Question 3: Experimental Design and Analysis (LAB) — 10 points

A

For describing a procedure that includes measuring h and the speed of the block as the block moves across the surface — **Point A1**

For a procedure that indicates a reasonable method of reducing experimental uncertainty — **Point A2**

Examples of acceptable responses may include the following:

- Repeating the experiment multiple times for the same value of h
- Repeating the experiment for multiple values of h

Example Response

Measure the height h at which the block-box system is released. Measure the speed of the block as the block slides across the horizontal surface. Repeat the measurement of the speed of the block for varying release heights.

B

For describing a graph that has linear trend that can be used to find g — **Point B1**

Examples of acceptable responses include the following:

- v^2 vs. $2h$
- $\frac{1}{2}v^2$ vs. h
- v^2 vs. h
- v vs. $\sqrt{h}$

Scoring Notes:

- Reponses that include the reciprocals of the preceding examples, in addition to other equivalent graphs, also earn this point.
- This point may be earned independently of the response in part A.

For correctly relating the slope of the best-fit line to g — **Point B2**

Examples of acceptable responses include the following:

Graph	Analysis
v^2 vs. $2h$	slope $= g$
$\frac{1}{2}v^2$ vs. h	slope $= g$
v^2 vs. h	slope $= 2g$
v vs. $\sqrt{h}$	slope $= \sqrt{2g}$

Example Response

Plot v^2 on the vertical axis and $2h$ on the horizontal axis. The slope of the best-fit line is equal to g.

AP Physics C: **Mechanics: 2025**

C

(i) For indicating appropriate quantities that could be plotted to produce a linear graph that can be used to determine μ, such as h **vs.** x_{max} — **Point C1**

Scoring Note: Reponses that include the reciprocal of the preceding example, in addition to other equivalent graphs, also earn this point.

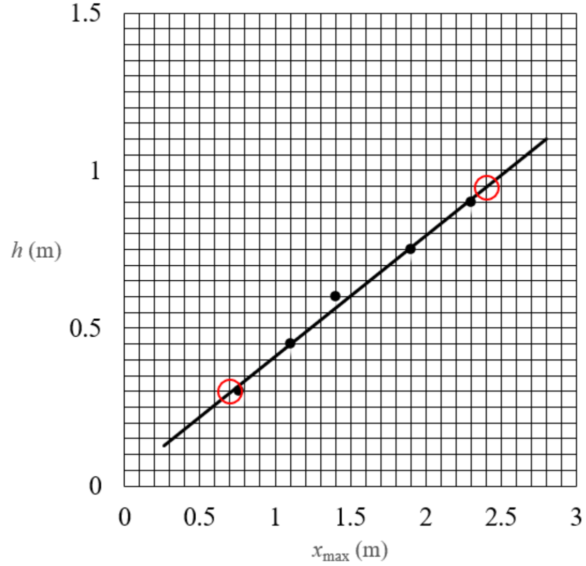
(ii) For labeling the axes (including units) with a linear scale — **Point C2**

For plotting data points consistent with **one** of the following: — **Point C3**

- The quantities indicated in part C (i)
- The quantities provided in Table 2
- The axes indicated on the grid

(iii) For drawing a line or curve that approximates the trend of the plotted data — **Point C4**

Example Response



D	For correctly relating the slope of the best-fit line to the value of μ		**Point D1**

Examples of acceptable responses includes the following:

Graph	Analysis
h vs. x_{max}	slope $= \mu$

For a value of μ within a range of 0.30 to 0.50 — **Point D2**

Example Response

$E_0 + W = E_f$

$mgh - F_f x_{max} = 0$

$mgh = \mu mg x_{max}$

$h = \mu x_{max}$

$y = mx + b$

$h = \mu x_{max}$

slope $= \mu$

slope $= \dfrac{0.95 \text{ m} - 0.30 \text{ m}}{2.4 \text{ m} - 0.70 \text{ m}}$

slope $= 0.38$

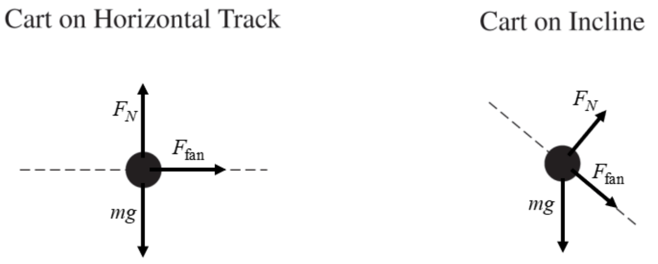
$\mu =$ slope $= 0.38$

Question 1: Free-Response Question — 15 points

(a)	For correctly drawing and labeling all the forces on the cart on the flat surface	**1 point**
	For correctly drawing and labeling the weight of the cart on the incline	**1 point**
	For correctly drawing and labeling the normal force on the cart on the incline	**1 point**
	For correctly drawing and labeling the force of the fan on the cart on the incline	**1 point**

Scoring note: A maximum of three points can be earned if there are any extraneous vectors.

Example responses for part (a)



Scoring note: Examples of appropriate labels for the force due to gravity include: F_G, F_g, F_{grav}, W, mg, Mg, "grav force," "F Earth on cart," "F on cart by Earth," $F_{\text{Earth on cart}}$, $F_{E,Cart}$, $F_{Cart,E}$. The labels G or g are not appropriate labels for the force due to gravity. F_n, F_N, N, "normal force," "ground force," or similar labels may be used for the normal force.

Total for part (a) — 4 points

(b)	For correctly applying Newton's second law for the cart on the flat surface	**1 point**

$F_{fan} = m_{cart} a_1$

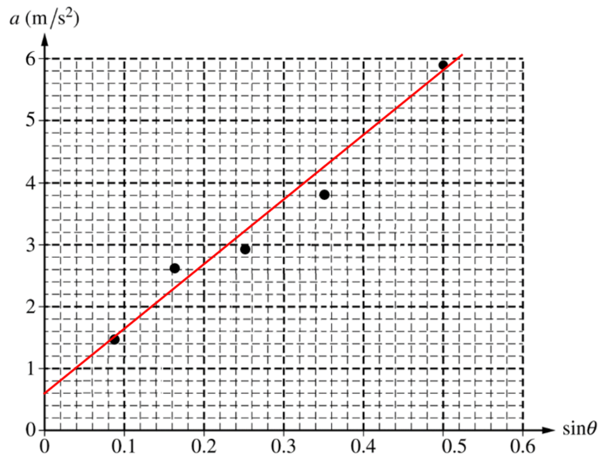
For the correct answer with units — **1 point**

$F_{fan} = (0.50 \text{ kg})\left(0.8 \text{ m/s}^2\right) = 0.40 \text{ N}$

Total for part (b) — 2 points

(c)	For including the correct component of weight in a Newton's second law equation for the cart $F_{fan} + mg\sin\theta = ma_2$	**1 point**
	For a correct Newton's second law equation $F_{fan} + mg\sin\theta = ma_2$	**1 point**
	For correct substitutions consistent with part (b) into the above equation $mg\sin\theta = ma_2 - F_{fan}$ $\theta = \sin^{-1}\left(\frac{ma_2 - F_{fan}}{mg}\right)$ $\theta = \sin^{-1}\left(\frac{(0.50\ \text{kg})(2.4\ \text{m/s}^2) - (0.50\ \text{kg})(0.8\ \text{m/s}^2)}{(0.50\ \text{kg})(9.8\ \text{m/s}^2)}\right)$ $\theta = 9.4°$	**1 point**
	Total for part (c)	**3 points**
(d)	For selecting "No" and an attempted justification	**1 point**
	For a correct justification	**1 point**
	Example response for part (d) *The mass of the cart cancels out in the equation used to find the angle of the incline.*	
	Total for part (d)	**2 points**

