Question 4: Paragraph — 7 points

(a) For indicating **one** of the following: **1 point**

- That the gravitational force would be smaller for a greater radius
- That the gravitational field strength would be smaller for a greater radius
- That the acceleration due to gravity would be smaller for a greater radius

For indicating **one** of the following: **1 point**

- The sphere travels the same vertical distance in both scenarios
- The amount of work done on the sphere is dependent on the magnitude of the gravitational force
- The change in gravitational potential energy is less on Planet X

Example Response

The mass is the same and the radius is larger, so the force of gravity is less. The work done depends on the force times distance. Because the distance is the same, the work is less.

Total for part (a) 2 points

(b) For relating a larger planetary mass to a **one** of the following: **1 point**

- A larger weight of the sphere
- A larger acceleration due to gravity g
- A larger gravitational field strength

For indicating that the period is inversely related to **one** of the following: **1 point**

- The acceleration due to gravity g
- The gravitational field strength

For indicating that the amount of stretch is dependent on **one** of the following: **1 point**

- The weight of the sphere
- The acceleration due to gravity g
- The gravitational field strength

For relating the length of the string to the period of the pendulum **1 point**

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**

Example Response

$T = 2\pi\sqrt{\frac{\ell}{g}}$. *On Planet* Y *the gravitational force on the sphere is larger than when on Earth. Therefore, the sphere will experience a larger acceleration due to gravity on Planet* Y*. Because "* g *" is in the denominator of the equation, a larger acceleration due to gravity leads to a potentially smaller period. However, the increased gravitational force exerted on the sphere by Planet* Y *could result in the string stretching. This could result in the length of the pendulum increasing. Because* T *increases with the length of the pendulum, a longer string could potentially lead to a larger period.*

Total for part (b) 5 points

Total for question 4 7 points

Question 2: Experimental Design — 12 points

(a)(i) For indicating two quantities that, when graphed together, produce a straight line whose slope can be used to determine the acceleration a — **1 point**

Example Response

Vertical Axis : *Position* Horizontal Axis : *Time squared*

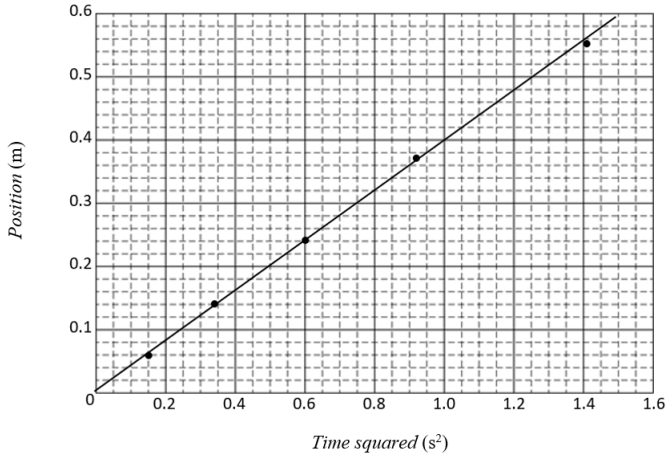
Position x (m)	Time t (s)	Time squared t^2 (s^2)
0.06	0.39	0.15
0.14	0.59	0.35
0.24	0.77	0.59
0.37	0.96	0.92
0.55	1.20	1.44

(a)(ii) The axes have a linear scale and are identified (labels **OR** units) so that when graphed correctly, the data will span more than half of the horizontal and vertical axes — **1 point**

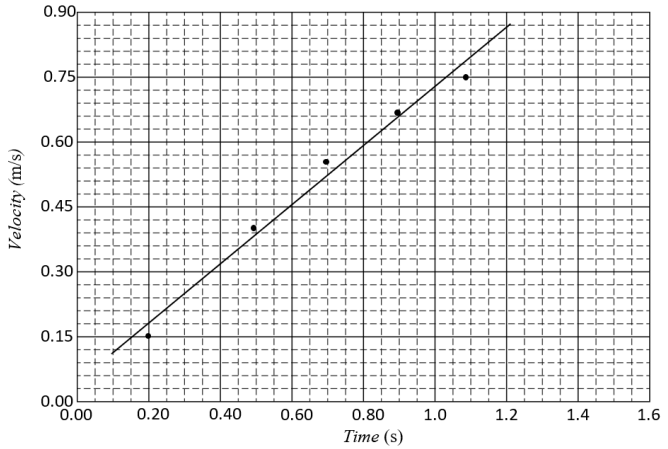
For plotting at least 4 of the data points correctly — **1 point**

For drawing a best-fit line that approximates the trend of the data — **1 point**

Example Response



Alternate Example Response



Scoring Note: The following tables represent the most common linearized graphs with the data that were used to determine the acceleration.

