# AP® Physics 1
# 2015 Scoring Guidelines

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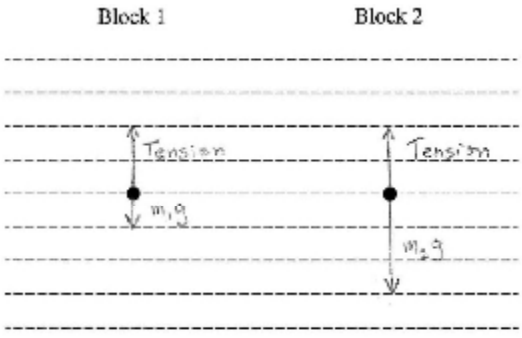
# AP® PHYSICS 1
# 2015 SCORING GUIDELINES

## 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

$T = m_1a + m_1g$

$m_2a = m_2g - m_1a - m_1g$

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

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

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## 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.

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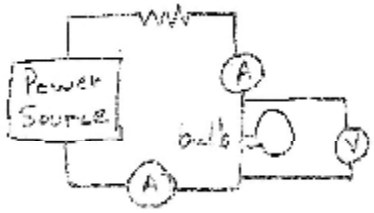
## Question 2

**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.

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## 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

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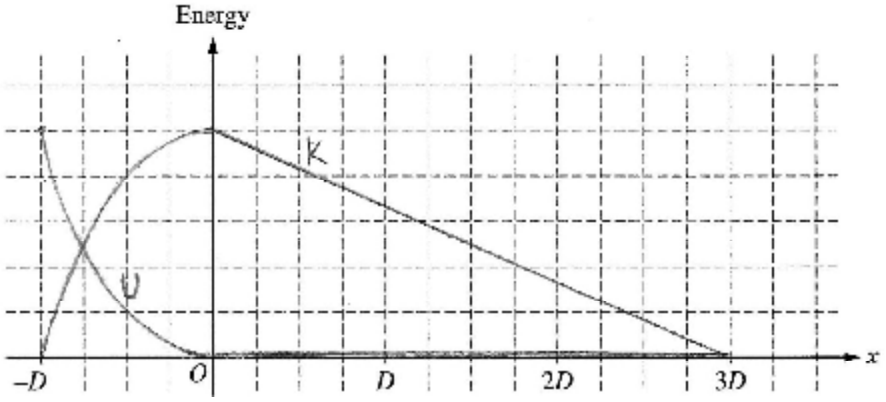
## Question 3

**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

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**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

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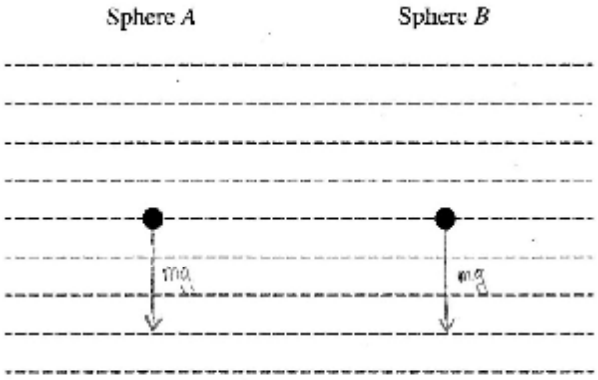
## Question 4

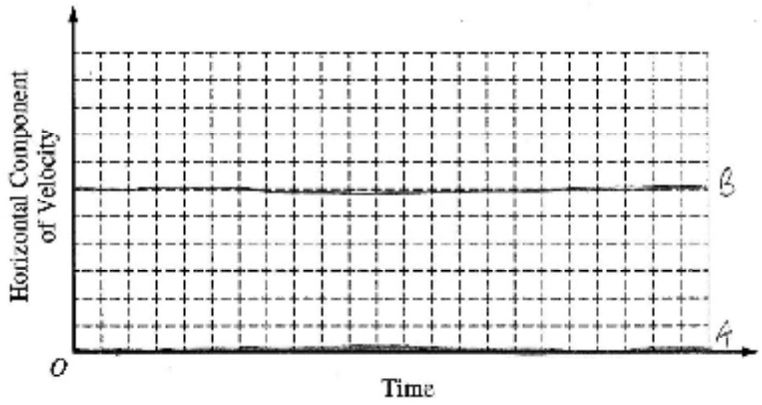
**7 points total** **Distribution of points**

(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 |

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## 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

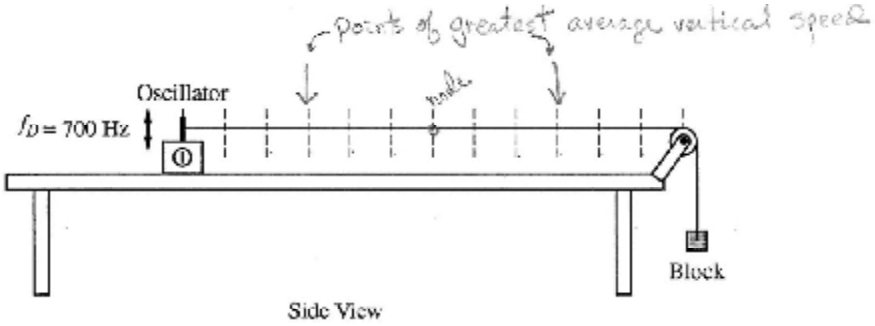
Note: Responses may refer to the physical differences between the strings in a variety of ways, e.g., different linear mass density, different total mass, different thicknesses of the same material

(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

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# AP® PHYSICS 1
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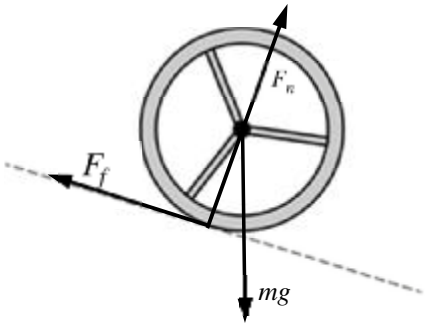
## Question 1

**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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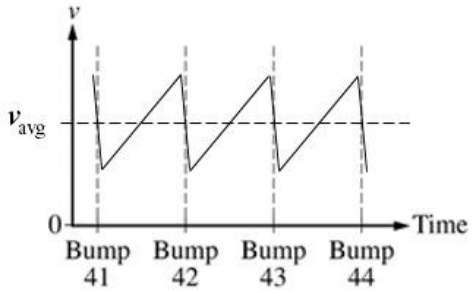
## Question 3

**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 $v_{avg}$.

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## 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 $\Delta V_B$ is less than $\Delta V_A$.