(e) **i.** For drawing an appropriate best-fit line — **1 point**



ii. For correctly calculating slope using two points from the best-fit line — **1 point**

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{(5-1)(\text{m/s}^2)}{(0.42-0.04)} = 10.52\ \text{m/s}^2$$

For correctly using an expression that relates the slope to the acceleration due to gravity — **1 point**

$$F_{net} = F_{fan} + mg\sin\theta = ma$$

$$\therefore a = g\sin\theta + \frac{F_{fan}}{m}$$

from $y = mx + b$

$a = (\text{slope})\sin\theta + (y\text{-intercept})$

$\therefore \text{slope} = g = 10.52\ \text{m/s}^2$

Total for part (e) — **3 points**

(f) For a correct explanation — **1 point**

Example response for part (f)

The mass of the cart is in the denominator of the y-intercept, so increasing the mass decreases the y-intercept without changing the rest of the graph. So the new line of data is predicted to be parallel to and below the original line.

Total for question 1 — **15 points**

Question 1: Free-Response Question — 15 points

(a) For correctly evaluating Newton's second law equations for the system at rest — **1 point**

$m_2g - f = (m_1 + m_2)a = 0 \therefore m_2g = f$

For correctly substituting for static friction into above equation: — **1 point**

$m_2g = f = \mu_sF_N = \mu_sm_1g$

$$\mu_s = \frac{m_2}{m_1} = \frac{(0.20\text{ kg})}{(0.44\text{ kg})} = 0.45$$

Total for part (a) — 2 points

(b) For correctly drawing and labeling the horizontal forces of friction and tension on block of mass m_1 — **1 point**

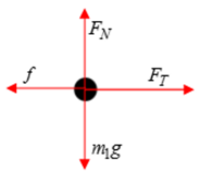
For correctly drawing and labeling the vertical forces of weight and normal force on block of mass m_1 — **1 point**

For correctly drawing and labeling forces of weight and tension on block of mass m_2 — **1 point**

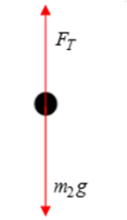
For indicating that the gravitational forces on each block are different — **1 point**

Example responses for part (b)

Block 1



Block 2



Scoring note: Examples of appropriate labels for the force due to gravity include: F_G, F_g, F_{grav}, W, mg, Mg, "grav force," "F Earth on block," "F on block by Earth," $F_{\text{Earth on block}}$, $F_{\text{E,Block}}$, $F_{\text{Block,E}}$. The labels G or g are not appropriate labels for the force due to gravity. F_n, F_N, N, "normal force," "ground force," or similar labels may be used for the normal force.

Total for part (b) — 4 points

(c) For correctly evaluating Newton's second law equation for block 1: — **1 point**

$T - f = m_1a$

For correctly evaluating Newton's second law equation for block 2: — **1 point**

$m_2g - T = m_2a$

Combining the two equations

$m_2g - f = (m_1 + m_2)a \therefore f = m_2g - (m_1 + m_2)a$

Scoring note: Both points are earned for a single correct Newton's second law equation for the two-block system.

For correctly substituting for kinetic friction into above equation — **1 point**

$$f = \mu_kF_N = \mu_km_1g = m_2g - (m_1 + m_2)a \therefore \mu_k = \frac{m_2g - (m_1 + m_2)a}{m_1g}$$

$$\mu_k = \frac{(0.20\text{ kg})(9.8\text{ m/s}^2) - (0.44\text{ kg} + 0.20\text{ kg})(2.3\text{ m/s}^2)}{(0.44\text{ kg})(9.8\text{ m/s}^2)} = 0.11$$

Total for part (c) — 3 points

(d) For selecting "Yes" and attempting a relevant justification — **1 point**

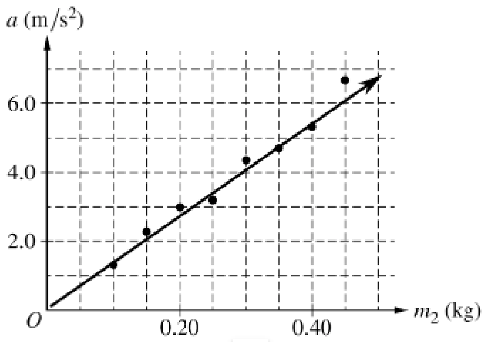
For a correct justification — **1 point**

Example response for part (d)

If the track is not level, the angle of the track must be incorporated into the equation for acceleration, and this could account for the larger coefficient of kinetic friction.

Total for part (d) — 2 points

(e) **i.** For drawing an appropriate best-fit line **1 point**



ii. For calculating slope using two points from the best-fit line **1 point**

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{(6-2)\left(\text{m/s}^2\right)}{(0.45-0.15)(\text{kg})} = 13.3\ \text{m/kg}\bullet\text{s}^2$$

For correctly using an expression that relates the slope to the acceleration due to gravity **1 point**

From $y = mx + b$

$a = (\text{slope})m_2 + (y\text{-intercept})$

$$a = \frac{m_2 g}{(m_1 + m_2)} \therefore \text{slope} = \frac{g}{(m_1 + m_2)}$$

$$g = \text{slope} \times (m_1 + m_2) = \left(13.3\ \text{m/kg}\bullet\text{s}^2\right)(0.44\ \text{kg} + 0.20\ \text{kg}) = 8.5\ \text{m/s}^2$$

Total for part (e) 3 points

(f) For a correct justification **1 point**

Example response for part (f)

The acceleration would be greater because there would be a component of the gravitational force on block 1 along the surface, which would be in the same direction as the tension force.

Total for question 1 15 points

2018

AP Physics C: Mechanics

Scoring Guidelines

2018 SCORING GUIDELINES

General Notes About 2018 AP Physics Scoring Guidelines

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

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

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

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

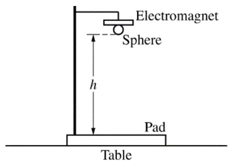
5. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but the use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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.

2018 SCORING GUIDELINES

Question 1

15 points total — **Distribution of points**



A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

(a) 2 points

While taking the first data point, the student notices that the electromagnet actually releases the sphere after the timer begins. Would the value of g calculated from this one measurement be greater than, less than, or equal to the actual value of g at the student's location?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

For selecting "Less than" with an attempt at a relevant justification		1 point
For a correct justification		1 point
Example: Because the measured time to fall the same distance will be larger, the acceleration must be less.		
Example: Because the time is larger and $a \propto 1/t^2$ *, then g must decrease.*		

2018 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

The electromagnet is replaced so that the timer begins when the sphere is released. The student varies the distance h. The student measures and records the time Δt of the fall for each particular height, resulting in the following data table.

h (m)	0.10	0.20	0.60	0.80	1.00
Δt (s)	0.105	0.213	0.342	0.401	0.451

(b) 1 point

Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for g.

Vertical axis: ____________

Horizontal axis: ____________

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given in the table. Label each row you use and include units.

For correctly indicating two variables that will yield a straight line that could be used to determine a value for g		1 point
Example: Vertical Axis: h *Horizontal Axis:* $(\Delta t)^2$		
Note: Student earns full credit if axes are reversed or if they use another acceptable combination.		

