Question 2: Translation Between Representations (TBR) — 12 points

A

For drawing one bar in Figure 2 that shows only gravitational potential energy (U_g) — **Point A1**

Scoring Note: The correct height of the bar is not required to earn this point.

For including only K and U_g in Figure 3 — **Point A2**

Scoring Note: The correct heights of the bars are not required to earn this point.

For drawing bars in figures 2 and 3 whose total height, respectively, equals $12E_0$ — **Point A3**

Example Response

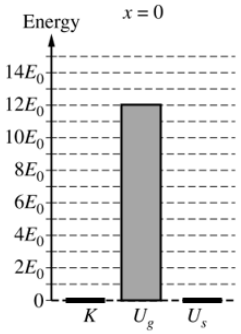


Figure 2

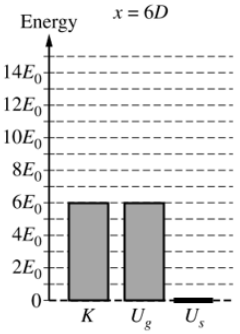


Figure 3

B

For a multistep derivation that includes conservation of energy — **Point B1**

For equating the gravitational potential energy to the spring potential energy — **Point B2**

For **one** of the following: — **Point B3**

- Substituting $12D\sin\theta$ for Δy in a gravitational potential energy expression
- Substituting $4D$ in for Δx in a spring potential energy expression

For a correct expression for k — **Point B4**

Accept any algebraic equivalent of **one** of the following:

- $k = \frac{3}{2}\frac{Mg\sin\theta}{D}$
- $\frac{3}{2}\frac{Mg\sin\theta}{D}$

Scoring Note: A correct, isolated, final expression of $k = \frac{3}{2}\frac{Mg\sin\theta}{D}$ earns points B2, B3, and B4.

Example Response

$E_0 = E_f$

$U_g = U_s$

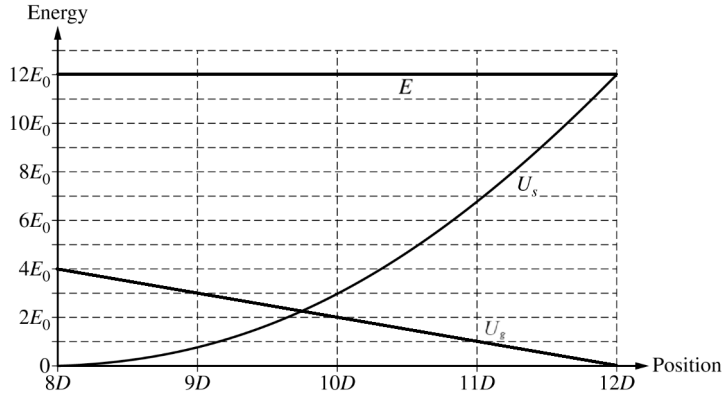
$mg\Delta y = \frac{1}{2}k(\Delta x)^2$

$Mg(12D\sin\theta) = \frac{1}{2}k(4D)^2$

$k = \frac{3}{2}\frac{Mg\sin\theta}{D}$

C	**(i)**	For sketching a horizontal line at $12E_0$, continuous from $8D$ to $12D$, with a label that indicates total mechanical energy	**Point C1**
	(ii)	For sketching a straight line that is decreasing with a label that indicates gravitational potential energy	**Point C2**
		For starting the line that represents gravitational potential energy at the point $(8D, 4E_0)$	**Point C3**

Example Response



D	For **one** of the following: • Indicating $v_{9D} > v_{8D}$ if the graph in part C shows $U_g + U_s$ at $x = 8D$ is **greater than** $U_g + U_s$ at $x = 9D$ • Indicating $v_{9D} < v_{8D}$ if the graph in part C shows $U_g + U_s$ at $x = 8D$ is **less than** $U_g + U_s$ at $x = 9D$ • Indicating $v_{9D} = v_{8D}$ if the graph in part C shows $U_g + U_s$ at $x = 8D$ is **equal to** $U_g + U_s$ at $x = 9D$	**Point D1**
	For a justification consistent with the graph that correctly relates the speed to the gravitational potential energy, spring potential energy, and either kinetic energy or total energy	**Point D2**

Example Response

The speed at $x = 9D$ is greater than the speed at $x = 8D$. From the graph, the kinetic energy at $x = 8D$ must be $8E_0$. At $x = 9D$, the spring potential energy is $< E_0$ and the gravitational potential energy is $3E_0$, leaving $> 8E_0$ of the energy as kinetic. Therefore, the speed must be greater at $x = 9D$ than at $x = 8D$.