(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

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## 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

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2017

# AP Physics 1: Algebra-Based

## Scoring Guidelines

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# AP® PHYSICS
# 2017 SCORING GUIDELINES

## General Notes About 2017 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. The requirements that have been established for the paragraph length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based and AP Physics 2: Algebra-Based Course and Exam Description*.

5. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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# AP® PHYSICS 1
# 2017 SCORING GUIDELINES

## Question 1

**7 points total** **Distribution of points**

(a) 2 points

Correct ranking: $(A = D = E) > (B = C)$ OR $A = D = E,\ B = C$

Note: A ranking must be given for any points to be earned for the explanation.

Note: The ranking must be correct to earn the full 2 points for the explanation.

For indicating $A = D = E$ in the ranking, with a valid explanation 1 point

Example: "*A*, *D*, and *E* are all connected across the battery, so they must have the same $\Delta V$ as the battery."

For indicating $B = C$ in the ranking, with a valid explanation 1 point

Example: "The same current flows through both bulbs *B* and *C*, so they have the same voltage drop across them. By Kirchhoff's voltage rule, the sum of the voltages in this circuit must add to zero, so each bulb has half the battery voltage."

Example 1: For each of bulbs *A*, *D*, and *E*, current can go around the circuit passing through only that bulb and the battery, and hence the potential drop across all three bulbs equals the voltage of the battery (because $\Delta V = 0$ for a complete loop). In circuit 2, *B* and *C* are in series so the overall potential drop (equal to the battery's voltage) is "shared" equally between the two bulbs (because they are identical) and the potential difference across each is half is the battery's voltage.

Example 2: *A*, *D*, and *E* are all connected directly across the battery terminals and therefore "get" the full battery potential difference. By contrast, the potential drop across the *BC* part of the circuit is "split" between *B* and *C*, and split equally.

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# 2017 SCORING GUIDELINES

## Question 1 (continued)

**Distribution of points**

(b) 5 points

Correct answers: Circuit 3 runs out first, circuit 2 runs out last

Note: In the paragraph response, "energy dissipation" or "current" are acceptable substitutes for "power."

For indicating that all three circuits draw different amounts of power — 1 point

Note: This point may be earned by addressing only two circuits in the response.

For explaining that the battery in circuit 2 delivers the least power using correct physical reasoning by addressing potential difference OR resistance — 1 point

For explaining that the battery in circuit 3 delivers the most power using correct physical reasoning by addressing potential difference OR resistance — 1 point

For an implicit or explicit statement that greater power results in shorter battery life — 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: The battery in circuit 3 runs out first, then the battery in circuit 1, and finally the battery in circuit 2. The power (rate of energy loss) of a battery is $P = I\Delta V$, and all three batteries have the same potential difference. So the rate of energy loss, and hence the order in which the batteries "die," is given by the ranking of the currents through the batteries. Circuit 3 has the most current because the availability of two paths (loops) makes the overall resistance of this circuit the lowest. Circuit 2 has the least current because there is only one loop, and it contains two bulbs, making the overall resistance greater than that of circuit 1.

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# AP® PHYSICS 1
# 2017 SCORING GUIDELINES

## Question 2

**12 points total** | **Distribution of points**

(a)

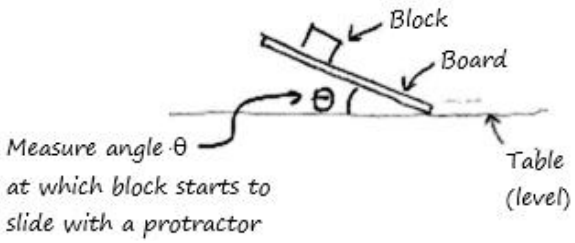
i. 3 points

For drawing a diagram of an experimental setup to measure the coefficient of friction that is feasible in a school physics lab — 1 point

For indicating the measurements necessary for calculating the coefficient of friction — 1 point

For indicating equipment necessary for measuring the quantities required to calculate the coefficient of friction — 1 point

Example:




ii. 3 points

For a description that is consistent with the diagram in part (a)(i), in enough detail that another student could replicate the experiment — 1 point

For a description that is a conceptually valid method to find quantities that would allow a calculation of a friction coefficient — 1 point

For including a valid method for reducing experimental error — 1 point

Example:

With the block at rest on the board, slowly lift one end of board until the block just begins to slide. Measure the angle between board and table and repeat several times with block at different locations on the board (with multiple trials at each location).

(b) 3 points

Note: In order to earn full credit for part (b), all terms (variables) must be indicated in the diagram and/or procedure of part (a).

For using Newton's second law (or reasoning in terms of zero net force) in one dimension, parallel to the board's surface, either explicitly or implicitly — 1 point

For using Newton's second law (or reasoning in terms of zero net force) in one dimension, perpendicular to the board's surface, either explicitly or implicitly — 1 point

Note: Replacing the normal force with $mg$ is "implicit" use of Newton's second law in the perpendicular direction for a horizontal surface. For a tilted surface, the appropriate trigonometric term should be included.

For a correct derived expression of the coefficient of static friction in terms of quantities indicated in part (a) — 1 point

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**Question 2 (continued)**

**Distribution of points**

(c) 2 points

Correct answer: "The static and kinetic coefficients are not equal."
Reasoning cannot earn credit if the incorrect selection is made.