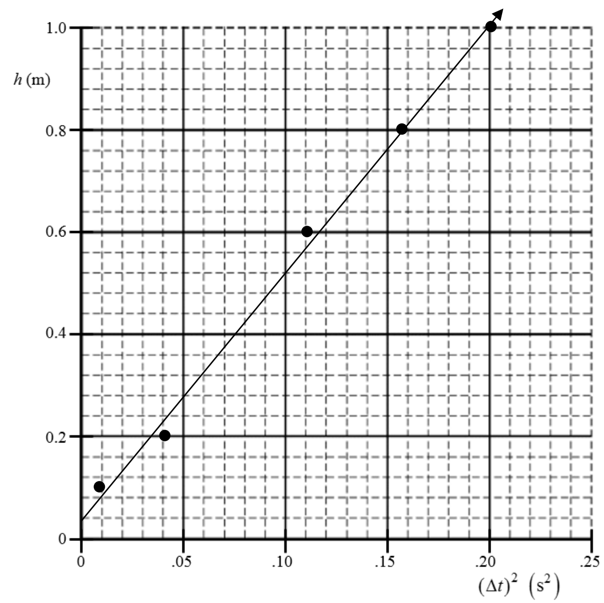
2018 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(c) 4 points

Plot the data points for the quantities indicated in part (b) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



For a correct scale that uses more than half the grid		1 point
For correctly labeling the axis with variables and units consistent with part (b)		1 point
For correctly plotting data consistent with part (b)		1 point
For drawing a straight line consistent with the plotted data		1 point

2018 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(d) 2 points

Using the straight line, calculate an experimental value for g.

For using points on the line rather than the data to calculate the slope		1 point
$\text{slope} = \dfrac{\Delta h}{\Delta(\Delta t)^2} = \dfrac{(0.80 - 0.20)\ \text{m}}{(0.160 - 0.039)\ \text{s}^2} = 4.96\ \text{m/s}^2$ (Linear regression $= 4.83\ \text{m/s}^2$)		
For correctly relating the slope to the acceleration due to gravity		1 point
$\text{slope} = \dfrac{1}{2}g \ \therefore\ g = 2 \times \text{slope} = 2 \times \left(4.96\ \text{m/s}^2\right)$		
$g = 9.92\ \text{m/s}^2$ (Linear regression $= 9.66\ \text{m/s}^2$)		

Another student fits the data in the table to a quadratic equation. The student's equation for the distance fallen y as a function of time t is $y = At^2 + Bt + C$, where $A = 5.75\ \text{m/s}^2$, $B = -0.524\ \text{m/s}$, and $C = +0.080\ \text{m}$. Vertically down is the positive direction.

(e) Using the student's equation above, do the following.

i. 1 point

Derive an expression for the velocity of the sphere as a function of time.

For correctly taking the time derivative of the given equation		1 point
$y = y_0 + v_1 t + \dfrac{1}{2}at^2 = At^2 + Bt + C$		
$v(t) = \dfrac{dy}{dt} = 2At + B$		
Note: Credit is earned for substituting numbers: $v(t) = \left(11.5\ \text{m/s}^2\right)t - 0.524\ \text{m/s}$.		

ii. 2 points

Calculate the new experimental value for g.

For correctly relating the given equation to a correct kinematic equation		1 point
$\Delta y = y - y_0 = v_1 t + \dfrac{1}{2}at^2$		
$y = y_0 + v_1 t + \dfrac{1}{2}at^2 = At^2 + Bt + C$		
For correctly relating the equation to the value of g		1 point
$A = \dfrac{1}{2}a = \dfrac{1}{2}g$		
$g = 2A = (2)\left(5.75\ \text{m/s}^2\right) = 11.5\ \text{m/s}^2$		

2018 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

iii. 1 point

Using $9.81\ \text{m/s}^2$ as the accepted value for g at this location, calculate the percent error for the value found in part (e)(ii).

For correctly calculating the percent error		1 point
$\%\text{error} = \dfrac{\lvert\text{acc} - \text{exp}\rvert}{\text{acc}} \times 100\% = \dfrac{\left\lvert\left(11.5\ \text{m/s}^2\right) - \left(9.81\ \text{m/s}^2\right)\right\rvert}{\left(9.81\ \text{m/s}^2\right)} \times 100\%$		
$\%\text{error} = 17.2\%$		
Note: Credit is earned if percent error is expressed as positive or negative.		

iv. 2 points

Assuming the sphere is at a height of 1.40 m at $t = 0$, calculate the velocity of the sphere just before it strikes the pad.

For relating the coefficients of the equation to the kinematic variables		1 point
$y = At^2 + Bt + C \ \therefore\ v_1 = B = -0.524\ \text{m/s}$		
$a = 2A = 2 \times \left(5.75\ \text{m/s}^2\right) = 11.5\ \text{m/s}^2$		
$y_0 = C = 0.080\ \text{m}$		
For correctly using an appropriate kinematics equation to determine the velocity of the sphere		1 point
$v_2^2 = v_1^2 + 2a\Delta y$		
$v = \sqrt{v_1^2 + 2a\Delta y} = \sqrt{(-0.524\ \text{m/s})^2 + (2)\left(11.5\ \text{m/s}^2\right)(1.40\ \text{m} - 0.080\ \text{m})}$		
$v = 5.54\ \text{m/s}$		
Alternate solution:		*Alternate Points*
For correctly determining the time of fall for the sphere		*1 point*
$y = At^2 + Bt + C$		
$1.40 = \left(5.75\ \text{m/s}^2\right)t^2 + (-0.524\ \text{m/s})t + (0.080\ \text{m})$		
$5.75t^2 - 0.524t - 1.32 = 0$		
$t = 0.53$ s or -0.44 s $\therefore t = 0.53$ s		
For correctly using the equation from part (e)(i)		*1 point*
$v(t) = \left(11.5\ \text{m/s}^2\right)(0.53\ \text{s}) - 0.524\ \text{m/s}$		
$v = 5.54\ \text{m/s}$		

AP PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(e)

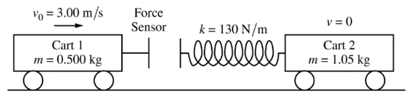
iv. (continued)

Alternate Solution — Conservation of Energy		
For relating the coefficients of the equation to the initial height and speed		1 point
$y = At^2 + Bt + C \;\therefore v_1 = B = -0.524 \text{ m/s}$		
$y_0 = C = 0.080 \text{ m}$		
For correctly using conservation of energy to determine the velocity of the sphere		1 point
$U_i + K_i = U_f + K_f$		
$mgh + \frac{1}{2}mv_1^2 = \frac{1}{2}mv^2$		
$v = \sqrt{2(11.5)(1.40 - 0.080) + (-0.524)^2} = 5.54 \text{ m/s}$		

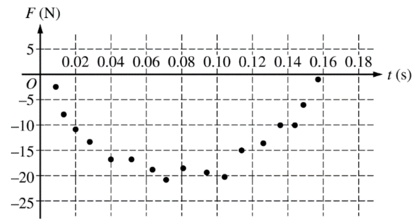
AP PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 2

15 points total **Distribution of points**



Two carts are on a horizontal, level track of negligible friction. Cart 1 has a sensor that measures the force exerted on it during a collision with cart 2, which has a spring attached. Cart 1 is moving with a speed of $v_0 = 3.00 \text{ m/s}$ toward cart 2, which is at rest, as shown in the figure above. The total mass of cart 1 and the force sensor is 0.500 kg, the mass of cart 2 is 1.05 kg, and the spring has negligible mass. The spring has a spring constant of $k = 130 \text{ N/m}$. The data for the force the spring exerts on cart 1 are shown in the graph below. A student models the data as the quadratic fit $F = \left(3200 \text{ N/s}^2\right)t^2 - \left(500 \text{ N/s}\right)t$.



