

**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**

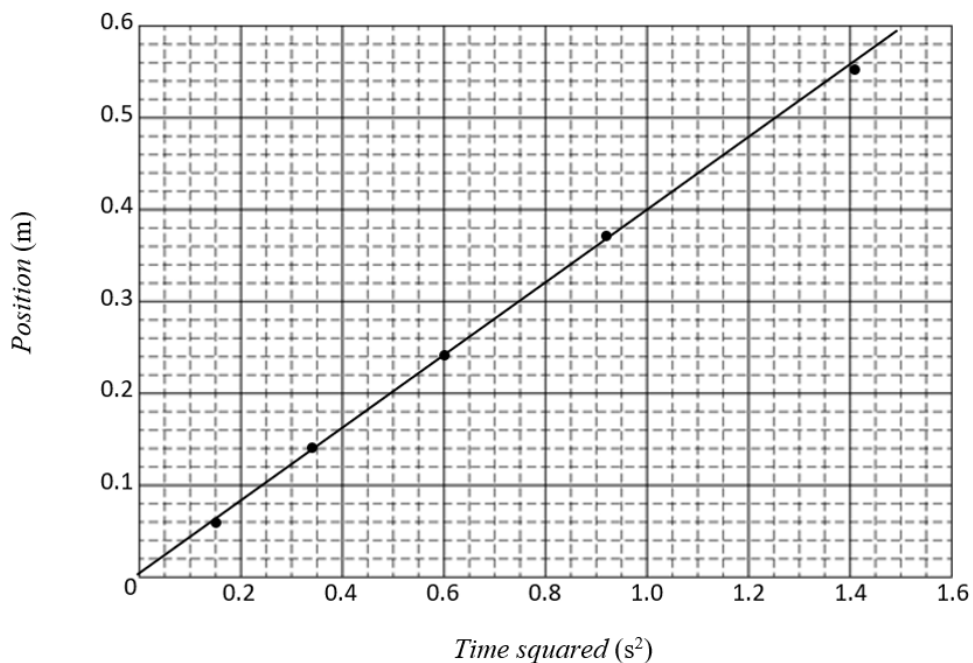
Vertical Axis : Position      Horizontal Axis : Time squared

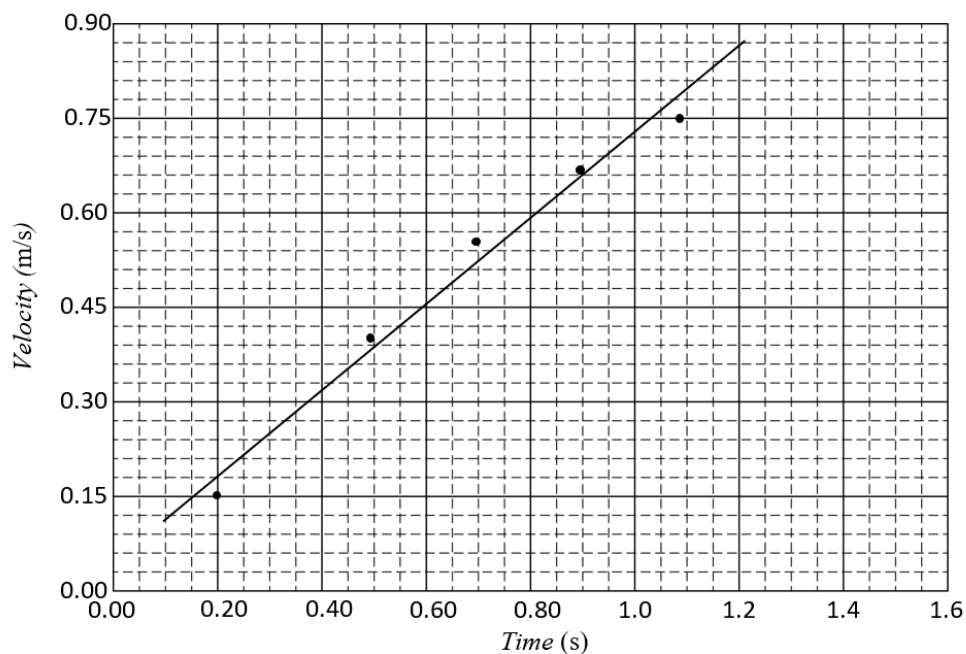
| Position $x$<br>(m) | Time $t$<br>(s) | Time squared $t^2$<br>(s <sup>2</sup> ) |
|---------------------|-----------------|-----------------------------------------|
| 0.06                | 0.39            | 0.15                                    |
| 0.14                | 0.59            | 0.35                                    |
| 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. $t$                           |                 |
|----------------------------------------------|-----------------|
| $v \left( \frac{\text{m}}{\text{s}} \right)$ | $t \text{ (s)}$ |
| 0.15                                         | 0.20            |
| 0.40                                         | 0.49            |
| 0.56                                         | 0.68            |
| 0.68                                         | 0.87            |
| 0.75                                         | 1.08            |