Graph: v vs. t	
$v\ \left(\frac{m}{s}\right)$	t (s)
0.15	0.20
0.40	0.49
0.56	0.68
0.68	0.87
0.75	1.08

Graph: $2x$ vs. t^2	
$2x$ (m)	$t^2\ (s^2)$
0.12	0.15
0.28	0.35
0.48	0.59
0.74	0.92
1.10	1.44

Graph: $2v_{avg}$ vs. t	
$2v_{avg}\ \left(\frac{m}{s}\right)$	t (s)
0.31	0.39
0.47	0.59
0.62	0.77
0.77	0.96
0.92	1.20

Graph: x vs. $\frac{1}{2}t^2$	
x (m)	$\frac{1}{2}t^2\ (s^2)$
0.06	0.08
0.14	0.17
0.24	0.30
0.37	0.46
0.55	0.72

Graph: $v_{avg}{}^2$ vs. x	
$v_{avg}{}^2\ \left(\frac{m^2}{s^2}\right)$	x (m)
0.02	0.06
0.06	0.14
0.10	0.24
0.15	0.37
0.21	0.55

Graph: $\sqrt{x}$ vs. t	
$\sqrt{x}\ (\sqrt{m})$	t (s)
0.24	0.39
0.37	0.59
0.49	0.77
0.61	0.96
0.74	1.20

(a)(iii) For attempting to find the slope, $\left(\frac{\text{rise}}{\text{run}}\right)$ or $\left(\frac{\Delta y}{\Delta x}\right)$, of the best-fit line drawn in part (a)(ii) **1 point**

Scoring Note: An indication that a calculator was used for linear regression to determine the value of the slope may earn this point.

For using the slope in a valid kinematic equation to calculate the acceleration **1 point**

Scoring Note: This point can be earned if evidence of a kinematic equation exists in graphed quantities (e.g., a graph of position as a function of $\frac{1}{2}t^2$).

Example Response

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{\Delta \text{ position}}{\Delta \text{ time}^2} = \frac{0.48 \text{ m} - 0.18 \text{ m}}{1.2 \text{ s}^2 - 0.4 \text{ s}^2} = 0.375 \ \frac{\text{m}}{\text{s}^2}$$

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

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

$$\text{slope} \times 2 = a$$

$$a = 0.75 \ \frac{\text{m}}{\text{s}^2}$$

Total for part (a) 6 points

(b)(i) For indicating a quantity to be measured **1 point**

Accept **one** of the following:

- The angle θ with the horizontal
- The height h and length L of the ramp

Scoring Note: Stating only the height needs to be measured can earn this point if an energy approach is used.

(b)(ii) For providing a correct expression relating the acceleration of gravity to the acceleration measured **1 point**

Scoring Note: If $\cos\theta$ is used, the response must specify that θ was measured from the vertical.

Example Response

$$mg_{\text{exp}} \sin\theta = ma$$

$$g_{\text{exp}} = \frac{a}{\sin\theta}$$

OR

$$\sin\theta = \frac{h}{L}$$

$$g_{\text{exp}} = \left(\frac{L}{h}\right)a$$

OR

$$mg_{\text{exp}}h = \frac{1}{2}mv^2$$

$$g_{\text{exp}}h = \frac{1}{2}v^2$$

$$v = \sqrt{2g_{\text{exp}}h}$$

$$v = at$$

$$at = \sqrt{2g_{\text{exp}}h}$$

$$g_{\text{exp}} = \frac{a^2t^2}{2h}$$

Total for part (b) 2 points

(c)(i) For identifying a physical factor that could have affected the result **1 point**

Accept **one** of the following:

- A physical factor in the materials used (e.g., the wheels have nonnegligible rotational inertia, the ramp was bumpy, the wheels were wobbly or not perfectly round, the base of the ramp was not level, the floor was not level.)
- A physical factor in the environment (e.g., the room was being accelerated, elevator, the experiment was performed at high elevation or on a different planet.)
- A physical error in measurement collection (e.g., time, position, or angle was measured incorrectly.)

Scoring Note: A statement of "Human error" does not earn this point.

(c)(ii) For correctly indicating the functional dependence between the reason listed in part (c)(i) and g_{exp} **1 point**

Accept **one** of the following:

- Correctly indicating the functional dependence between the physical factor in the materials used and g_{exp} (e.g., if the rotational inertia of the rotating wheels is nonnegligible, the cart will have a smaller acceleration and g_{exp} will be smaller.)
- Correctly indicating the functional dependence between the physical factor in the environment and g_{exp} (e.g., if the experiment was performed at a high elevation, the acceleration will be smaller and g_{exp} will be smaller.)
- Correctly indicating the functional dependence between the physical error in the measurement collection and g_{exp} (e.g., if the angle of the ramp is smaller than the measured value, the cart will have a smaller acceleration and g_{exp} will be smaller.)