AP® Physics 1
2016 Scoring Guidelines

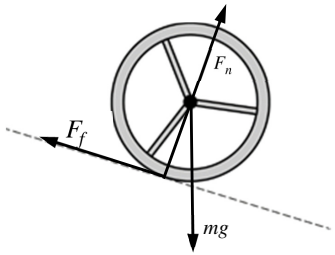
2016 SCORING GUIDELINES

Question 1

7 points total **Distribution of points**

(a)

i. 2 points



For a labeled arrow representing the gravitational force, starting at the wheel's center and directed downward — 1 point

For labeled arrows representing the friction and normal forces or a single arrow representing the resultant of the friction and normal forces (i.e., the force exerted on the wheel by the surface), with no extraneous forces — 1 point

The friction force should start at the wheel-ramp contact and be directed up and left along the ramp.

The normal force should start at the wheel-ramp contact and be perpendicular to the ramp and toward the wheel's center. It does not have to go exactly through the center but must come reasonably close.

ii. 1 point

Correct answer: The friction force

No points are earned if the wrong force is given.

For correctly explaining that friction is the only force that exerts a torque with respect to the wheel's center of mass — 1 point

This point is also earned for a causal chain of reasoning about forces: e.g., the gravitational force leads to a normal force (and acceleration down the ramp), which leads to a frictional force, which exerts a torque (or changes the angular velocity).

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Question 1 (continued)

Distribution of points

(b) 2 points

For an expression for the sum of the force components parallel to the ramp that recognizes that there are two forces with components parallel to the ramp — 1 point

The expression need not be correct or consistent with the force diagram in part (a).

$$\sum F_{\parallel} = Mg\sin\theta - F_f$$

For indicating that the frictional force is $(0.4)Mg\sin\theta$ (explicitly or implicitly) and correctly solving for the acceleration in terms of correct variables — 1 point

$$\sum F_{\parallel} = Mg\sin\theta - (0.4)Mg\sin\theta$$

$$a = \frac{\sum F_{\parallel}}{M} = \frac{Mg\sin\theta - 0.4Mg\sin\theta}{M} = \frac{0.6Mg\sin\theta}{M}$$

$$a = 0.6g\sin\theta$$

(c)

i. 1 point

Correct answer: Block

No credit for answer without explanation.

For a correct explanation in terms of forces — 1 point

Example: The wheel experiences a counteracting frictional force, so the block has a greater net force exerted upon it and therefore has greater acceleration.

ii. 1 point

For a correct explanation in terms of energy conservation — 1 point

Example: Both object-Earth systems lose the same amount of potential energy and therefore gain the same amount of kinetic energy. With the ice block — but not the wheel — all the kinetic energy is translational, and none is rotational, so the block is faster.

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Question 2

12 points total — **Distribution of points**

Note: For parts (a) and (b), quantities that are proportional to mechanical energy, rather than energy itself, may be calculated, because terms like g or the ball's mass do not change during the experiment.

(a) 4 points

Parts i, ii, and iii are scored as a unit.

For an overall plan in which quantities are measured that could be used to compare mechanical energy before and after a collision with a hard surface — 1 point

For a conceptually plausible plan to measure pre- and post-collision positions and/or speeds that could be used to compare pre- and post-collision mechanical energies, without extraneous equipment and/or measurements — 1 point

For having lab equipment and measurement procedures well specified — 1 point

For a procedure that includes trials of different pre-collision speeds, ranging from low speed to high speed (as is needed to test the student's hypothesis) — 1 point

Example 1:

i. The drop height of the ball and the bounce height.
ii. A meterstick to measure the heights and a video camera to record the ball's motion.
iii. Place the meterstick upright against the wall.
Drop the ball from 10 different drop heights, using the video camera to record the bounce heights.