(a) 3 points

Using integral calculus, calculate the total impulse delivered to cart 1 during the collision.

For using the given force equation in the integral to determine the impulse delivered to the cart		1 point
$J = \int F \bullet dt = \int 3200t^2 - 500t \; dt$		
For integrating the force using the correct limits or constant of integration		1 point
$J = \int_{t=0}^{t=0.16 \text{ s}} \left(3200t^2 - 500t\right)dt = \left[\frac{3200}{3}t^3 - 250t^2\right]_{t=0}^{t=0.16}$		
$J = \left(\left(\frac{3200}{3}\right)(0.16)^3 - (250)(0.16)^2\right) - 0$		
For a correct answer		1 point
$J = -2.03 \text{ N} \bullet \text{s}$		

2018 SCORING GUIDELINES

Question 2 (continued)

Distribution of points

(b)

i. 1 point

Calculate the speed of cart 1 after the collision.

For correct substitution into the impulse-momentum equation of the answer from part (a) to determine the speed of cart 1		1 point
$J = m_1(v_{1f} - v_{1i}) \therefore v_{1f} = \dfrac{J}{m_1} + v_{1i} = \dfrac{(-2.03\ \text{N}\bullet\text{s})}{(0.500\ \text{kg})} + (3.00\ \text{m/s})$		
$v_{1f} = -1.06\ \text{m/s}$		

ii. 1 point

In which direction does cart 1 move after the collision?

____ Left ____ Right

____ The direction is undefined, because the speed of cart 1 is zero after the collision.

For correctly selecting “Left”		1 point

(c)

i. 2 points

Calculate the speed of cart 2 after the collision.

For using a correct equation to determine the speed of cart 2		1 point
$-J = -m_1(v_{1f} - v_{1i}) = m_2 v_{2f} \therefore v_{2f} = \dfrac{-J}{m_2}$		
For correct substitution of the answer from part (a)		1 point
$v_{2f} = \dfrac{(2.03\ \text{N}\bullet\text{s})}{(1.05\ \text{kg})}$		
$v_{2f} = 1.93\ \text{m/s}$		

2018 SCORING GUIDELINES

Question 2 (continued)

Distribution of points

(c)

i. (continued)

Alternate solution		*Alternate Points*
For using the conservation of momentum to calculate the speed of cart 2 after the collision		*1 point*
$m_1 v_{1i} = m_1 v_{1f} + m_2 v_{2f} \therefore v_{2f} = \dfrac{m_1(v_{1i} - v_{1f})}{m_2}$		
For correct substitution of the answer from part (b)(i)		*1 point*
$v_{2f} = \dfrac{(0.500\ \text{kg})((3.00\ \text{m/s}) - (-1.06\ \text{m/s}))}{(1.05\ \text{kg})} = 1.93\ \text{m/s}$		

ii. 2 points

Show that the collision between the two carts is elastic.

For indicating that the initial and final kinetic energies must be equal		1 point
$K_{1i} = K_{1f} + K_{2f}$		
For correct substitutions of answers from parts (b)(i) and (c)(i) into the calculations of the initial and final kinetic energies		1 point
$\left(\frac{1}{2}\right)(0.500\ \text{kg})(3.00\ \text{m/s})^2 = \left(\frac{1}{2}\right)(0.500\ \text{kg})(-1.06\ \text{m/s})^2 + \left(\frac{1}{2}\right)(1.05\ \text{kg})(1.93\ \text{m/s})^2$		
$2.25\ \text{J} \approx 2.24\ \text{J}$		

(d)

i. 2 points

Calculate the speed of the center of mass of the two-cart-spring system.

For using the equation for the conservation of momentum to calculate the speed for the center of mass of the system		1 point
$m_1 v_{1i} = (m_1 + m_2) v_{cm} \therefore v_{cm} = \dfrac{m_1 v_{1i}}{(m_1 + m_2)}$		
For correct substitution into the equation above		1 point
$v_{cm} = \dfrac{(0.500\ \text{kg})(3.00\ \text{m/s})}{(0.500\ \text{kg} + 1.05\ \text{kg})} = 0.97\ \text{m/s}$		

AP PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 2 (continued)

Distribution of points

(d) (continued)
ii. 3 points

Calculate the maximum elastic potential energy stored in the spring.

For using conservation of energy to calculate the maximum elastic potential energy stored in the spring		1 point
$K_i = K_f + U_{Sf}$		
For using the speed of the center of mass of the system for kinetic energy		1 point
$\frac{1}{2}m_1v_{1i}^2 = \frac{1}{2}(m_1+m_2)v_{cm}{}^2 + U_{Sf}$		
$U_{Sf} = \frac{1}{2}m_1v_{1i}^2 - \frac{1}{2}(m_1+m_2)v_{cm}{}^2$		
For correct substitution into above equation		1 point
$U_S = \left(\frac{1}{2}\right)(0.500\ \text{kg})(3.00\ \text{m/s})^2 - \frac{1}{2}(0.500\ \text{kg} + 1.05\ \text{kg})(0.97\ \text{m/s})^2$		
$U_S = 1.52\ \text{J}$		
Alternate Solution:		*Alternate Points*
For correctly determining the magnitude of the maximum force exerted between the carts		1 point
Set $\frac{dF}{dt} = 0 = 6400t - 500 \therefore 6400t = 500 \therefore t = 0.078\ \text{s}$		
$F_{MAX} = 3200(0.078)^2 - 500(0.078) = -19.5$		
$\lvert F_{MAX}\rvert = 19.5\ \text{N}$		
Note: Can estimate from the graph, and accept the range of 20 N to 21 N.		
For calculating the maximum compression of the spring		1 point
$F_{MAX} = -kx_{MAX}$		
$x_{MAX} = -\frac{F_{MAX}}{k} = -\frac{(-19.5\ \text{N})}{(130\ \text{N/m})} = 0.15\ \text{m}$		
Note: If estimating from the graph, accept the range from 0.15 m to 0.16 m.		
For substituting into an equation for the elastic potential energy at maximum spring compression		1 point
$U_S = \frac{1}{2}kx_{MAX}^2 = \left(\frac{1}{2}\right)(130\ \text{N/m})(0.15\ \text{m})^2$		
$U_S = 1.46\ \text{J}$		
Note: If estimating from the graph, accept range from 1.46 J to 1.70 J.		

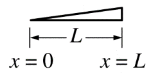
Units point: 1 point for correct units on all calculated answers

AP PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 3

15 points total **Distribution of points**

$$\lambda = \left(\frac{2M}{L^2}\right)x$$



A triangular rod, shown above, has length L, mass M, and a nonuniform linear mass density given by the equation $\lambda = \frac{2M}{L^2}x$, where x is the distance from one end of the rod.

(a) 3 points

Using integral calculus, show that the rotational inertia of the rod about its left end is $ML^2/2$.