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

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

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

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

| Graph: $\sqrt{x}$ vs. $t$                   |                 |
|---------------------------------------------|-----------------|
| $\sqrt{x} \text{ (}\sqrt{\text{m}}\text{)}$ | $t \text{ (s)}$ |
| 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.

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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  $\frac{1}{2}t^2$ ).

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**Example Response**

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

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

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

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

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

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**Total for part (a) 6 points**

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**(b)(i)** For indicating a quantity to be measured**1 point**Accept **one** of the following:

- The angle  $\theta$  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.

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**(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  $\theta$  was measured from the vertical.

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**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**

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

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

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

$$v = at$$

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

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

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**Total for part (b) 2 points**

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(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  $g_{\text{exp}}$

1 point

Accept **one** of the following:

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

### Example Response

*The expression I derived for the value for  $g_{\text{exp}}$  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  $g_{\text{exp}}$  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**
- 

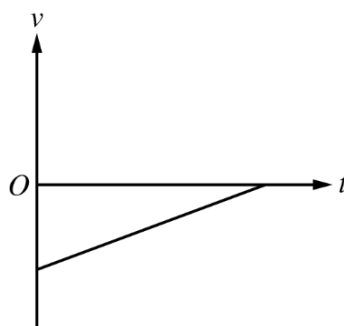
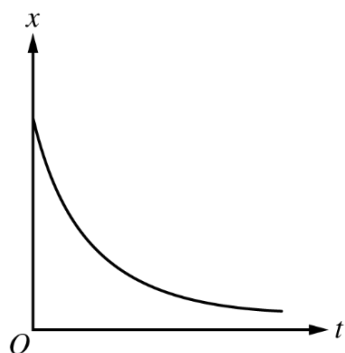
For **one** of the following:

**1 point**

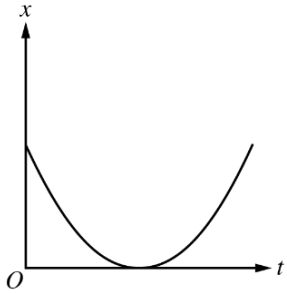
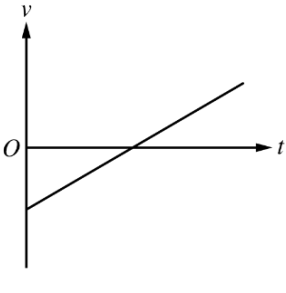
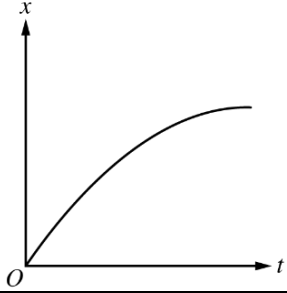
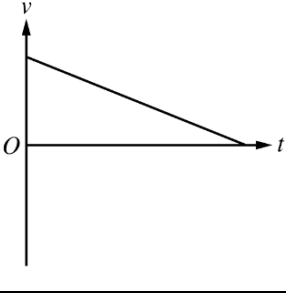
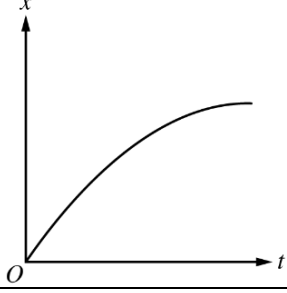
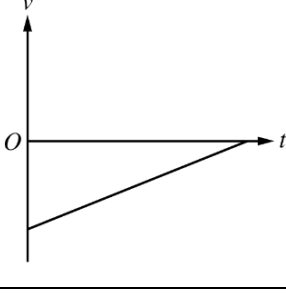
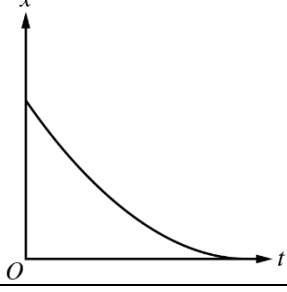
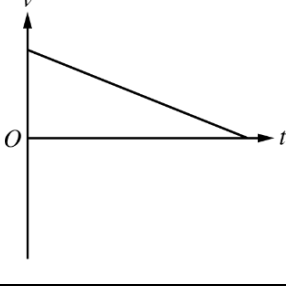
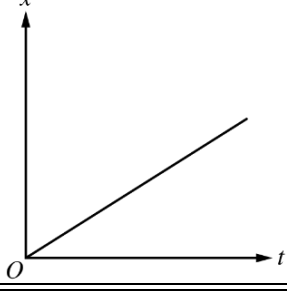
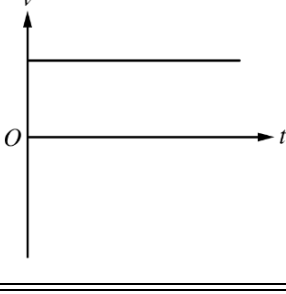
- Drawing a line with a positive slope and a negative vertical intercept for the  $v$  vs.  $t$  graph
- Drawing a  $v$  vs.  $t$  graph that is consistent with the  $x$  vs.  $t$  graph that shows acceleration

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**Example Response**



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

|                                                                                     |                                                                                     |                |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------|
|    |    | Earns 2 points |
|    |    | Earns 1 point  |
|   |   | Earns 1 point  |
|  |  | Earns 1 point  |
|  |  | Earns 0 points |

Total for part (d) 2 points

Total for question 2 12 points

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# **AP Physics 1: Algebra-Based Scoring Guidelines**

**AP<sup>®</sup> 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.

## 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.

## 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.

## 2017 SCORING GUIDELINES

## Question 2

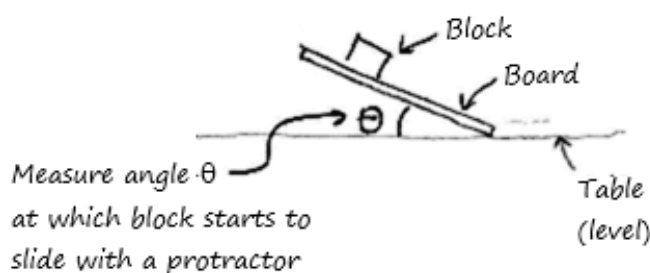
12 points total

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 |

**2017 SCORING GUIDELINES****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.

## 2017 SCORING GUIDELINES

## 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.

## 2017 SCORING GUIDELINES

## 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 pointFor a dimensionally correct expression for the post-collision angular momentum that includes  $I\omega$  1 pointFor 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.