Example 2:

i. The speed of the ball immediately before and immediately after it bounces.
ii. A photogate near the floor, at a height just above the diameter of the ball, to measure the ball's speed.
iii. Drop the ball through the photogate.
Record the speeds measured by the photogate before and after the bounce.
Change the drop height of the ball at least five times, covering a range of heights from "low" to "high."

(b) 4 points

For describing how to plot or otherwise represent the data in a way that could be used to test the hypothesis — 1 point

For describing how to compare the post-collision to pre-collision mechanical energy (or a plausible alternative) to quantify the elasticity of the collision — 1 point

For comparing the low-speed versus high-speed results — 1 point

For addressing the hypothesis with an analysis such as a slope, ratio, or difference — 1 point

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Question 2 (continued)

Distribution of points

(b) (continued)

Example 1:

Make a graph of the bounce height h_f as a function of the drop height h_i. If the data are consistent with the hypothesis, then the data will (1) lie close to the line $h_f = h_i$ for low drop heights, and (2) lie below this line for high drop heights.

Example 2:

Make a graph of $v_f^2 - v_i^2$ as a function of v_i, where v_f and v_i are the ball's speed just after and just before the bounce, respectively. If the data are consistent with the hypothesis, then $v_f^2 - v_i^2$ will (1) be close to zero for low speeds, and (2) be negative for high speeds.

(c)

i. 2 points

For drawing a graph or table that shows that the low-speed collisions are nearly perfectly elastic — 1 point

For drawing a graph or table that shows a violation of a physics principle for higher-speed collisions — 1 point

Example for energy conservation:

A graph of the ratio $\frac{\text{Post-collision mechanical energy}}{\text{Pre-collision mechanical energy}}$ as a function of pre-collision speed, in which the graph stays near 1.0 for low initial speeds but becomes greater than 1.0 for high-speed collisions.

ii. 2 points

For a correct description of the aspect of the graph or table that shows a violation of the physical principle indicated — 1 point

For a correct explanation of why the representation shows a violation of the physical principle indicated — 1 point

Example for energy conservation using the graph described above: The value of the energy ratio shows a violation of conservation of energy when it becomes greater than 1.0 because the final energy cannot be greater than the initial energy.

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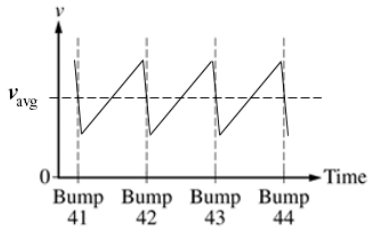
Question 3

12 points total **Distribution of points**

(a)



i. 3 points

For having a constant upward slope in each segment between bumps 1 point
For having the velocity "reset" abruptly at each bump (i.e., as a sawtooth function, not a sinusoidal curve) to a minimum positive value that is the same for each bump 1 point
For having the same maximum value in each cycle that occurs near the bump times (This point can be earned for a sinusoidal curve with peaks at the bump times.) 1 point

ii. 1 point

For drawing a v_{avg} line that is horizontal and consistent with the graph drawn, even if that graph is wrong 1 point

(b) 2 points

Correct answer: Greater than
No points are earned if the correct answer is selected, but the explanation is completely incorrect or there is no explanation.
No points are earned if the wrong answer is selected.
For indicating that there is more time between bumps 1 point
For connecting that the cart has more time or more distance to accelerate between bumps 1 point
Example: The maximum speed is greater because the cart has more space (or time) to accelerate (build up speed) between bumps.

Alternate solution in terms of energy *Alternate points*

For indicating that the potential energy difference increases due to increased height between successive bumps *1 point*
For relating the increase in potential energy to an increase in kinetic energy *1 point*

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Question 3 (continued)

Distribution of points

(c) 2 points

Correct answer: Greater than
No points are earned if the correct answer is selected, but the explanation is completely incorrect or there is no explanation.
No points are earned if the wrong answer is selected.
For indicating that the acceleration is greater 1 point
For indicating that the component of the gravitational force increases 1 point

Alternate solution in terms of energy *Alternate points*

For indicating that the potential energy difference increases due to increased height between successive bumps *1 point*
For relating the increase in potential energy to an increase in kinetic energy *1 point*

(d)

i. 2 points

Correct answer: No
No points are earned if the correct answer is selected, but the explanation is completely incorrect or there is no explanation.