For relating x to r properly in an integral to calculate the moment of inertia		1 point
$I = \int r^2dm = \int x^2dm$		
For correctly using the linear mass density to substitute into the equation above		1 point
$m = \int \lambda dx = \int \left(2M/L^2\right)xdx \therefore dm = \left(2M/L^2\right)xdx$		
$I = \int \left(2M/L^2\right)x^3dx$		
For integrating using the correct limits or constant of integration		1 point
$I = \int_{x=0}^{x=L} \left(2M/L^2\right)x^3dx = \left[\frac{\left(2M/L^2\right)x^4}{4}\right]_{x=0}^{x=L} = \frac{2M}{L^2}\left(\frac{L^4}{4} - 0\right) = ML^2/2$		

2018 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

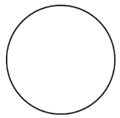


Figure 1

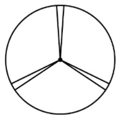


Figure 2

The thin hoop shown above in Figure 1 has a mass M, radius L, and a rotational inertia around its center of ML^2. Three rods identical to the rod from part (a) are now fastened to the thin hoop, as shown in Figure 2 above.

(b) 2 points

Derive an expression for the rotational inertia I_{tot} of the hoop-rods system about the center of the hoop. Express your answer in terms of M, L, and physical constants, as appropriate.

For setting the total rotational inertia for the hoop-rod system equal to the sum of the rotational inertias of the hoop and the three rods		1 point
$I = 3I_{rod} + I_{hoop}$		
$I = 3\left(ML^2/2\right) + ML^2$		
For a correct answer with work		1 point
$I = \frac{5}{2}ML^2$		

The hoop-rods system is initially at rest and held in place but is free to rotate around its center. A constant force F is exerted tangent to the hoop for a time Δt.

(c) 3 points

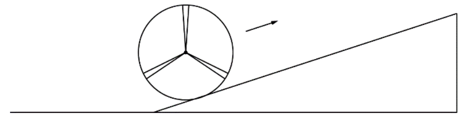
Derive an expression for the final angular speed ω of the hoop-rods system. Express your answer in terms of M, L, F, Δt, and physical constants, as appropriate.

For using an appropriate equation to determine the final angular speed of the hoop		1 point
$\tau\Delta t = I(\omega_2 - \omega_1)$		
$Fr\Delta t = I\omega$		
$\omega = \frac{Fr\Delta t}{I}$		
For relating the lever arm to the length of the rod		1 point
$\omega = \frac{FL\Delta t}{I}$		
For correct substitution from part (b)		1 point
$\omega = \frac{FL\Delta t}{\left(\frac{5}{2}\right)ML^2} = \frac{2F\Delta t}{5ML}$		

2018 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

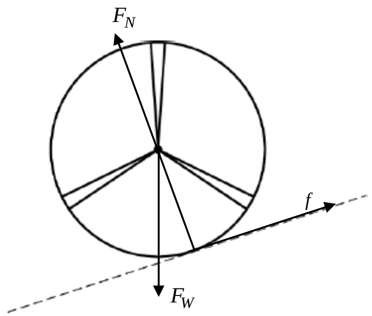


The hoop-rods system is rolling without slipping along a level horizontal surface with the angular speed ω found in part (c). At time $t = 0$, the system begins rolling without slipping up a ramp, as shown in the figure above.

(d)

i. 3 points

On the figure of the hoop-rods system below, draw and label the forces (not components) that act on the system. Each force must be represented by a distinct arrow starting at, and pointing away from, the point at which the force is exerted on the system.



For drawing the weight of the hoop-rod system in the correct direction		1 point
For drawing the normal force in the correct direction		1 point
For drawing the frictional force in the correct direction		1 point
Note: A maximum of two points can be earned if there are any extraneous vectors or any vector has an incorrect point of exertion.		

AP® PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

ii. 1 point

Justify your choice for the direction of each of the forces drawn in part (d)(i).

For a correct justification of the direction of the forces in part (d)(i)		1 point
Example: The normal force is always perpendicular to the surface, so it will be directed up and to the left. The gravitational force is always vertically downward. The friction will be opposite of the direction of rotation; therefore, it is directed up the incline.		

(e) 3 points

Derive an expression for the change in height of the center of the hoop from the moment it reaches the bottom of the ramp until the moment it reaches its maximum height. Express your answer in terms of M, L, I_{tot}, ω, and physical constants, as appropriate.

For including both linear and rotational kinetic energy in an equation for the conservation of energy to determine the final height of the hoop		1 point
$K_1 = U_{g2}$		
$\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 = mgH$		
$H = \dfrac{\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2}{mg}$		
For correct substitution of $v = L\omega$		1 point
$H = \dfrac{\frac{1}{2}m(L\omega)^2 + \frac{1}{2}I_{tot}\omega^2}{mg}$		
$H = \dfrac{\frac{1}{2}\left(m_{tot}L^2 + I_{tot}\right)\omega^2}{m_{tot}g}$		
For correct substitution of inertias into energy equation		1 point
$H = \dfrac{\frac{1}{2}\left((3M + M)L^2 + I_{tot}\right)\omega^2}{(3M + M)g} = \dfrac{\left(4ML^2 + I_{tot}\right)\omega^2}{8Mg}$		

2017

AP® CollegeBoard

AP Physics C: Mechanics
Scoring Guidelines

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.

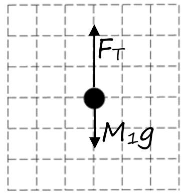
SCORING GUIDELINES

Question 1

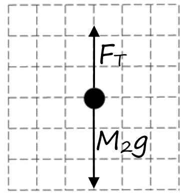
15 points total | **Distribution of points**

(a) 3 points

Block of Mass M_1



Block of Mass M_2



For correctly drawing and labeling the vectors for the weight of the block and the tension for block M_1 with the tension larger than the weight — 1 point

For correctly drawing and labeling the vectors for the weight of the block and the tension for block M_2 with the weight larger than the tension — 1 point

For correctly drawing tension on the two blocks as equal in magnitude — 1 point

Note: If any extraneous vectors are drawn, only a maximum of two points may be earned.

(b) 3 points

For correctly applying Newton's second law to block 1 — 1 point

$F_T - M_1 g = M_1 a$

For correctly applying Newton's second law to block 2 — 1 point

$M_2 g - F_T = M_2 a$

For combining the two equations above in such a way that will lead to the correct equation — 1 point

$M_2 g - M_1 g = (M_1 + M_2)a$

$$a = \frac{(M_2 - M_1)}{(M_1 + M_2)} g$$

(c) 1 point

For indicating variables that will create a straight line whose slope can be used to determine g — 1 point

Example: Vertical axis: a

Horizontal axis: $\dfrac{(M_2 - M_1)}{(M_1 + M_2)}$

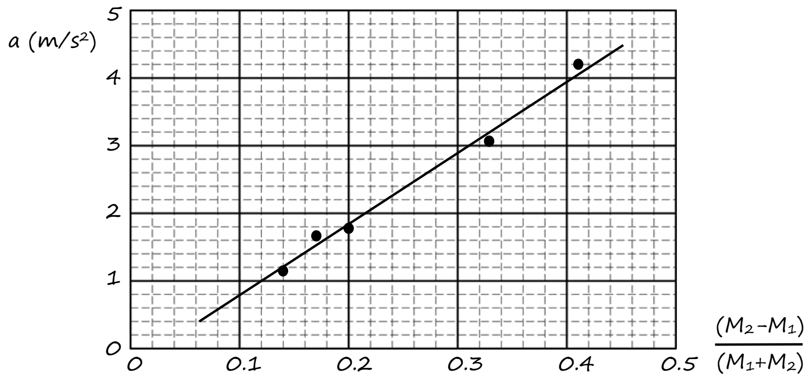
Note: Full credit is earned if axes are reversed, or if the student uses another acceptable combination.

