

Question 1: Free-Response Question

15 points

- (a)(i) For a multi-step derivation with an application of the conservation of mechanical energy that indicates that all of the energy of the system is initially U_s **1 point**

Example Response

$$E_{\text{initial}} = E_{\text{final}}$$

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

For a correct solution for v

1 point

Example Response

$$v = x_c \sqrt{\frac{k}{m}}$$

Example Solution

$$E_{\text{initial}} = E_{\text{final}}$$

$$U_s = K$$

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

$$v = \sqrt{\frac{kx_c^2}{m}}$$

$$v = x_c \sqrt{\frac{k}{m}}$$

- (a)(ii) For a derivation to solve for the speed at x_2 that includes **one** of the following: **1 point**

- An appropriate application of the conservation of energy
- An appropriate kinematics equation

Example Responses

$$K_{\text{initial}} - \Delta E_{\text{friction}} = K_{\text{final}} \quad \text{OR} \quad v^2 = v_0^2 + 2a\Delta x$$

For **one** of the following that is consistent with the previous point in the response for part (a)(ii): **1 point**

- A correct expression for the energy dissipated by friction
- A correct expression for the acceleration of the block in the region with nonnegligible friction

Example Responses

$$\Delta E_{\text{friction}} = \mu mgD \quad \text{OR} \quad a = -\mu g$$

For attempting to derive an expression for $v_{A,B}$ by using the conservation of momentum **1 point**

Example Response

$$m_{\text{initial}}v_{\text{initial}} = m_{A,B}v_{A,B}$$

For substituting the expression for the speed at x_2 that is consistent with the first point of the response in part (a)(ii) and substituting the correct masses into an expression for conservation of momentum **1 point**

Example Response

$$v_{A,B} = \frac{m\sqrt{\frac{kx_c^2}{m}} - 2\mu gD}{4m}$$

Example Solutions

$$E_{x1} = E_{\text{before collision}}$$

$$K_{x1} - \Delta E_{\text{friction}} = K_{\text{before collision}}$$

$$\frac{1}{2}m\left(\sqrt{\frac{kx_c^2}{m}}\right)^2 - \mu mgD = \frac{1}{2}mv_2^2$$

$$v_2 = \sqrt{\frac{kx_c^2}{m} - 2\mu gD}$$

$$\Sigma p_{\text{before collision}} = \Sigma p_{\text{after collision}}$$

$$m_A v_2 = m_{A,B} v_{A,B}$$

$$m_A v_2 = (m + 3m)v_{A,B}$$

$$v_{A,B} = \frac{m\sqrt{\frac{kx_c^2}{m} - 2\mu gD}}{4m}$$

$$v_{A,B} = \frac{1}{4}\sqrt{\frac{kx_c^2}{m} - 2\mu gD}$$

OR

$$v_2^2 = v^2 + 2a\Delta x$$

$$v_2^2 = \left(x_c\sqrt{\frac{k}{m}}\right)^2 + 2aD$$

$$v_2 = \sqrt{\frac{kx_c^2}{m} + 2aD}$$

$$\Sigma F_x = -F_f = ma$$

$$-\mu mg = ma$$

$$a = -\mu g$$

$$v_2 = \sqrt{\frac{kx_c^2}{m} - 2\mu gD}$$

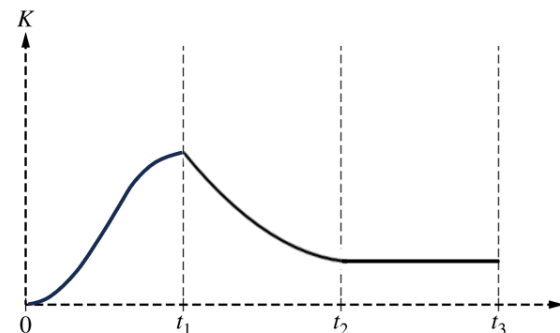
$$\Sigma p_{\text{before collision}} = \Sigma p_{\text{after collision}}$$

$$m_A v_2 = m_{A,B} v_{A,B}$$

$$m_A v_2 = (m + 3m)v_{A,B}$$

$$v_{A,B} = \frac{m\sqrt{\frac{kx_c^2}{m} - 2\mu gD}}{4m}$$

$$v_{A,B} = \frac{1}{4}\sqrt{\frac{kx_c^2}{m} - 2\mu gD}$$

Total for part (a) 6 points**(b)(i)** For a nonlinear sketch that begins at zero and increases for the entire time interval $0 \leq t \leq t_1$ **1 point**For a sketch that decreases for the entire time interval $t_1 \leq t \leq t_2$ but does not go to zero **1 point**For a sketch that is concave up for the time interval $t_1 \leq t \leq t_2$ **1 point**For a continuous function for the time interval $t_1 \leq t \leq t_3$ that has a horizontal line that is greater than zero for the time interval $t_2 \leq t \leq t_3$ **1 point****Example Response****(b)(ii)** For a statement about the change in kinetic energy that is consistent with the graph drawn in the response for part (b)(i) **1 point**For a correct explanation for why the kinetic energy is increasing, such as **one** of the following: **1 point**

- An increasing graph means positive work is being done on the block.
- An external force is exerted on Block A, causing the velocity of the block to increase and the kinetic energy of the block to increase.
- Mechanical energy is conserved and/or there is no work done for the block-spring system, and the potential energy decreases.

