sqrt{\frac{3}{10}} = 0.548$ seconds

(e) Calculate the speed of block 2 as it leaves the table.

$V = \frac{\Delta x}{\Delta t} = \frac{4L}{\sqrt{\frac{3}{10}}} = \frac{3}{\sqrt{\frac{3}{10}}} = 5.477$ m/s

(f) Calculate the speed of block 1 just after it collides with block 2.

$P_1 + P_2 = P_{1f} + P_{2f}$

$mv_1 + mv_2 = mv_{1f} + mv_{2f}$

$(3m)(\sqrt{20(.75)}) + (m)(0) = (3m)(x) + (m)(5.477)$

$11.619 + 0 = 3x + 5.477$

$6.142 = 3x$

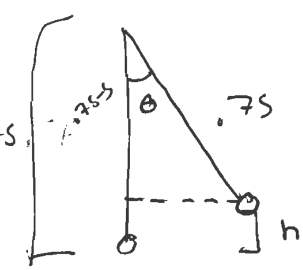
$x = 2.047$ m/s

(g) Calculate the angle θ_{MAX} that the string makes with the vertical, as shown in the original figure, when block 1 is at its highest point after the collision.

$\frac{1}{2}3M v^2 = 3Mgh$

$\frac{1}{2}(2.047)^2 = 10h$

$H = 0.210m$



$\frac{O}{H}$ C A

$\cos(\theta) = \frac{A}{H}$

$\theta = \cos^{-1}(\frac{A}{H})$

$\theta = \cos^{-1}(\frac{.75 - H}{.75}) = 43.897°$

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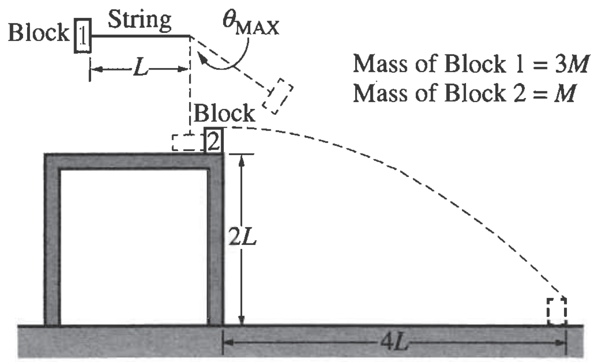

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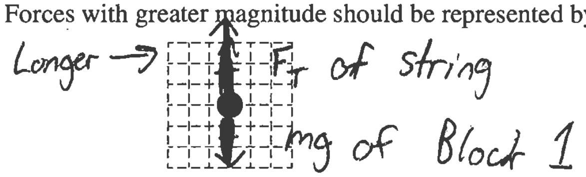
2. A pendulum of length L consists of block 1 of mass $3M$ attached to the end of a string. Block 1 is released from rest with the string horizontal, as shown above. At the bottom of its swing, block 1 collides with block 2 of mass M, which is initially at rest at the edge of a table of height $2L$. Block 1 never touches the table. As a result of the collision, block 2 is launched horizontally from the table, landing on the floor a distance $4L$ from the base of the table. After the collision, block 1 continues forward and swings up. At its highest point, the string makes an angle θ_{MAX} to the vertical. Air resistance and friction are negligible. Express all algebraic answers in terms of M, L, and physical constants, as appropriate.

(a) Determine the speed of block 1 at the bottom of its swing just before it makes contact with block 2.

$mgh = \frac{1}{2}mv^2 \qquad v = \sqrt{2gh}$

(b) On the dot below, which represents block 1, draw and label the forces (not components) that act on block 1 just before it makes contact with block 2. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. Forces with greater magnitude should be represented by longer vectors.



(c) Derive an expression for the tension F_T in the string when the string is vertical just before block 1 makes contact with block 2. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

$\Sigma F = ma \qquad a = \frac{v^2}{r}$

$F_T - mg = m\left(\frac{v^2}{r}\right)$

$F_T = \frac{mv^2}{L} + mg$

For parts (d)–(g), the value for the length of the pendulum is $L = 75$ cm.