2017 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(d) 3 points



For using a correct scale that uses more than half the grid and for correctly labeling the axes, including units as appropriate — 1 point
For correctly plotting the data — 1 point
For drawing a straight best-fit line consistent with the plotted data — 1 point

(e) 2 points

For correctly calculating the slope using the best-fit line and not the data points, unless the points fall on the best-fit line — 1 point
(Note: Credit may be given for the linear regression only if the student states linear regression is used.)

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(3.0 - 1.0)\ \text{m/s}^2}{(0.31 - 0.12)} = 10.5\ \text{m/s}^2$$

For correctly relating the slope to g — 1 point

$g = \text{slope} = 10.5\ \text{m/s}^2$ (using linear regression yields $10.1\ \text{m/s}^2$)

2017 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(f) 2 points

Correct answer: "Lower"

For including a correct statement about the acceleration of the blocks — 1 point
For including a correct statement about the forces on the blocks — 1 point

Example: Because the block M_1 is on the table, the net force on the system increases, and therefore the acceleration increases. Because the acceleration of M_2 increases, the net force on M_2 must increase. Therefore, there must be a greater difference in the magnitude of the two forces on M_2. Because the weight of block M_2 stays the same, the retarding force — the tension in the string — must decrease.

(g) 1 point

For a correct justification — 1 point

Example: Block M_1 will experience friction with the table. The acceleration of the system will decrease and this will decrease the slope of the line; therefore, the value of g is determined by the experiment.

;CORING GUIDELINES

Question

15 points total | **Distribution of points**

(a)

i. 2 points

For correctly using conservation of energy for the block moving down the incline — 1 point

$U_g = K$

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

For a correct answer — 1 point

$v = \sqrt{2gh}$

ii. 1 point

Correct answer: "Greater than"

For a correct justification — 1 point

Example: The speed is proportional to the square root of the change in height. So if the height is reduced by a factor of 2, the speed is reduced by a factor of $\sqrt{2} \approx 1.41$. Therefore, the speed halfway down the ramp is more than half the speed at the bottom of the ramp.

Note: If the incorrect selection is made, the justification cannot earn credit.

(b) 1 point

For correctly using conservation of energy, consistent with part (a), for the block compressing the spring — 1 point

$U_g = U_S$

$mgh = \frac{1}{2}kx_{\max}^2$

$x_{\max} = \sqrt{\frac{2mgh}{k}}$

(c) 2 points

For indicating a simple harmonic motion approach — 1 point

For a correct answer — 1 point

$t = \frac{1}{4}T = \left(\frac{1}{4}\right)\left(2\pi\sqrt{\frac{m}{k}}\right) = \frac{\pi}{2}\sqrt{\frac{m}{k}}$

2017 SCORING GUIDELINES

Question continued)

Distribution of points

(d)

i. 3 points

For correctly applying Newton's second law for the horizontally sliding block — 1 point

For correctly indicating that the direction of F_{net} is opposite the direction of motion — 1 point

$F_{net} = ma$

$-\beta v^2 = ma$

For expressing the equation as a differential equation — 1 point

$-\beta v^2 = m\frac{dv}{dt}$

ii. 3 points

For correctly separating variables — 1 point

$-\frac{\beta}{m}dt = \frac{1}{v^2}dv$

For correctly integrating the equation above — 1 point

$\int -\frac{\beta}{m}dt = \int \frac{1}{v^2}dv$

$-\frac{\beta}{m}[t] = \left[-\frac{1}{v}\right]$

For using the correct limits or constant of integration — 1 point

$-\frac{\beta}{m}[t]_0^t = \left[-\frac{1}{v}\right]_{v_0}^{v(t)}$

$-\frac{\beta t}{m} = -\frac{1}{v(t)} - \left(-\frac{1}{v_0}\right)$

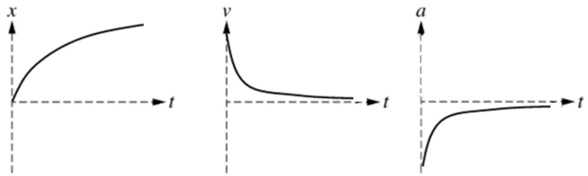
$\frac{1}{v(t)} = \frac{1}{v_0} + \frac{\beta t}{m}$

2017 SCORING GUIDELINES

Question continued)

Distribution of points

(e) 3 points



For a displacement curve that is concave down and approaching a horizontal asymptote	1 point
For a velocity curve that is concave up and has the horizontal axis as an asymptote	1 point
For an acceleration curve that is concave down and has the horizontal axis as an asymptote	1 point

Note: If an incorrect nonlinear velocity graph is generated, 1 point is earned if the position and acceleration graphs are consistent with the velocity graph.

Note: Full credit is earned if all three graphs are flipped vertically.

2017 SCORING GUIDELINES

Question 3

15 points total **Distribution of points**

(a) 2 points

For correctly applying conservation of energy to the cylinder rolling down the incline — 1 point

$U_{g\_top} = K_{table}$

$K_{table} = mgh = (0.50\text{ kg})\left(9.8\text{ m/s}^2\right)(1.0\text{ m})(\sin 30)$

For a correct answer with units — 1 point

$K_{table} = 2.45\text{ J}$ (or 2.5 J using $g = 10\text{ m/s}^2$)

(b) 3 points

For correctly setting the kinetic energy of the cylinder equal to the sum of both the linear and rotational kinetic energy — 1 point

$K = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

For correctly substituting into the above equation for the linear velocity and moment of inertia of the cylinder — 1 point

$$K = \frac{1}{2}MR^2\omega^2 + \frac{1}{2}\left(\frac{1}{2}MR^2\right)\omega^2 = \frac{1}{2}M(R\omega)^2 + \frac{1}{4}M(R\omega)^2 = \frac{3}{4}M(R\omega)^2$$

$$\omega = \sqrt{\frac{4K}{3MR^2}} = \sqrt{\frac{(4)(2.45\text{ J})}{(3)(0.50\text{ kg})(0.10\text{ m})^2}}$$

For correct substitution into the equation above — 1 point

$\omega = 25.6\text{ rad/s}$ (or 26.0 rad/s using $g = 10\text{ m/s}^2$)

(c) 2 points

For using a correct expression for the ratio of the rotational kinetic energy to the total kinetic energy of the cylinder — 1 point

$$\frac{K_{rot}}{K_{tot}} = \frac{\frac{1}{2}I\omega^2}{\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 + mgh} = \frac{\frac{1}{4}M(R\omega)^2}{\frac{3}{4}M(R\omega)^2 + Mgh_{\text{table}}} = \frac{(R\omega)^2}{3(R\omega)^2 + 4gh_{\text{table}}}$$

For substituting into the above equation — 1 point

$$\frac{K_{rot}}{K_{tot}} = \frac{[(0.10\text{ m})(25.6\text{ rad/s})]^2}{(3)(0.10\text{ m})^2(25.6\text{ rad/s})^2 + (4)\left(9.81\text{ m/s}^2\right)(0.75\text{ m})}$$

$\frac{K_{rot}}{K_{tot}} = 0.133$ (or 0.135 using $g = 10\text{ m/s}^2$)

2017 SCORING GUIDELINE

Question 3 (continued)

Distribution of points

(c) (continued)