For identifying group 5's results as outliers, or indicating the presence of an outlier — 1 point
For a conclusion that coefficients are not the same, justified by either removing the outlier or noting the coefficients are different for each group — 1 point

(d) 1 point

For a valid argument that indicates the coefficient of static friction is a property of the two surfaces, and is consistent with the selected answer — 1 point

Example 1: Selects "Remain the same"
Referring to the equation in part (b), coefficient does not depend on mass.
Example 2: Selects "Remain the same"
The coefficient depends on the nature of the surfaces involved, not the masses or normal force of the objects involved.
Example 3: Selects "Decrease"
The increased normal force will cause smoothing of the surfaces, decreasing the coefficient of friction.
Example 4: Selects "Increase"
The increased normal force will cause the surfaces to become gouged, increasing the coefficient of friction.

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# AP® PHYSICS 1
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## Question 3

**12 points total** | **Distribution of points**

(a) 1 point

Correct answer: "To the right of *C*"
Reasoning cannot earn credit if the incorrect selection is made.

For an explanation that the torque exerted by the disk or the angular momentum of the disk is greater when farther from the pivot — 1 point

Example 1: The disk exerts a greater torque on the rod when it pushes the rod farther from the pivot.
Example 2: The disk has greater angular momentum when it's farther from the pivot. The disk loses almost all its speed during the collision and hence gives the rod almost all its angular momentum. So the rod ends up with more angular momentum when the disk hits it farther from the pivot.

(b) 2 points

Correct answer: "Yes"
If "No" is selected, the explanation may still earn full credit if an incorrect selection was made in part (a).

For a selection consistent with the selection from part (a) — 1 point
For indicating that the equation shows that $\omega$ increases with increasing $x$ — 1 point

Example: According to the equation, $\omega$ increases with $x$; a bigger $x$ produces a bigger angular speed. This agrees with my reasoning from part (a), where I said a bigger $x$ creates a bigger angular speed after the collision.

(c) 3 points

For focusing on functional dependence (instead of, for example, considering units/dimensions) — 1 point
For addressing $m_{\text{disk}}$, $I$, or both — 1 point
For correctly concluding that the equation is wrong because of the dependence on $m_{\text{disk}}$, $I$, or both — 1 point

Example: If $m_{\text{disk}}$ is large, then more angular momentum will be transferred during the collision. But the equation shows the angular speed decreasing with increasing $m_{\text{disk}}$, because it is in the denominator.

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**Question 3 (continued)**

**Distribution of points**

(d) 4 points

For using an expression of conservation of angular momentum for the disk and rod — 1 point
Note: This point is not awarded for equating angular and linear momentum.

For indicating that the initial angular momentum of the system is equal to $m_{\text{disk}} v_0 x$ — 1 point

For a dimensionally correct expression for the post-collision angular momentum that includes $I\omega$ — 1 point

For indicating the correct rotational inertia of the system after the collision: $I + m_{\text{disk}} x^2$ — 1 point

(e) 2 points

Correct answer: "Greater than"

For indicating, either directly or by analogy to the linear case, that the disk's angular momentum with respect to the pivot changes more in the bouncy scenario than in the original scenario OR for using a similar argument in terms of impulse — 1 point
Note: This point is for describing what happens to the disk.

For using conservation of angular momentum or momentum-impulse reasoning to conclude that the rod gains more angular momentum, and hence more angular speed, in the bouncy scenario — 1 point
Note: This point is for describing what happens to the rod.

Example: After the bouncy collision, the disk has angular momentum in the clockwise direction. To keep the system angular momentum constant, the magnitude of the rod's counterclockwise angular momentum must be greater than before.

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## Question 4

**7 points total** **Distribution of points**

(a) 3 points

Correct answer: "No"
Note: If the wrong answer is selected, partial credit can be earned for the justification.

For attempting to use conservation of energy to compare the two blocks — 1 point
For explicitly or implicitly indicating that the launch velocities are different — 1 point
For stating or implying that the time to reach the ground is the same for both blocks — 1 point

Example: The amount of potential energy converted to kinetic energy is different for the two blocks. The potential energy is proportional to the change in height, which is smaller for block 2. Therefore, at the edge of the table, block 1 will have more kinetic energy than block 2, and hence a larger speed. The launches are both horizontal and from the same height, so the blocks will spend the same amount of time in the air. Because $d = vt$, the distances will be different for the two blocks (as the speeds are different).

(b)

i. 2 points

Correct answer: "The two blocks land the same distance from their respective tables."

For indicating that the change in potential energy from release to launch is the same for the two cases — 1 point
For an indication (explicit or implicit) that the launch velocities are the same — 1 point

ii. 2 points

Correct answer: "Block 1"

For indicating that the average speed or velocity on the slide is higher for Team 1, OR that block 1 reaches its maximum speed in less time — 1 point
For a valid explanation of why the average speed or velocity is higher for team 1, OR why block 1 reaches its maximum speed in less time — 1 point

Example: Because the ramp on Table 1 is initially steeper, block 1 has a higher average speed while it's on the ramp so it launches off the table before block 2.