Example Response

The expression I derived for the value for g_{exp} did not take into consideration that the wheels had any rotational inertia. If the wheels have rotational inertia and are rotating, the acceleration of the cart would be less than $g\sin\theta$, so the value of g_{exp} would be less than $9.8\ \frac{\text{m}}{\text{s}^2}$.

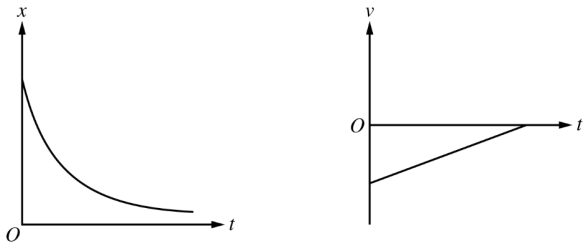
Total for part (c) 2 points

(d) For sketching a concave up curve with an initially negative slope for the graph of position as a function of time **1 point**

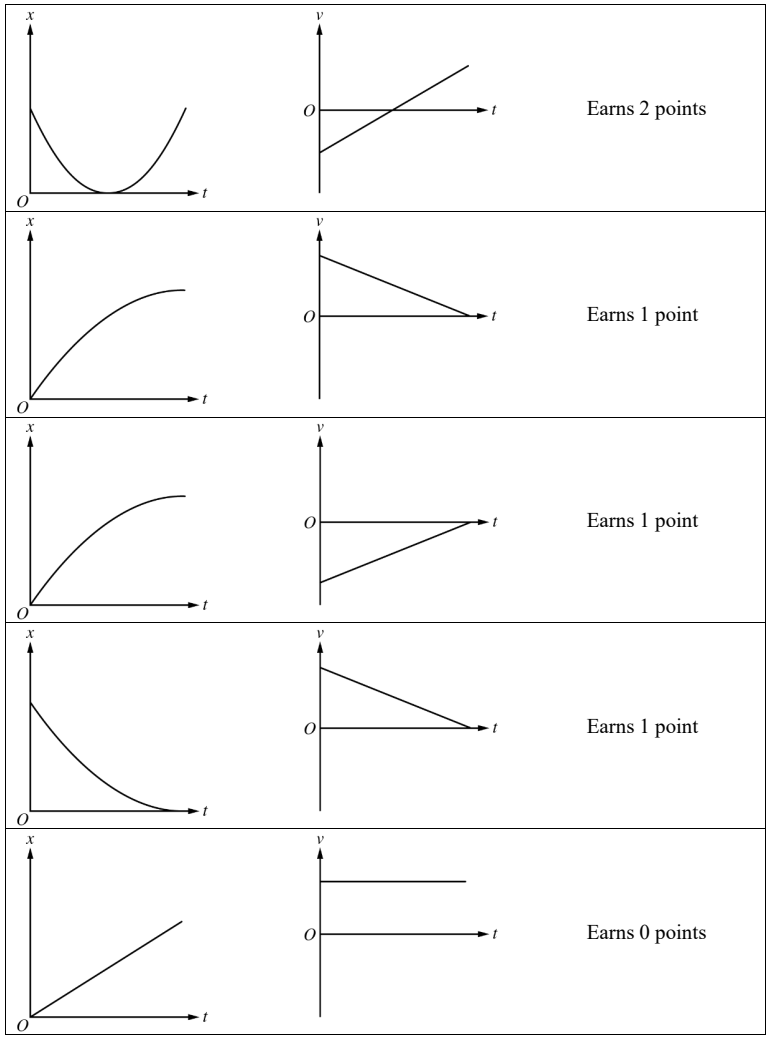
For **one** of the following: **1 point**

- Drawing a line with a positive slope and a negative vertical intercept for the v vs. t graph
- Drawing a v vs. t graph that is consistent with the x vs. t graph that shows acceleration

Example Response



Scoring Note: The following are alternate example graphs with the points the response would earn.



Total for part (d) 2 points

Total for question 2 12 points

Question 2: Qualitative/Quantitative Translation 12 points

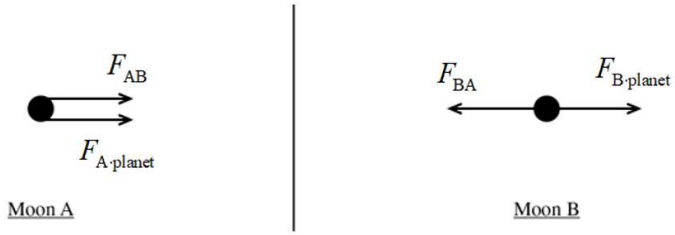
(a) For two forces directed to the right on Moon A, correctly labeled, with no extraneous forces **1 point**

For two horizontal forces in opposite directions on Moon B. The labels on the forces must be correct and distinguishable from each other, with no extraneous forces. **1 point**

Scoring Notes:

- Acceptable labels for forces include: F_{AB}, $F_{A\text{ on }B}$, F_{planet}, F_{moon}, F_0, F_p, F_{gA}, etc.
- Maximum 1 point can be earned if the arrows do not start on the dot.