Alternate Solution — *Alternate Points*

For using a correct expression for the ratio of the rotational kinetic energy to the total potential energy of the cylinder — *1 point*

$$\frac{K_{rot}}{K_{tot}} = \frac{\frac{1}{2}I\omega^2}{U_{total}} = \frac{\frac{1}{4}M(R\omega)^2}{Mg(h+y)}$$

For substituting into the above equation — *1 point*

$$\frac{K_{rot}}{U_{total}} = \frac{\frac{1}{4}(R\omega)^2}{g(h+y)} = \frac{\frac{1}{4}[(0.10\text{ m})(25.6\text{ rad/s})]^2}{(9.81\text{ m/s}^2)((1.0\text{ m})\sin(30^\circ) + (0.75\text{ m}))}$$

$$\frac{K_{rot}}{U_{total}} = 0.13 \textit{ (or } 0.135 \textit{ using } g = 10\text{ m/s}^2\textit{)}$$

(d) 2 points

For correctly using motion in the vertical direction to calculate the time for the cylinder to reach the floor — 1 point

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$$

$$y - y_0 = 0 - \frac{1}{2}gt^2$$

Determine the time for the cylinder to reach the floor

$$y - y_0 = -\frac{1}{2}gt^2$$

$$0 - y = -\frac{1}{2}gt^2$$

$$t = \sqrt{\frac{2y}{g}} = \sqrt{\frac{(2)(0.75\text{ m})}{(9.81\text{ m/s}^2)}} = 0.39\text{ s}$$

For correctly using the equation for constant speed in the horizontal direction — 1 point

$$x - x_0 = v_{0x}t$$

$$x - x_0 = R\omega t$$

$$x - x_0 = R\omega\sqrt{\frac{2y}{g}}$$

$$D = R\omega t = (0.10\text{ m})(25.6\text{ rad/s})(0.39\text{ s})$$

$$D = 1.0\text{ m}$$

2017 SCORING GUIDELINE

Question 3 (continued)

Distribution of points

(e)

i. 2 points

For selecting “Equal to” and attempting a relevant justification — 1 point
For a correct justification — 1 point

Example: Because the sphere falls the same height as the cylinder and because they have the same mass, the sphere-Earth system has the same initial potential energy and, therefore, the same total kinetic energy when it reaches the floor.

ii. 2 points

For selecting “Less than” and attempting a relevant justification — 1 point
For a correct justification — 1 point

Example: Because the rotational inertia of the sphere is less than the rotational inertia of the cylinder, the sphere will rotate faster and, because $v = r\omega$, will move with a greater linear speed. Because the mass is the same and the linear speed is greater, the sphere will have a greater linear kinetic energy. Because the total kinetic energies of the sphere and cylinder are the same, the sphere must have less rotational kinetic energy.

iii. 2 points

For selecting “Greater than” and attempting a relevant justification — 1 point
For a correct justification — 1 point

Example: Because the sphere has a greater linear speed as it leaves the table, it will travel a greater horizontal distance before it reaches the floor.

AP® Physics C: Electricity and Magnetism 2015 Scoring Guidelines

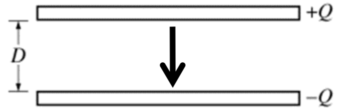
2015 SCORING GUIDELINES

Question 1

15 points total | **Distribution of points**

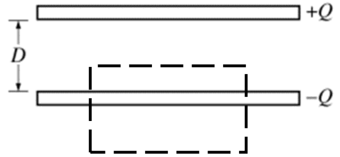
(a)

i. 1 point



For at least one arrow between the plates pointing downward from the positive plates toward the negative plate and no extraneous arrows pointing in any other direction — 1 point

ii. 1 point



For drawing an appropriate Gaussian surface (enclosing at least the inner edge of one of the plates) that can be used to determine the electric field between the plates — 1 point

iii. 3 points

For using a correct statement of Gauss's law — 1 point

$\oint \vec{E} \bullet d\vec{A} = \dfrac{Q}{\varepsilon_0}$

For applying Gauss's law, using an enclosed charge and surface area consistent with the surface drawn in part (a)-ii — 1 point

$E(A_{GS}) = \dfrac{q_{enc}}{\varepsilon_0}$ (A_{GS} is the area of the end of the Gaussian surface between the plates)

$E = \dfrac{q_{enc}}{\varepsilon_0 A_{GS}}$ $\left(\text{using } \sigma = \dfrac{q_{enc}}{A_{GS}}\right)$

$E = \dfrac{\sigma}{\varepsilon_0}$ $\left(\text{using } \sigma = \dfrac{Q}{A}\right)$

For a correct answer with work shown — 1 point

$E = \dfrac{Q}{\varepsilon_0 A}$

2015 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(b) 1 point

Comparing the equation for electric field between parallel plates to the given equation:

$$E = \frac{Q}{\kappa \varepsilon_0 A} = \frac{Q}{\varepsilon_0 \kappa_0 e^{-x/D} A}$$

For an answer consistent with part (a)-iii — 1 point

$$\kappa = \kappa_0 e^{-x/D}$$

(c)

i. 1 point

Using the equation relating the electric field to potential difference

$$E = -\frac{dV}{dx}$$

For a correct differential equation — 1 point

$$\frac{dV}{dx} = -\left(-\frac{Q}{\varepsilon_0 \kappa_0 e^{-x/D} A}\right)$$

$$\frac{dV}{dx} = \frac{Q}{\varepsilon_0 \kappa_0 e^{-x/D} A}$$

Alternate Solution: — *Alternate Point*

Using the equation relating the electric field to potential difference:

$$\Delta V = -\int \vec{E} \cdot d\vec{r}$$

For a correct differential equation — *1 point*

$$\Delta V = -\int -\frac{Q}{\varepsilon_0 \kappa_0 e^{-x/D} A} dx$$

$$\Delta V = \int \frac{Q}{\varepsilon_0 \kappa_0 e^{-x/D} A} dx$$

AP Physics C: **Mechanics: 2015**

2015 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(c) (continued)

ii. 4 points

Separating the variables in the differential equation from part (c)(i):

$$\frac{dV}{dx} = \frac{Q}{\varepsilon_0 \kappa_0 e^{-x/D} A}$$

$$dV = \left(\frac{Q}{\varepsilon_0 \kappa_0 A}\right) e^{x/D} dx$$

For using the correct limits of integration in attempting to integrate the equation above — 1 point

$$\int_{V_0}^{V_D} dV = \left(\frac{Q}{\varepsilon_0 \kappa_0 A}\right) \int_0^D e^{x/D} dx$$

For correctly integrating the equation — 1 point

$$\left[V\right]_{V_0}^{V_D} = \left(\frac{Q}{\varepsilon_0 \kappa_0 A}\right) \left[D e^{x/D}\right]_0^D$$

$$\left(V_D - V_0\right) = \left(\frac{QD}{\varepsilon_0 \kappa_0 A}\right) \left(e^{D/D} - e^0\right)$$

For an expression that gives the correct absolute value of the potential difference between the plates — 1 point

For having the potential difference be positive — 1 point

$$\Delta V = \left(\frac{QD}{\varepsilon_0 \kappa_0 A}\right)(e - 1)$$

$$\Delta V = \frac{1.72 QD}{\varepsilon_0 \kappa_0 A}$$

(d) 1 point

Using the equation for capacitance:

$$C = \frac{Q}{\Delta V} = \frac{Q}{\left(\frac{QD}{\varepsilon_0 \kappa_0 A}\right)(e - 1)}$$

For an answer consistent with part (c)-ii — 1 point

$$C = \frac{\varepsilon_0 \kappa_0 A}{D(e - 1)}$$

$$C = \frac{\varepsilon_0 \kappa_0 A}{1.72 D}$$

2015 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(e) 3 points

For selecting $U_V > U_C$ — 1 point

For correctly comparing the capacitance or the potential difference with the varying dielectric constant to the capacitance or the potential difference with the uniform dielectric constant — 1 point

For correctly comparing the two stored energies consistent with the comparison of the capacitances or potential differences — 1 point

Example: According to the equation from part (d), $C_C > C_V$. Since $U = \dfrac{Q^2}{2C}$, if the charge stored on the two capacitors is the same, then $U_V > U_C$.