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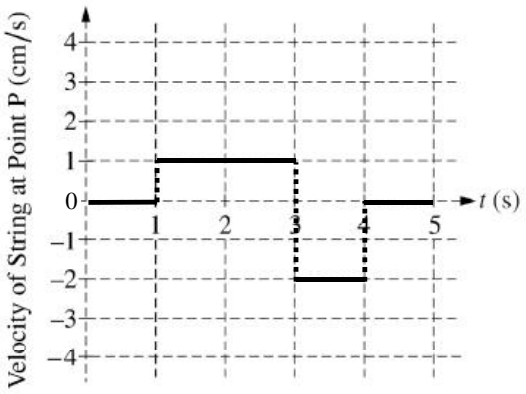
# 2017 SCORING GUIDELINES

## Question 5

**7 points total** **Distribution of points**

(a) 3 points

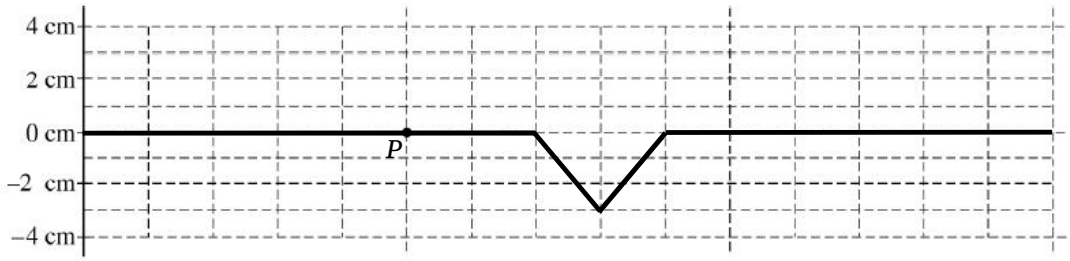



For indicating zero velocity for $0 < t < 1$ s and $4$ s $< t < 5$ s — 1 point

For indicating two different non-zero constant velocities, one at the interval $1$ s $< t < 3$ s and the other at the interval $3$ s $< t < 4$ s — 1 point

For indicating a maximum velocity of $+1$ cm/s and a minimum velocity of $-2$ cm/s — 1 point

(b) 4 points




For drawing a single pulse and zero elsewhere — 1 point

For drawing a single pulse that is triangular (need not be isosceles or of two-unit extent) — 1 point

For drawing a single pulse with the correct maximum displacement from equilibrium of $-3$ cm — 1 point

For drawing a single pulse at the correct location that is two units wide between the 7th and 9th grid lines (i.e., 2 grid lines to the right of *P* to 4 grid lines to the right of *P*) and zero elsewhere — 1 point

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2018

# AP Physics 1: Algebra-Based

## Scoring Guidelines

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# AP® PHYSICS
# 2018 SCORING GUIDELINES

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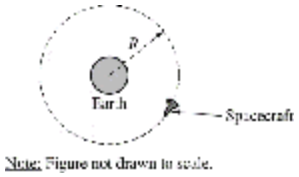
# AP® PHYSICS 1
# 2018 SCORING GUIDELINES

## Question 1

**7 points total** **Distribution of points**

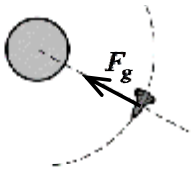


Note: Figure not drawn to scale.

A spacecraft of mass $m$ is in a clockwise circular orbit of radius $R$ around Earth, as shown in the figure above. The mass of Earth is $M_E$.

(a) LO / SP: 3.A.2.1 / 1.1; 3.B.2.1 / 1.1, 1.4
2 points

In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.



Note: Figure not drawn to scale.

| | | |
|---|---|---|
| For an arrow directed toward Earth's center | | 1 point |
| For a correct label on the arrow representing the gravitational force, where the arrow is pointing toward Earth's center | | 1 point |
| Note: A maximum of 1 point may be earned if extraneous forces are present. | | |

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## Question 1 (continued)

**Distribution of points**

(b) LO / SP: 2.B.2.1 / 2.2; 3.A.1.1 / 1.5, 2.2; 3.B.1.3 / 1.5, 2.2; 3.B.2.1 / 1.1, 1.4, 2.2, 3.C.1.2 / 2.2
4 points

i. 3 points

Derive an equation for the orbital period $T$ of the spacecraft in terms of $m$, $M_E$, $R$, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

| | | |
|---|---|---|
| For using (or implying) Newton's second law and equating the centripetal force to the gravitational force:<br>$F_g = ma = \frac{mv^2}{R}$ $\qquad$ $\frac{GmM_E}{R^2} = \frac{mv^2}{R}$ | | 1 point |
| For explicitly or implicitly determining that the speed of the spacecraft is:<br>$v = \frac{2\pi R}{T}$ | | 1 point |
| For a correct answer algebraically equivalent to:<br>$T = \sqrt{\frac{4\pi^2 R^3}{GM_E}}$ | | 1 point |
| Note: It is acceptable to leave answer in terms of $T^2$<br>$T^2 = \frac{4\pi^2 R^3}{GM_E}$ | | |

ii. 1 point

A second spacecraft of mass $2m$ is placed in a circular orbit with the same radius $R$. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

| | | |
|---|---|---|
| Correct answer: "Equal to"<br>Note: For an incorrect answer consistent with part (b)(i), the explanation is still graded for consistency with part (b)(i). | | |
| For a correct explanation that the period of the spacecraft does not depend on the spacecraft mass (or only depends on the mass of Earth and the radius of the orbit) OR an explanation consistent with the answer from (b)(i) | | 1 point |
| Note: The explanation must be consistent with the checked answer. | | |

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# AP® PHYSICS 1
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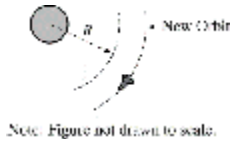
## Question 1 (continued)

**Distribution of points**

(c) LO / SP: 2.B.1.1 / 2.2; 3.A.1.1 / 1.5, 2.2; 3.B.1.3 / 1.5, 2.2; 3.B.2.1 / 1.1, 1.4, 2.2; 3.C.1.2 / 2.2
1 point

The first spacecraft is moved into a new circular orbit that has a radius greater than $R$, as shown in the figure below.




Note: Figure not drawn to scale.

Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

| | | |
|---|---|---|
| Correct answer: "Less than"<br>Note: If the wrong selection is made, the explanation is not graded. | | |
| For a correct explanation of why speed decreases with increasing orbital radius | | 1 point |
| Example:<br>Derivation step in (b)(i) shows that speed decreases with increasing $R$. | | |

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## Question 1 (continued)

Learning Objectives (LO)

**LO 2.B.1.1**: The student is able to apply $F = mg$ to calculate the gravitational force on an object with mass $m$ in a gravitational field of strength $g$ in the context of the effects of a net force on objects and systems. [See Science Practices 2.2 and 7.2]

**LO 2.B.2.1**: The student is able to apply $g = GM/r^2$ to calculate the gravitational field due to an object with mass $M$, where the field is a vector directed toward the center of the object of mass $M$. [See Science Practice 2.2]

**LO 3.A.1.1**: The student is able to express the motion of an object using narrative, mathematical, and graphical representations. [See Science Practices 1.5, 2.1, and 2.2]

**LO 3.A.2.1**: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [See Science Practice 1.1]

**LO 3.B.1.3**: The student is able to re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [See Science Practices 1.5 and 2.2]

**LO 3.B.2.1**: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, and 2.2]

**LO 3.C.1.2**: The student is able to use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion (for circular orbital motion only in Physics 1). [See Science Practice 2.2]

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## Question 2

**12 points total** **Distribution of points**

A group of students prepare a large batch of conductive dough (a soft substance that can conduct electricity) and then mold the dough into several cylinders with various cross-sectional areas $A$ and lengths $\ell$. Each student applies a potential difference $\Delta V$ across the ends of a dough cylinder and determines the resistance $R$ of the cylinder. The results of their experiments are shown in the table below.

| Lab Station | $A\ (\text{m}^2)$ | $\ell$ (m) | $\Delta V$ (V) | $R\ (\Omega)$ | Example: $RA\ (\Omega\cdot\text{m}^2)$ | Example: $\ell/A\ (\text{m}^{-1})$ |
|---|---|---|---|---|---|---|
| 1 | 0.00049 | 0.030 | 1.02 | 23.6 | 0.012 | 61 |
| 2 | 0.00049 | 0.050 | 2.34 | 31.5 | 0.015 | 102 |
| 3 | 0.00053 | 0.080 | 3.58 | 61.2 | 0.032 | 151 |
| 4 | 0.00057 | 0.150 | 6.21 | 105.0 | 0.060 | 263 |

(a) LO / SP: 1.E.2.1 / 4.1; 5.B.9.3 / 2.2; 5.C.3.2 / 4.1, 5.1
7 points

The students want to determine the resistivity of the dough cylinders.

i. 2 points

Indicate below which quantities could be graphed to determine a value for the resistivity of the dough cylinders. You may use the remaining columns in the table above, as needed, to record any quantities (including units) that are not already in the table.

Vertical Axis: _____ Horizontal Axis: _____

| | | |
|---|---|---|
| For quantities derived from $R$, $\ell$, and $A$ only | | 1 point |
| For choosing two quantities that, graphed together, can be used to determine the resistivity | | 1 point |

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# 2018 SCORING GUIDELINES

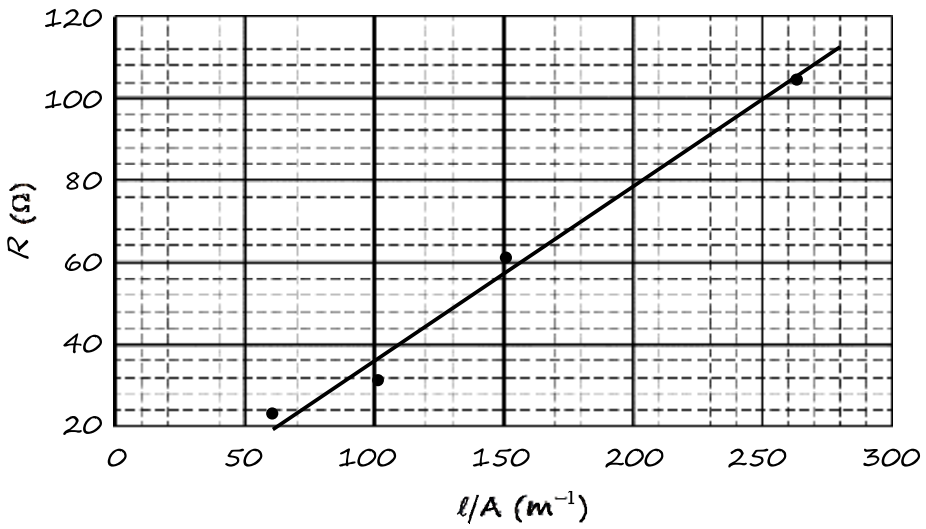
## Question 2 (continued)

**Distribution of points**

(a) (continued)

ii. 3 points

On the grid below, plot the appropriate quantities to determine the resistivity of the dough cylinders. Clearly scale and label all axes, including units as appropriate.




| | | |
|---|---|---|
| Note: The following points can be earned only if the graphed points correspond to the quantities chosen in (a)(i). | | |
| For a linear scale where the plotted data uses at least half the grid | | 1 point |
| For labeling both axes, with units as appropriate | | 1 point |
| For data points plotted that represent the appropriate trend based on chosen quantities<br>Note: The appropriate trend depends on the choice of graphed quantities and may be e.g., linear, inversely proportional, etc. | | 1 point |

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## Question 2 (continued)

**Distribution of points**

(a) (continued)

iii. 2 points

Use the above graph to estimate a value for the resistivity of the dough cylinders.

| | | |
|---|---|---|
| For correctly using the slope of the graph to find the resistivity or a statement that a calculator was used to find the appropriate value from the graph | | 1 point |
| For a correct value of the resistivity $\rho = 0.42\ \Omega\cdot m\ (\pm 0.03)$ calculated from graph or data | | 1 point |

(b) LO / SP: 1.E.2.1 / 4.1
1 point

Another group of students perform the experiment described in part (a) but shape the dough into long rectangular shapes instead of cylinders. Will this change affect the value of the resistivity determined by the second group of students?
____ Yes ____ No
Briefly justify your reasoning.