For indicating that v_{avg} is not proportional to M 1 point
For connecting the equation to the data 1 point
Examples:
The y-intercept of the graph is not zero, but the equation indicates that it should be zero.
Doubling the mass from the graph does not double v_{avg}, but the equation indicates that it should double.
If "yes" is selected, one point may be earned for explaining that v_{avg} increases with M or that v_{avg} looks (approximately) proportional to M for a limited portion of the data (e.g., the points at M = 1.0 kg and M = 2.0 kg).

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Question 3 (continued)

Distribution of points

(d)

ii. 2 points

Correct answer: No

For indicating that the distance dependency is incorrect — 1 point

For indicating that, according to the equation, greater d leads to a smaller v_{avg}, OR — 1 point

for stating or implying the contradiction between this inverse relation and the reasoning of part (b)

Credit is earned for any answer that is consistent with reasoning in part (b).

Example: According to the equation, a larger d corresponds to a smaller v_{avg}, because they are inversely proportional. But according to the reasoning of part (b), a bigger distance d between the bumps leads to a larger maximum average speed, showing that the equation is implausible.

If "yes" is selected, one point can be earned for indicating that an increase in the angle increases v_{avg}.

2016 SCORING GUIDELINES

Question 4

7 points total

Distribution of points

(a) 3 points

Correct ranking is $(A = D) > (B = C)$.

For indicating that the potential difference is the same across A and D because the current is the same through each (A and D are in series.) — 1 point

For indicating that the potential difference is the same across B and C because B and C are in parallel — 1 point

For indicating that the potential difference is less across B (and/or C) than across A (and/or D) because the current splits or the current is less through B and C — 1 point

Example: The full battery current passes through both A and D, so they have the same current. Because they have the same resistance, $\Delta V_A = \Delta V_D$. B and C are in parallel, so $\Delta V_B = \Delta V_C$. Less than the full current passes through B, and A and B have the same resistance, so ΔV_B is less than ΔV_A.

(b) 2 points

Correct answer: Decrease

No points are earned if the correct answer is selected, but the explanation is completely incorrect, or there is no explanation.

If the wrong answer is selected, up to one point can still be earned.

For indicating that the effective resistance of the circuit increases — 1 point

For a correct explanation of why the current through A decreases based on changes in current or potential difference throughout the circuit — 1 point

Examples:

Because B is replaced with an infinite resistance, the effective resistance of the circuit increases and the battery current decreases. Because the battery current decreases and that current equals the current through A, the current through A decreases.

When B is removed, the effective resistance of that piece of the circuit increases because there is no longer a parallel combination there. Because the resistance is greater, the potential difference across that piece is a greater percent of the total. So the potential difference across A decreases and thus the current through it decreases.

2016 SCORING GUIDELINES

Question 4 (continued)

Distribution of points

(c) 2 points

Correct answer: Increase
No points are earned if the correct answer is selected, but the explanation is completely incorrect, or there is no explanation.
If the wrong answer is selected, up to one point can still be earned.
For indicating that all the current from the battery passes through C; the current no longer splits — 1 point
For making either a current argument or potential difference argument for the increase (i.e., an argument for why an increase in current through C more than compensates for the decrease in the full current or explaining that, by the loop rule, the potential difference across C must increase in order for the potential difference around the circuit loop to remain zero) — 1 point

2016 SCORING GUIDELINES

Question 5

7 points total

Distribution of points

(a) 2 points

For indicating that there is more rope or weight below one point than the other — 1 point
For indicating (explicitly or implicitly) that the tension at any point counteracts or supports the weight below that point — 1 point
Examples:
The rope at P supports more weight than the rope at Q so the tension must be higher at P.
The section of rope below P has an upward force from the rope above it and a downward gravitational force. The same goes for Q. Because the gravitational force is greater on the longer section (the section below P), the upward force — the tension — must be greater at P.