2015 SCORING GUIDELINES

Question 2

15 points total — **Distribution of points**

(a)

i. 2 points

Using Ohm's law:

$V = IR$

For a correct application of Kirchhoff's loop rule — 1 point

$\mathcal{E} = Ir + IR$

$I = \dfrac{\mathcal{E}}{(r+R)}$

For a correct expression for the measured voltage across the variable resistor — 1 point

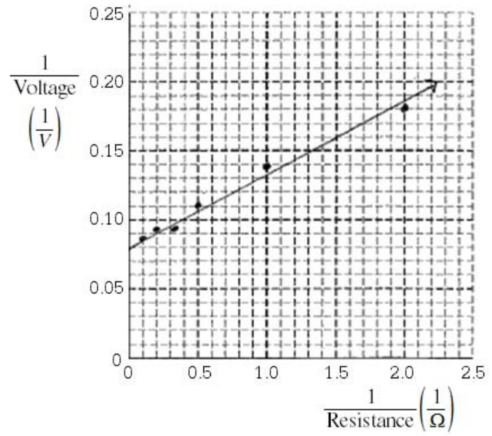
$V = \dfrac{\mathcal{E}}{(r+R)}R$

ii. 1 point

For an expression of $1/V$ as a function of $1/R$ consistent with answer from part (a)(i) — 1 point

$\dfrac{1}{V} = \left(\dfrac{r}{\mathcal{E}}\right)\dfrac{1}{R} + \dfrac{1}{\mathcal{E}}$

(b) 4 points



For correctly labeling both axes with variables and units — 1 point

For correctly scaling both axes with an acceptable and appropriate scale — 1 point

For correctly plotting the data points — 1 point

For correctly drawing a straight line that best represents the data — 1 point

2015 SCORING GUIDELINES

Question 2 (continued)

	Distribution of points
(c)	
i. 2 points	
For using a value for the y-intercept consistent with the straight line drawn in part (b)	1 point
$y = mx + b$	
$b = 0.080\ 1/\text{V}$	
For a correct substitution into the equation from part (a)(ii)	1 point
$\frac{1}{V} = \frac{(r+R)}{\mathcal{E}}\frac{1}{R}$	
$\frac{1}{V} = \frac{r}{\mathcal{E}}\frac{1}{R} + \frac{1}{\mathcal{E}}$	
$b = 1/\mathcal{E}$	
$\mathcal{E} = 1/(0.080\ 1/\text{V})$	
$\mathcal{E} = 12.5\ \text{V}$	
ii. 2 points	
For calculating the slope using the straight line from part (b) and not data points	1 point
$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{(0.151 - 0.100)}{(1.50 - 0.40)} = 0.0463\ \Omega/\text{V}$	
For a correct substitution into equation from part (a)(ii)	1 point
$m = \frac{r}{\mathcal{E}}$	
$r = m\mathcal{E}$	
$r = (0.0463\ \Omega/\text{V})(12.5\ \text{V})$	
$r = 0.58\ \Omega$	
(d) 2 points	
For using Ohm's law	1 point
$\mathcal{E} = Ir$	
For a correct substitution of values from part (c):	1 point
$(12.5\ \text{V}) = I(0.58\ \Omega)$	
$I = 21.6\ \text{A}$	
(e) 2 points	
For selecting "The voltmeter with high resistance"	1 point
For a correct justification	1 point
Example: The voltmeter acts like a resistor in a circuit with the battery. It will measure the potential difference across its own internal resistance. The higher its internal resistance, the closer its potential difference will be to the emf of the battery.	

2015 SCORING GUIDELINES

Question 3

15 points total	Distribution of points
(a) 3 points	
For properly using a correct equation to calculate the magnetic flux	1 point
$\Phi_B = \int \vec{B} \bullet d\vec{A}$	
For correct substitution of the area and trigonometric function	1 point
$\Phi_B = BA(\cos\theta) = B\pi r^2(\cos\theta)$	
For correct substitution into the above equation	1 point
$\Phi_B = 4(1 - 0.2t)\pi(0.10\ \text{m})^2(\cos 60°)$	
$\Phi_B = 0.063 - 0.013t$ (or in terms of a and b, $\Phi_B = a(1 - bt)(0.016)$)	
(b) 2 points	
For using a correct equation to solve for the emf	1 point
$\mathcal{E} = -\frac{d\Phi_B}{dt}$	
Substituting the expression from part (a):	
$\mathcal{E} = \frac{d}{dt}(0.063 - 0.013t)$	
For an answer consistent with part (a)	1 point
$\mathcal{E} = 0.013\ \text{V}$	
Note: Any sign on the answer is ignored.	
(c)	
i. 1 point	
For a substitution into Ohm's law consistent with the answer from part (b)	1 point
$V = IR$	
$I = \frac{(0.013\ \text{V})}{(50\ \Omega)}$	
$I = 2.6 \times 10^{-4}\ \text{A}$	
ii. 2 points	
The correct choice is "Counterclockwise".	
For a justification that incorporates that the original magnetic field is changing	1 point
For a justification that correctly relates the induced current to the direction of a new magnetic field created by that current	1 point
Example: Looking down at the loop from P, the vertical component of the magnetic field of the loop is upward and decreasing. To oppose this change, the current in the loop must create a magnetic field that is directed upward at point P. This requires a counterclockwise current in the loop.	

2015 SCORING GUIDELINES

Question 3 (continued)

		Distribution of points
(d)	2 points	
	For using a correct equation to calculate the energy dissipated $E = Pt = I^2Rt$ or $E = Pt = \left(\mathcal{E}^2/R\right)t$	1 point
	For a substitution into either of the above equations with the answer from part (c)(i) or part (b) $E = \left(2.6\times10^{-4}\ \text{A}\right)^2(50\ \Omega)(4.0\ \text{s})$ or $E = \dfrac{(0.013\ \text{V})^2}{(50\ \Omega)}(4.0\ \text{s})$ $E = 1.4\times10^{-5}\ \text{J}$	1 point
(e)	4 points	
	For selecting both “Zero” for the net magnetic force and “Nonzero” for the Net magnetic torque	1 point
	For indicating the forces on directly opposite sides of the loop are in opposite directions	1 point
	For concluding that the forces cancel & net force is zero	1 point
	For indicating that the torques add & net torque is nonzero	1 point
	Example: Since the current changes direction relative to the magnetic field as you go around the loop, the magnetic field will exert force of equal magnitude but opposite direction on opposite sides of the loop. These forces all cancel out resulting in zero net force. However, since this force is up on one side of the loop and down on the other side of the loop, this will create torques that rotate the loop in the same direction. Therefore, the net torque is not zero.	
Units	1 point	
	For correct units on at least two parts with a calculated numerical answer and no incorrect units	1 point