| | | |
|---|---|---|
| Correct answer: "No"<br>Note: If the wrong selection is made, the explanation is not graded. | | |
| For indicating that resistivity only depends on material, not shape | | 1 point |

(c) LO / SP: 1.E.2.1 / 4.1; 5.B.9.2 / 4.2; 5.B.9.3 / 2.2; 5.C.3.2 / 4.1, 4.2; 5.C.3.3 / 1.4, 2.2
4 points

Describe an experimental procedure to determine whether or not the resistivity of the dough cylinders depends on the temperature of the dough. Give enough detail so that another student could replicate the experiment. As needed, include a diagram of the experimental setup. Assume equipment usually found in a school physics laboratory is available.

| | | |
|---|---|---|
| For explicitly or implicitly controlling all variables (e.g., length and area) except for temperature | | 1 point |
| For a plausible way to change the temperature of the dough | | 1 point |
| For indicating that the temperature will be varied | | 1 point |
| For a valid and feasible experiment in which resistance, OR voltage and current, are appropriately measured | | 1 point |
| Example: Make two dough cylinders of the same length and cross-sectional area. Keep one cylinder at room temperature, and heat the other cylinder on a hot plate to 30°C (measured with a thermometer). Apply the same voltage to each cylinder (measured with a voltmeter), and measure the current through each cylinder with an ammeter. | | |

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## Question 2 (continued)

Learning Objectives (LO)

**LO 1.E.2.1**: The student is able to choose and justify the selection of data needed to determine resistivity for a given material. [See Science Practice 4.1]

**LO 5.B.9.2**: The student is able to apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\Delta V = 0$) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches. [See Science Practices 4.2, 6.4, and 7.2]

**LO 5.B.9.3**: The student is able to apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch. [See Science Practices 2.2, 6.4, and 7.2]

**LO 5.C.3.2**: The student is able to design an investigation of an electrical circuit with one or more resistors in which evidence of conservation of electric charge can be collected and analyzed. [See Science Practices 4.1, 4.2, and 5.1]

**LO 5.C.3.3**: The student is able to use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit. [See Science Practices 1.4 and 2.2]

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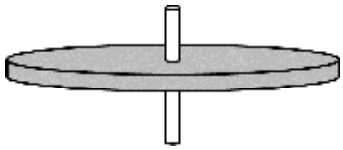
## Question 3

**12 points total** **Distribution of points**



The disk shown above spins about the axle at its center. A student's experiments reveal that, while the disk is spinning, friction between the axle and the disk exerts a constant torque on the disk.

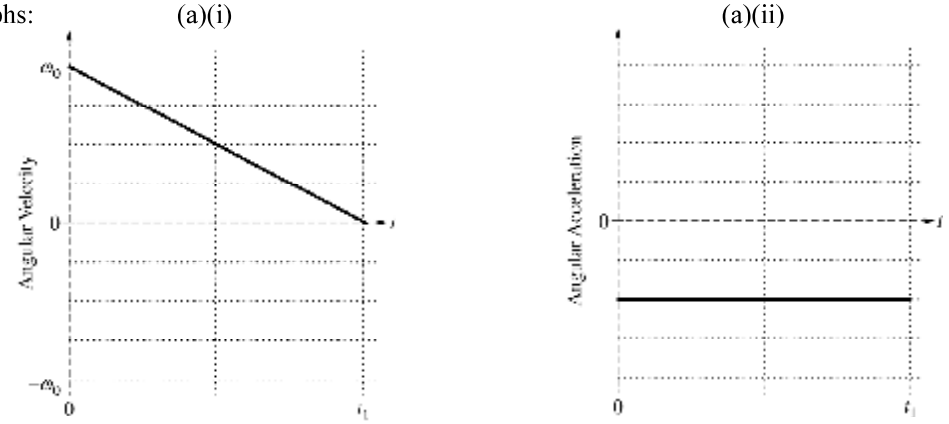
(a) LO / SP: 3.A.1.1 / 1.5, 2.2; 3.F.1.1 / 1.4; 3.F.2.1 / 6.4; 4.D.2.1 / 1.2, 1.4
4 points

At time $t = 0$ the disk has an initial counterclockwise (positive) angular velocity $\omega_0$. The disk later comes to rest at time $t = t_1$.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time $t$ from $t = 0$ until the disk comes to rest at time $t = t_1$.

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time $t$ from $t = 0$ until the disk comes to rest at time $t = t_1$.

Example graphs: (a)(i) (a)(ii)




i. 2 points

| | | |
|---|---|---|
| For a curve that has an angular velocity of $+\omega_0$ at time $t = 0$ and decreases to zero at time $t = t_1$ | | 1 point |
| For a curve that is a straight line with a negative slope showing the angular velocity approaching zero (can be a positive slope, if the initial angular velocity on the graph is negative) | | 1 point |

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## Question 3 (continued)

**Distribution of points**

(a) (continued)
ii. 2 points

| | | |
|---|---|---|
| For a curve that is negative for the entire time | | 1 point |
| For a curve that is a constant nonzero function | | 1 point |

(b) LO / SP: 3.A.1.1 / 1.5, 2.2; 3.F.2.1 / 6.4; 4.D.1.1 / 1.2, 1.4; 4.D.2.1 / 1.2, 1.4; 4.D.3.1 / 2.2
3 points

The magnitude of the frictional torque exerted on the disk is $\tau_0$. Derive an equation for the rotational inertia $I$ of the disk in terms of $\tau_0$, $\omega_0$, $t_1$, and physical constants, as appropriate.