## 2017 SCORING GUIDELINES

## 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.

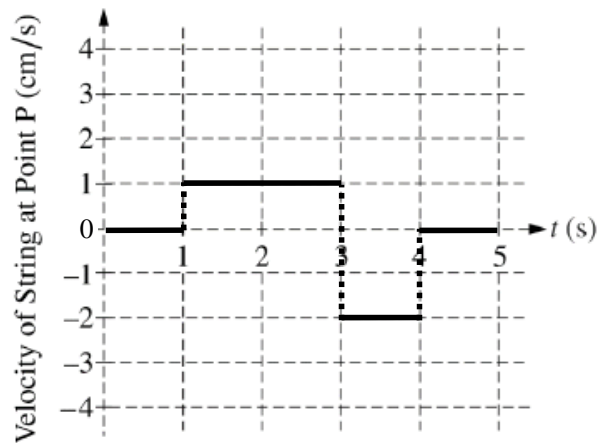
## 2017 SCORING GUIDELINES

## 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

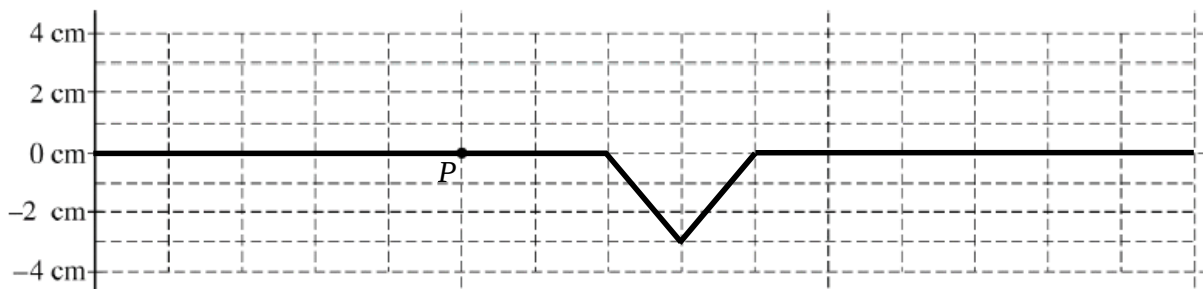
For indicating two different non-zero constant velocities, one at the interval  
 $1$  s  $< t < 3$  s and the other at the interval  $3$  s  $< t < 4$  s

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 7<sup>th</sup>  
and 9<sup>th</sup> 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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# **AP<sup>®</sup> Physics 1**

## **2016 Scoring Guidelines**

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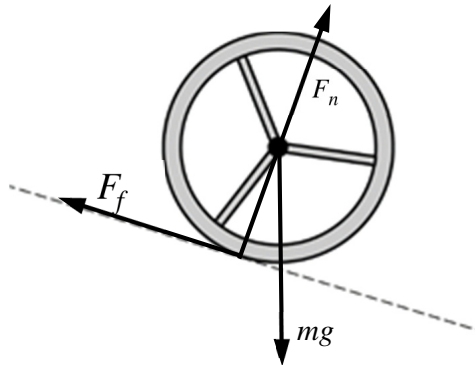
## 2016 SCORING GUIDELINES

## 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).

## 2016 SCORING GUIDELINES

## 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  
The expression need not be correct or consistent with the force diagram in part (a). 1 point

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

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

Example: The wheel experiences a counteracting frictional force, so the block has a greater net force exerted upon it and therefore has greater acceleration. 1 point

ii. 1 point

For a correct explanation in terms of energy conservation

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. 1 point

## 2016 SCORING GUIDELINES

## 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 |
|--------------------------------------------------------------------------------------|---------|

## 2016 SCORING GUIDELINES

## 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.

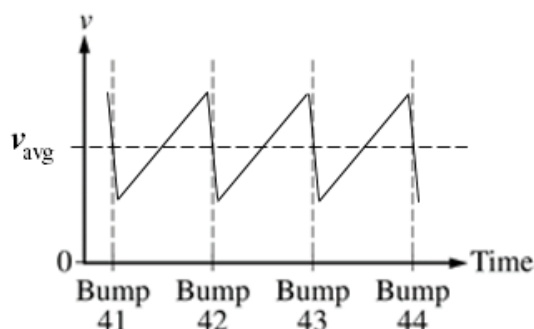
## 2016 SCORING GUIDELINES

## 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  $v_{\text{avg}}$  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  $v_{\text{avg}}$  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  $v_{\text{avg}}$ , but the equation indicates that it should double.If “yes” is selected, one point may be earned for explaining that  $v_{\text{avg}}$  increaseswith  $M$  or that  $v_{\text{avg}}$  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).

**2016 SCORING GUIDELINES****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  $v_{\text{avg}}$ , OR  
for stating or implying the contradiction between this inverse relation and the  
reasoning of part (b)

1 point

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  $v_{\text{avg}}$ ,

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  $v_{\text{avg}}$ .

## 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 pointFor indicating that the potential difference is the same across  $B$  and  $C$  because  $B$  and  $C$  are in parallel 1 pointFor 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.

## 2016 SCORING GUIDELINES

## Question 4 (continued)

Distribution  
of points

(c) 2 points

Correct answer: Increase

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

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

For indicating that all the current from the battery passes through  $C$ ; the current no longer splits 1 pointFor 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