(d) Calculate the time between the instant block 2 leaves the table and the instant it first contacts the floor.

$\Delta X = X_0 + V_0 t + \frac{1}{2}at^2$

$2(.75) = \frac{1}{2}(9.8)(t)^2$

$t = .553$ seconds

(e) Calculate the speed of block 2 as it leaves the table.

$4L = V_x t$

$4(.75) = V_x(.553 \text{ sec})$

$V_x = 5.422$ m/s

(f) Calculate the speed of block 1 just after it collides with block 2.

$V_{1I} + V_{1F} = V_{2I} + V_{2F}$

~~$V_y = \sqrt{2(9.8)(2L)} = \sqrt{2g(\Delta X)} = 5.422$ m/s~~

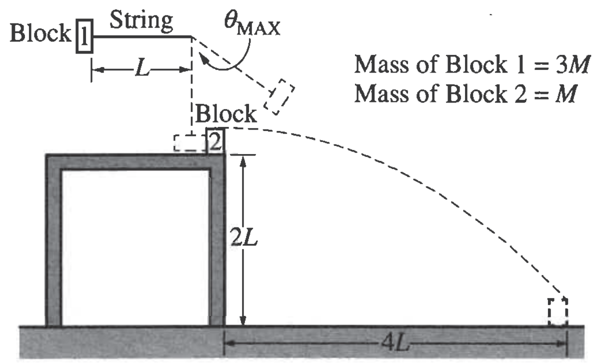
$V_x = 5.422$ m/s

$V_{B1} = 5.422$ m/s

$0 + V_{1f} = 0 + 5.422$ m/s

(g) Calculate the angle θ_{MAX} that the string makes with the vertical, as shown in the original figure, when block 1 is at its highest point after the collision.

$\theta_{max} = 42°$



Note: Figure not drawn to scale.

2. A pendulum of length L consists of block 1 of mass $3M$ attached to the end of a string. Block 1 is released from rest with the string horizontal, as shown above. At the bottom of its swing, block 1 collides with block 2 of mass M, which is initially at rest at the edge of a table of height $2L$. Block 1 never touches the table. As a result of the collision, block 2 is launched horizontally from the table, landing on the floor a distance $4L$ from the base of the table. After the collision, block 1 continues forward and swings up. At its highest point, the string makes an angle θ_{MAX} to the vertical. Air resistance and friction are negligible. Express all algebraic answers in terms of M, L, and physical constants, as appropriate.

(a) Determine the speed of block 1 at the bottom of its swing just before it makes contact with block 2.

$ME_i = ME_f$

$PE = KE$

$mgh = \frac{1}{2}mv^2$

$(3m)(10)(L) = \frac{1}{2}(3m)v^2$

$30mL = \frac{3}{2}mv^2$

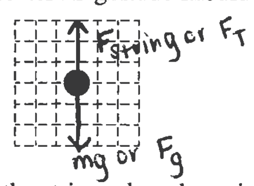
$30L = \frac{3}{2}v^2$

$20L = v^2$

$v = \sqrt{20L}$

$v = 2\sqrt{5L}$ or $v = \sqrt{2gL}$

(b) On the dot below, which represents block 1, draw and label the forces (not components) that act on block 1 just before it makes contact with block 2. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. Forces with greater magnitude should be represented by longer vectors.



(c) Derive an expression for the tension F_T in the string when the string is vertical just before block 1 makes contact with block 2. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

$\sum F = ma$

$F_T - mg = ma$

$F_T = ma + mg$

$F_T = m(a + g)$

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For parts (d)–(g), the value for the length of the pendulum is $L = 75$ cm.

(d) Calculate the time between the instant block 2 leaves the table and the instant it first contacts the floor.