(b) 5 points

For indicating that the wavelength is longer near the top of the rope (or shorter near the bottom) — 1 point
For indicating (explicitly or implicitly) that the frequency is the same throughout the rope — 1 point
For using $v = \lambda f$ to conclude that wave speed is greater near the top of the rope (or less near the bottom), based on the difference in wavelength — 1 point
For indicating (explicitly or implicitly) that, as stated in part (a), tension is greater near the top of the rope (or less near the bottom) — 1 point
For a response that has sufficient paragraph structure, as described in the published requirements for the paragraph-length response — 1 point

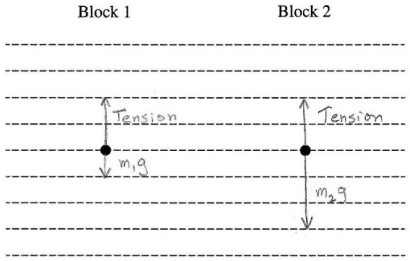
AP® Physics 1
2015 Scoring Guidelines

2015 SCORING GUIDELINES

Question 1

7 points total **Distribution of points**

(a) 2 points



For drawing two vectors starting on the dots that point upward, have the same length and are labeled as the tension force — 1 point

For drawing two vectors starting on the dots that point downward, where the vector for block 1 is smaller than the vector for block 2 and both are labeled as the gravitational force — 1 point

One earned point is deducted for drawing any extraneous vectors.

One earned point is deducted for vector lengths that do not allow the system to accelerate in the proper direction.

(b) 3 points

For writing an equation for Newton's second law for block 1 — 1 point

$m_1a = T - m_1g$

For writing an equation for Newton's second law for block 2 — 1 point

$m_2a = m_2g - T$

For eliminating T to obtain an equation that can be solved for the acceleration — 1 point

$T = m_1a + m_1g$

$m_2a = m_2g - m_1a - m_1g$

$(m_2 + m_1)a = (m_2 - m_1)g$

$a = (m_2 - m_1)g/(m_2 + m_1)$

2015 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(b) (continued)

Alternate solution — *Alternate points*

The system of two blocks must move as a unit, so the acceleration of the system is the acceleration of block 2.

For writing an equation showing that the net force acting on the system is the difference in masses times the acceleration of gravity — *1 point*

$F_{net} = (m_2 - m_1)g$

For writing an equation that relates the net force to the sum of the masses and the acceleration of the system — *1 point*

$F_{net} = (m_2 + m_1)a$

For writing an equation that can be solved for the acceleration in terms of the variables used in the summation of forces equations — *1 point*

$(m_2 + m_1)a = (m_2 - m_1)g$

$a = (m_2 - m_1)g/(m_2 + m_1)$

(c) 2 points

The acceleration of the new system, and thus of block 2, is smaller.

For indicating that the mass of the system is larger — 1 point

For a clear indication that the tension on block 2 is greater — 1 point

Alternate solution — *Alternate points*

For indicating that the mass of the system is larger — *1 point*

For indicating that the net force exerted on the system stays the same — *1 point*

Notes:

No points are earned for a correct prediction without a reasonable attempt at an explanation.

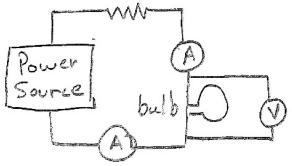
No points are earned for an incorrect prediction, regardless of the explanation.

2015 SCORING GUIDELINES

Question 2

12 points total **Distribution of points**

(a) 5 points



For drawing a circuit in which the power source, resistor, and bulb are wired in series — 1 point
For connecting at least one ammeter in series with the bulb — 1 point
For connecting the voltmeter across the bulb in parallel — 1 point
For describing measurements that can plausibly be used to answer question 1 — 1 point
Example: Measure the current entering and leaving the bulb with ammeters connected in series on either side of the bulb.
For describing measurements that can plausibly be used to answer question 2 — 1 point
Example: Measure the potential difference across the bulb with a voltmeter connected in parallel with the bulb.
The response does not need to mention multiple measurements.

(b)

(i) 1 point

For describing an analytical method of using the data, and explaining how that analytical method can be used to answer question 1 — 1 point
Example: If the current is the same on both sides of the bulb, then the number of electrons per second entering and leaving the bulb is the same.

(ii) 1 point

For describing an analytical method of using the data, and explaining how that analytical approach can be used to answer question 2 — 1 point
Example: If the potential difference across the bulb is not zero, then electrons that leave the bulb have different electric potential energy than electrons that enter it.