| | | |
|---|---|---|
| For using an equation for the rotational version of Newton's second law | | 1 point |
| For using an appropriate rotational kinematics equation<br>$\alpha = \Delta\omega/\Delta t$ | | 1 point |
| For a correct answer in terms of the listed quantities, derived from first principles<br>$I = \frac{\tau_0 t_1}{\omega_0}$<br>Note: This point is still earned if there is a minus sign, e.g., from using $-\tau_0$ or $-\omega_0$. | | 1 point |

| | | |
|---|---|---|
| *Alternate solution using angular momentum and rotational impulse:* | | |
| *For defining and using angular momentum*<br>$L = I\omega$ | | 1 point |
| *For using rotational impulse*<br>$\Delta L = \tau \Delta t$ | | 1 point |
| *For a correct answer in terms of the listed quantities, derived from first principles*<br>$I = \frac{\tau_0 t_1}{\omega_0}$<br>*Note: This point is still earned if there is a minus sign, e.g., from using* $-\tau_0$ *or* $-\omega_0$. | | 1 point |

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## Question 3 (continued)

**Distribution of points**

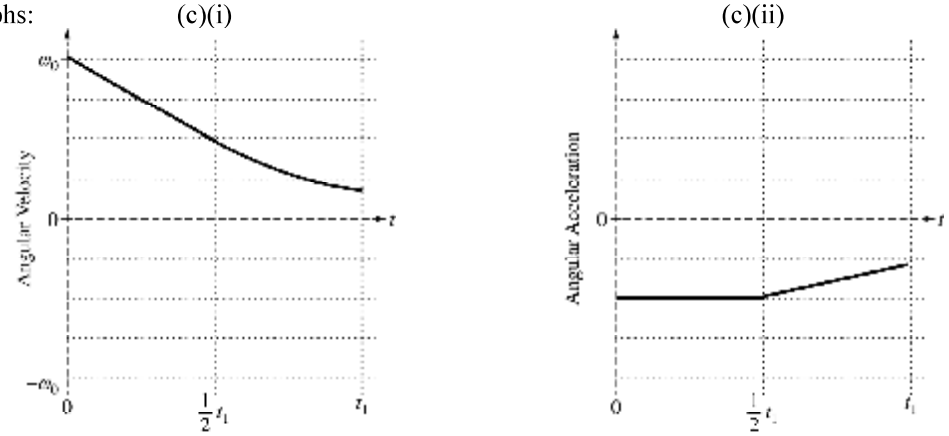
(c) LO / SP: 3.A.1.1 / 1.5, 2.2; 3.A.3.1 / 6.4, 7.2; 3.F.1.1 / 1.4; 3.F.2.1 / 6.4; 4.D.1.1 / 1.2, 1.4; 4.D.2.1 / 1.2,1.4
4 points

In another experiment, the disk again has an initial positive angular velocity $\omega_0$ at time $t = 0$. At time $t = \frac{1}{2}t_1$, the student starts dripping oil on the contact surface between the axle and the disk to reduce the friction. As time passes, more and more oil reaches that contact surface, reducing the friction even further.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time from $t = 0$ to $t = t_1$, which is the time at which the disk came to rest in part (a).

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time from $t = 0$ to $t = t_1$.

Example graphs: (c)(i) (c)(ii)




i. 3 points

| | | |
|---|---|---|
| For curve with a clear change of slope or curvature at $\frac{1}{2}t_1$ and showing a decrease in speed thereafter | | 1 point |
| For a curve that indicates slowing at a decreasing rate between times $\frac{1}{2}t_1$ and $t_1$ | | 1 point |
| For a curve that does not reach zero at or before time $t_1$ | | 1 point |

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## Question 3 (continued)

**Distribution of points**

(c) (continued)

ii. 1 point

| | | |
|---|---|---|
| For a curve with decreasing magnitude between times $\frac{1}{2}t_1$ and $t_1$<br>Note: The acceleration may reach zero at or before time $t_1$. If so, it must remain zero for the remaining time. | | 1 point |

(d) LO / SP: 3.F.2.1 / 6.4

1 point

The student is trying to mathematically model the magnitude $\tau$ of the torque exerted by the axle on the disk when the oil is present at times $t > \frac{1}{2}t_1$. The student writes down the following two equations, each of which includes a positive constant ($C_1$ or $C_2$) with appropriate units.

(1) $\tau = C_1\left(t - \frac{1}{2}t_1\right)$ (for $t > \frac{1}{2}t_1$)

(2) $\tau = \frac{C_2}{\left(t + \frac{1}{2}t_1\right)}$ (for $t > \frac{1}{2}t_1$)

Which equation better mathematically models this experiment?

____ Equation (1) ____ Equation (2)

Briefly explain why the equation you selected is plausible and why the other equation is not plausible.

| | | |
|---|---|---|
| Correct answer: "Equation (2)"<br>Note: If the wrong selection is made, the explanation is not graded. | | |
| For stating that Equation (2) is plausible because the frictional torque decreases with increasing time, whereas in Equation (1) torque increases with increasing time | | 1 point |
| Examples:<br>Equation (2) because $\tau$ decreases. In Equation (1), it doesn't.<br>Equation (2) is plausible because the frictional torque decreases as more oil reaches the contact surface over time. Equation (1) is not plausible because it shows friction increasing as more oil reaches the surface over time. | | |

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## Question 3 (continued)

Learning Objectives (LO)

**LO 3.A.1.1**: The student is able to express the motion of an object using narrative, mathematical, and graphical representations. [See Science Practices 1.5, 2.1, and 2.2]

**LO 3.A.3.1**: The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [See Science Practices 6.4 and 7.2]

**LO 3.F.1.1**: The student is able to use representations of the relationship between force and torque. [See Science Practice 1.4]

**LO 3.F.2.1**: The student is able to make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis. [See Science Practice 6.4]

**LO 4.D.1.1**: The student is able to describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system. [See Science Practices 1.2 and 1.4]

**LO 4.D.2.1**: The student is able to describe a model of a rotational system and use that model to analyze a situation in which angular momentum changes due to interaction with other objects or systems. [See Science Practices 1.2 and 1.4]

**LO 4.D.3.1**: The student is able to use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum. [See Science Practice 2.2]

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## Question 4

**7 points total** **Distribution of points**

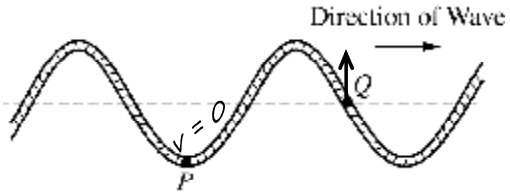
A transverse wave travels to the right along a string.