Example Response



Total for part (a) 2 points

(b)(i) For indicating the force vectors on Moon A point in the same direction and therefore, the magnitudes add, while the force vectors on Moon B point in opposite directions and the magnitudes are to be subtracted **1 point**

Example Response

The force vectors on Moon A point in the same direction and therefore add, while the force vectors on Moon B point in opposite directions and will subtract.

(b)(ii) For a justification based on the inverse relation between gravitational force and distance **1 point**

Scoring Note: This point may be earned in either part (b)(i) or (b)(ii).

For indicating Moon B is closer to the planet than Moon A, and therefore, the gravitational force exerted by the planet is larger for Moon B than for Moon A **1 point**

Example Response

The gravitational force is greater for objects that are closer together, and Moon B is closer to the planet than Moon A, so the gravitational force from the planet is greater for Moon B than for Moon A.

Total for part (b) 3 points

(c)	For using the law of gravitation at least once	**1 point**
	For substituting in correct distances in all expressions	**1 point**
	For substituting in correct masses in all expressions	**1 point**
	For correctly adding terms for ΣF_A and subtracting terms for ΣF_B	**1 point**

Scoring Note: An overall negative sign on either force is acceptable.

Example Response

Moon A

$F_g = G\frac{m_1 m_2}{r^2}$

$\Sigma F_A = F_{A\text{-planet}} + F_{AB}$

$\Sigma F_A = G\frac{m_0 m_p}{R_A{}^2} + G\frac{m_0{}^2}{(R_A - R_B)^2}$

$\Sigma F_A = Gm_0\left(\frac{m_p}{R_A{}^2} + \frac{m_0}{(R_A - R_B)^2}\right)$

Moon B

$F_g = G\frac{m_1 m_2}{r^2}$

$\Sigma F_B = F_{B\text{-planet}} - F_{BA}$

$\Sigma F_B = G\frac{m_0 m_p}{R_B{}^2} - G\frac{m_0{}^2}{(R_A - R_B)^2}$

$\Sigma F_B = Gm_0\left(\frac{m_p}{R_B{}^2} - \frac{m_0}{(R_A - R_B)^2}\right)$

Total for part (c) 4 points

(d)(i)	For addressing the functional dependence expressed in the equations from part (c)	**1 point**

Scoring Notes:

- It is not necessary to use the functional dependence correctly to earn this point.
- This point may be earned in either part (d)(i) or (d)(ii).

	For a correct explanation for why the expressions in part (c) either support or do not support the reasoning consistent with response in part (b)(i)	**1 point**

Example Response

Yes. For the net force on Moon A, both force terms have the same sign, so they add, while for the net force on Moon B, the two terms have opposite signs, so they have a canceling effect.

(d)(ii)	For a correct explanation for why the expressions in part (c) either support or do not support the reasoning consistent with response in part (b)(ii)	**1 point**

Example Response

The gravitational force has an inverse relationship with distance. If Moon A is very far away, ΣF_A from part (c) will be small. If Moon B is close to the planet while Moon A is far away, the force toward the planet would be big while the force toward the moon would be small such that ΣF_B could be larger than ΣF_A.

Total for part (d) 3 points

Total for question 2 12 points

AP® Physics 1
2016 Scoring Guidelines

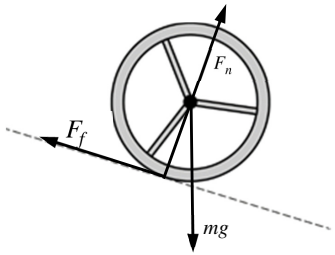
2016 SCORING GUIDELINES

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

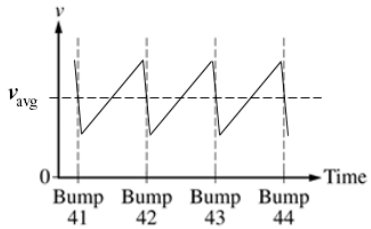
Example for energy conservation using the graph described above: The value of the energy ratio shows a violation of conservation of energy when it becomes greater than 1.0 because the final energy cannot be greater than the initial energy.

2016 SCORING GUIDELINES

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*

2016 SCORING GUIDELINES

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.

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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