2015 SCORING GUIDELINES

Question 2 (continued)

Distribution of points

(c)

(i) 1 point

For any of the following: — 1 point
Describing any changes to the circuit needed to have a setup that can plausibly be used to determine whether the bulb's resistance is constant as a function of current.
Describing changes to a circuit that are not needed but do not impair the ability to determine whether the bulb's resistance is constant as a function of current.
Correctly indicating that no changes are needed.
Example based on circuit diagram in part (a): Remove one of the ammeters.

(ii) 1 point

For describing any additional measurements needed to determine whether current varies linearly as a function of voltage, or indicating that none are needed if the appropriate multiple measurements are mentioned in part (a) or (c)(i) — 1 point
Example: Measure the current through the bulb and the potential difference across the bulb for multiple settings of the power source.

(d) 3 points

For describing an analytical method in which data are represented or manipulated in some way that can plausibly be used to determine whether current varies linearly as a function of potential difference — 1 point
Examples:
Graphing measurements of current as a function of potential difference
Calculating the ratio of current to potential difference for multiple settings of the power source
For identifying that linearity is the relevant feature for determining whether the bulb is ohmic — 1 point
Examples:
Evaluating whether a plot of current as a function of voltage is linear
Evaluating whether the ratio of current to potential difference is constant
For describing a strategy for evaluating whether the conclusion of linearity is valid for a given data set taking into account the meter uncertainties — 1 point
Examples:
Drawing error boxes that represent the uncertainties of the meters around each point and evaluating whether a straight line can be drawn that goes through all the error boxes.
Indicating that small differences in the ratios could be due to uncertainty in the meters and would not discount the conclusion that the bulb is ohmic

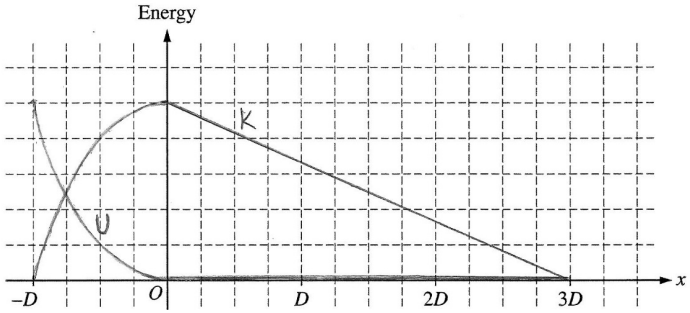
2015 SCORING GUIDELINES

Question 3

12 points total

Distribution of points

(a) 4 points



For sketching either energy curve with a reasonably correct shape between $x = -D$ and $x = 0$, with zero and maximum values at the correct locations — 1 point

For sketching two curves from $x = -D$ to $x = 0$ with shapes and values such that the total energy is constant (even if the curves are incorrect) — 1 point

For sketching potential energy equal to zero from $x = 0$ to $x = 3D$ — 1 point

For sketching kinetic energy as a linear function from its maximum value at $x = 0$ to zero at $x = 3D$ — 1 point

(b)

(i) 1 point

For identifying that the student is correct that the block will have more energy when it leaves the spring — 1 point

(ii) 1 point

For identifying that the student is incorrect about the new final position of the block because the spring's energy does not scale linearly with its compression — 1 point

2015 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

(c) 3 points

For indicating that the final energy in the spring (which becomes the mechanical energy of the block as it reaches the rough track) is four times the original energy in the spring — 1 point

For indicating that the frictional force remains the same — 1 point

For equating the initial energy in the spring to an expression that shows that the energy dissipated by friction is proportional to the distance the block slides down the rough track — 1 point

Example:

$U_1 = \frac{1}{2}kD^2$ and $U_2 = \frac{1}{2}k(2D)^2$ so $U_2 = 4U_1$

$W_1 = \mu mg(3D)$ and $W_2 = \mu mg\Delta x_2$

$W_1 = U_1$ and $W_2 = U_2 = 4U_1 = 4W_1$

$\mu mg\Delta x_2 = 4(\mu mg(3D))$

$\Delta x_2 = 4(3D) = 12D$

(d) 3 points

For indicating that the student's correct reasoning that the block has more energy in the second situation is expressed by the calculations comparing the initial energy in the spring — 1 point