$\Delta x = v_0 t + \frac{1}{2} a t^2$

$\frac{4(.75)}{5} = 0 + \frac{\frac{1}{2}(10)t^2}{5}$

$\sqrt{0.6} = \sqrt{t^2}$

$t = 0.77$ seconds

(e) Calculate the speed of block 2 as it leaves the table.

$v = \sqrt{g2(.75)}$

$v = \sqrt{20(.75)}$

$v = 3.87$ m/s

$p_i = p_f$

$v_2 = \frac{3}{4} v_i$

$v_2 = \left(\frac{3}{4}\right)(3.87)$

$v_2 = 2.91$ m/s

(f) Calculate the speed of block 1 just after it collides with block 2.

$\frac{1}{4}(3.87) = v_1$

$v_1 = 0.97$ m/s

(g) Calculate the angle θ_{MAX} that the string makes with the vertical, as shown in the original figure, when block 1 is at its highest point after the collision.

$(.75)$ co

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Question 2

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

Overview

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

- Determination of the speed of a block attached to the end of a string, which is released from rest
- Creation of a free-body diagram to represent the forces that are exerted on an object undergoing vertical circular motion
- Determination of a specific force exerted on an object undergoing vertical circular motion
- Calculation of the time of fall from kinematic equations of an object in projectile motion given a horizontal launch from a specific height
- Calculation of the horizontal speed of the object from kinematic equations given a horizontal launch from a specific height
- Calculation of the final speed of the block attached to the string after a collision with a second block from conservation of momentum in a one-dimensional collision
- Calculation of the maximum angle a pendulum will make using conservation of mechanical energy

Sample: M Q2 A
Score: 13

In part (a) 1 point was earned for correctly calculating the speed of block 1 with an acceptable substitution of $g = 10\ \text{m/s}^2$. In part (b) 2 points were earned for correctly drawing and labeling the weight of the block and the tension in the string, where the tension is drawn longer than the weight of the block, and for no extraneous vectors drawn. In part (c) no points were earned because an appropriate equation (Newton's second law) is not used to calculate the tension in the string, and a correct answer is not obtained. In part (d) 2 points were earned for using a correct kinematic equation to calculate the time and for a correct answer. In part (e) 2 points were earned for using a correct kinematic equation to calculate the speed and for substituting the time from part (d) into the kinematic equation. In part (f) 3 points were earned for indicating the use of the correct conservation of momentum to calculate the speed, for correctly substituting the masses into the equation, and for substituting the speeds from parts (a) and (e) into the equation. In part (g) 3 points were earned for using conservation of energy to calculate the angle, for correctly substituting both an equivalent expression of $h = L(1 - \cos\theta)$ and the speed from part (f) into the equation.

Sample: M Q2 B
Score: 7

Parts (b), (d), and (e) received full credit, 2 points each. In part (a) no points were earned because the speed of block 1 is calculated incorrectly. In part (c) an appropriate equation (Newton's second law) is used to calculate the tension in the string, but a correct answer is not obtained, so 1 point was earned. In part (f) no points were earned because conservation of momentum is not used to calculate the speed, the masses are not correctly substituted into the equation, and the speeds from parts (a) and (e) are not substituted into the equation. In part (g) an incorrect answer is shown with no work provided, so no points were earned.

Question 2 (continued)

Sample: M Q2 C
Score: 3

Part (a) received full credit, 1 point. In part (b) the weight of the block and the tension in the string are correctly drawn and labeled with no extraneous vectors, but the tension is not drawn longer than the weight of the block, so 1 point was earned. In part (c) an appropriate equation (Newton's second law) is used to calculate the tension in the string, but a correct answer is not obtained, so 1 point was earned. In part (d) no points were earned because a correct kinematic equation is not used, and horizontal and vertical one-dimensional motion is not combined in the stated equation. In part (e) no points were earned for not using a correct kinematic equation to calculate the speed. In part (f) no points were earned because appropriate conservation of momentum equations are not used, and a correct answer is not shown. In part (g) an inconclusive expression is written, so no points were earned.