(a) LO / SP: 3.A.1.1 / 1.5; 6.A.1.2 / 1.2
4 points

Two dots have been painted on the string. In the diagrams below, those dots are labeled *P* and *Q*.

i. 2 points

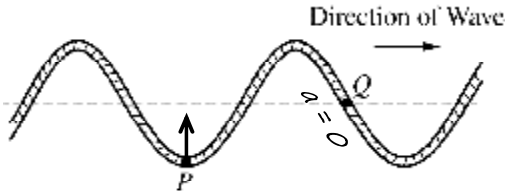
The figure below shows the string at an instant in time. At the instant shown, dot *P* has maximum displacement and dot *Q* has zero displacement from equilibrium. At each of the dots *P* and *Q*, draw an arrow indicating the direction of the instantaneous velocity of that dot. If either dot has zero velocity, write "$v = 0$" next to the dot.




| | | |
|---|---|---|
| For "$v = 0$" at point *P* | | 1 point |
| For an upward arrow at point *Q* | | 1 point |

ii. 2 points

The figure below shows the string at the same instant as shown in part (a)(i). At each of the dots *P* and *Q*, draw an arrow indicating the direction of the instantaneous acceleration of that dot. If either dot has zero acceleration, write "$a = 0$" next to the dot.




| | | |
|---|---|---|
| For an upward arrow at point *P* | | 1 point |
| For "$a = 0$" at point *Q* | | 1 point |

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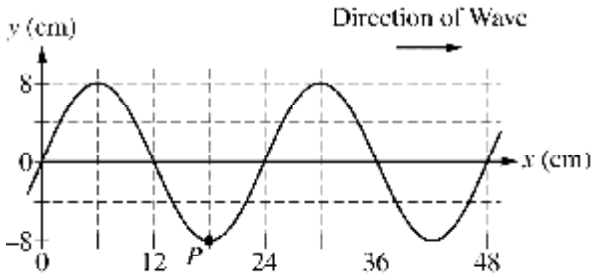
## Question 4 (continued)

**Distribution of points**

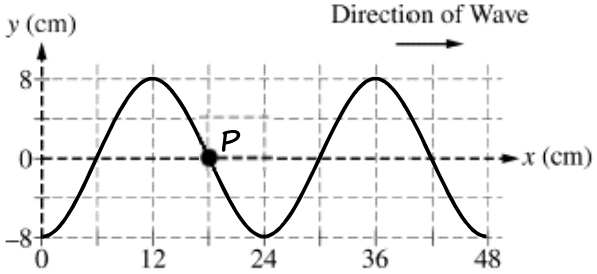
The figure below represents the string at time $t = 0$, the same instant as shown in part (a) when dot $P$ is at its maximum displacement from equilibrium. For simplicity, dot $Q$ is not shown.




(b) LO / SP: 3.A.1.1 / 1.5; 6.A.1.2 / 1.2
2 points

i. 1 point

On the grid below, draw the string at a later time $t = T/4$, where $T$ is the period of the wave.
Note: Do any scratch (practice) work on the grid at the bottom of the page. Only the sketch made on the grid immediately below will be graded.




| | | |
|---|---|---|
| For a curve shifted to the right by 1/4 of a wavelength (1 gridline) with the same wavelength as the original wave (for example, as indicated by a negative minimum at $x = 0$) | | 1 point |

ii. 1 point
On your drawing above, draw a dot to indicate the position of dot $P$ on the string at time $t = T/4$ and clearly label the dot with the letter $P$.

| | | |
|---|---|---|
| For point $P$ on the string and at the dot's original $x$ position, 3/4 of a wavelength (3 grid units) to right of origin | | 1 point |

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## Question 4 (continued)

**Distribution of points**

(c) LO / SP: 6.A.3.1 / 1.4
1 point

Now consider the wave at time $t = T$. Determine the distance traveled (not the displacement) by dot $P$ between times $t = 0$ and $t = T$.

| | | |
|---|---|---|
| For the correct numerical answer: 32 cm | | 1 point |

---

Learning Objectives (LO)

**LO 3.A.1.1**: The student is able to express the motion of an object using narrative, mathematical, and graphical representations. [See Science Practice 1.5]

**LO 6.A.1.2**: The student is able to describe representations of transverse and longitudinal waves. [See Science Practice 1.2]

**LO 6.A.3.1**: The student is able to use graphical representation of a periodic mechanical wave to determine the amplitude of the wave. [See Science Practice 1.4]

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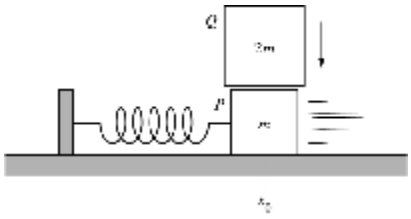
## Question 5

**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 |

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## 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: $A_{PQ} < A_P$.<br>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<br>OR<br>For stating or implying that the maximum potential energy equals the total mechanical energy just after the collision (Simply stating that $E_{\text{tot}} = \frac{1}{2}kA^2$ 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.*<br>*Note: The third point can be earned if energy loss is stated.* | | *2 points* |

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## Question 5 (continued)

| | |
|---|---|
| Example:<br>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:<br>$K_P = \frac{1}{2}mv_{max}^2$ $\quad$ $K_{PQ} = \frac{1}{2}(3m)\left(\frac{v_{max}}{3}\right)^2 = \frac{1}{6}mv_{max}^2 = \frac{1}{3}K_P$<br>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*. | |

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## 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]

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