For indicating that the student's correct reasoning that the block will slide farther is expressed by an equation that indicates that the work done by friction to stop the block in the second situation is some factor greater than the work done in the first situation — 1 point

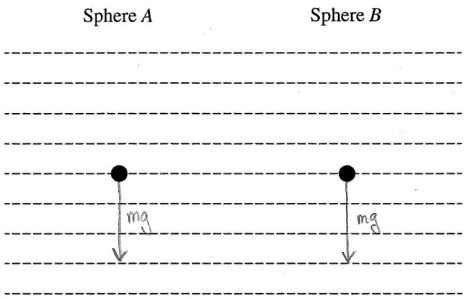
For indicating that the student's incorrect reasoning that energy scales linearly with the spring's compression is corrected by the expression for the initial energy of the spring — 1 point

2015 SCORING GUIDELINES

Question 4

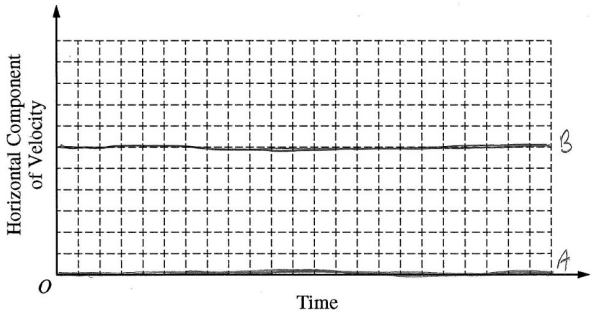
7 points total **Distribution of points**

(a) 1 point



For sketching only one force pointing straight down from each sphere and indicating that this force represents the force of gravity — 1 point

(b) 1 point



For sketching a horizontal line at zero velocity for sphere *A,* and sketching a horizontal line at some non-zero velocity for sphere *B* — 1 point

(c) 5 points

For indicating that the difference in horizontal motion does not affect the vertical motion of the spheres — 1 point
For indicating that both spheres start with the same vertical velocity — 1 point
For indicating that both spheres have the same vertical acceleration — 1 point
For indicating that falling the same height would take the same time — 1 point
For no incorrect or irrelevant statements — 1 point

2015 SCORING GUIDELINES

Question 5

7 points total **Distribution of points**

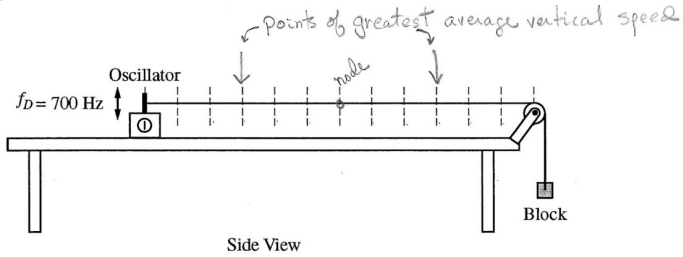
(a) 3 points

For reasoning that since the strings all have the same length, and since the wavelength of the fundamental depends on the length, all four waves have the same wavelength (e.g., $\lambda_1 = 2L$) — 1 point
For reasoning that since the wavelengths are all the same, different frequencies correspond to different velocities of the waves on the strings — 1 point
For reasoning that all the string tensions are the same due to the same mass M of each block, and therefore the linear mass densities must be different for different velocities since $v = \sqrt{F_T/(m/L)}$ (or since the vertical component of the tension will result in different vertical accelerations for strings with different masses) — 1 point
Note: Responses may refer to the physical differences between the strings in a variety of ways, e.g., different linear mass density, different total mass, different thicknesses of the same material

(b) 2 points

For combining $v = f\lambda$ with $v = \sqrt{F_T/(m/L)}$ (or referring to such an equation written in part (a)) — 1 point
For indicating how the equation leads to the conclusion that frequency would not be proportional to the inverse of the linear mass density — 1 point

(c) 2 points



For any indication of the second harmonic on the string, or a wave drawn such that $\lambda_2 = L$. — 1 point
For points which are at the antinodes of the second harmonic, or at the antinodes of any standing wave drawn on the string — 1 point
Notes:
Full credit is earned for having two points that are located one fourth the length of the string and three fourths the length of the string from the oscillator.
One earned point is deducted for each incorrect point marked on the figure