For a correct explanation for why the graph is nonlinear, such as **one** of the following: **1 point**

- The rate at which the slope of the graph changes is related to the rate at which work is being done on the block.
- The external force exerted on Block A is changing, which causes a nonuniform change in the velocity of Block A, which results in a nonuniform change in kinetic energy.

Example Response

From $0 < t < t_1$, the kinetic energy of Block A increases. The force exerted on the block by the compressed spring transfers the elastic potential energy in the block-spring system to the kinetic energy of the block. Because the force exerted by the spring is not applied at a constant rate, the kinetic energy of the block does not increase at a constant rate.

Total for part (b) 7 points

(c)	For selecting $f_{2\ell} < f_\ell$ with an attempt at a relevant justification	1 point
	For correctly applying an equation that relates the length of a pendulum to the period or frequency of the pendulum	1 point
Example Response		
The period of a pendulum is calculated by using $T = 2\pi\sqrt{\frac{L}{g}}$. Therefore, as the length is increased, the period will also increase. Because frequency and period are inversely related, an increase in period will result in a decrease in frequency.		
Total for part (c)		2 points
Total for question 1		15 points

Question 1: Free-Response Question**15 points**

(a)(i)	For a multi-step derivation that includes one of the following:	1 point
	- An application of conservation of energy that indicates that the initial mechanical energy of the system is U_g - An application of Newton's second law that includes the frictional force, including sign	
	For one of the following that is consistent with the previous point:	1 point
	- An expression for the energy dissipated by friction, including the correct sign - A substitution of acceleration in a kinematics equation	
Example Responses		
$\Delta E_{\text{friction}} = -F_f D$ OR $v^2 = v_0^2 + 2\left(\frac{F_{g,x} - F_f}{2m}\right)\Delta x$		
	For a correct expression for v	1 point

Example Response

$$v = \sqrt{2gD(\sin\theta - \mu\cos\theta)}$$

Example Solutions

$$\begin{aligned}
 E_{\text{initial}} &= E_{\text{final}} \\
 U_g - \Delta E_{\text{friction}} &= K \\
 m_A g D \sin\theta - \mu m_A g D \cos\theta &= \frac{1}{2} m_A v^2 & \text{OR} & \\
 a &= \frac{F_{\text{net}}}{m} \\
 2ma &= F_{g,x} - F_f \\
 2ma &= 2mg \sin\theta - \mu(2m)g \cos\theta \\
 a &= g \sin\theta - \mu g \cos\theta \\
 gD \sin\theta - \mu gD \cos\theta &= \frac{1}{2} v^2 \\
 v &= \sqrt{2gD(\sin\theta - \mu\cos\theta)} \\
 v^2 &= v_0^2 + 2a\Delta x \\
 v^2 &= 0^2 + 2(g \sin\theta - \mu g \cos\theta)D \\
 v &= \sqrt{2gD(\sin\theta - \mu\cos\theta)}
 \end{aligned}$$

(a)(ii)	For using the conservation of momentum to find $v_{A,B}$	1 point
	For equating the kinetic energy after the collision between the blocks to the maximum elastic potential energy of the compressed spring	1 point
Example Response		
$K_{\text{after collision}} = U_{s, \text{max}}$		
	For indicating v before the collision between the blocks and the spring is equal to $v_{A,B}$	1 point

Example Solution

$$p_{\text{before collision}} = p_{\text{after collision}}$$

$$2mv = (2m + m)v_{A,B}$$

$$v_{A,B} = \frac{2m\sqrt{2gD(\sin\theta - \mu\cos\theta)}}{(3m)}$$

$$v_{A,B} = \frac{2}{3}\sqrt{2gD(\sin\theta - \mu\cos\theta)}$$

$$E_{\text{after collision}} = E_{\text{max compression of spring}}$$

$$K_{\text{after collision}} = U_{s, \text{max}}$$

$$\frac{1}{2}(2m + m)(v_{A,B})^2 = \frac{1}{2}kx^2$$

$$(3m)\left(\frac{2}{3}\sqrt{2gD(\sin\theta - \mu\cos\theta)}\right)^2 = kx_c^2$$

$$k = \frac{(3m)}{x_c^2}\left(\frac{2}{3}\sqrt{2gD(\sin\theta - \mu\cos\theta)}\right)^2$$

$$k = \frac{8}{3}\frac{mgD(\sin\theta - \mu\cos\theta)}{x_c^2}$$

Total for part (a) 6 points

(b)(i) For a sketch that increases linearly during the time interval $0 \leq t < t_1$ 1 point

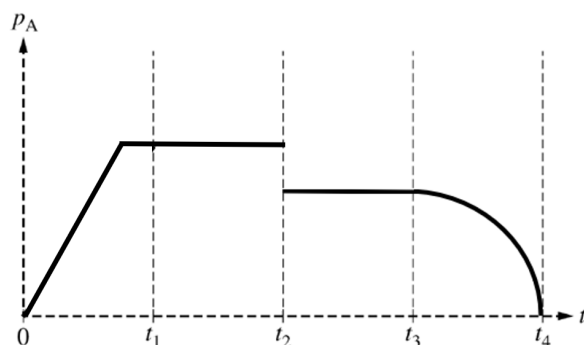
Scoring Note: A sketch that only increases linearly from $t = 0$ to $t = t_1$ earns this point.

For a horizontal line for the time interval $t_1 \leq t \leq t_2$ that is continuous at t_1 1 point

For a horizontal line for the time interval $t_2 \leq t \leq t_3$ that has a smaller magnitude than the previous time interval 1 point

For drawing a concave down curve, continuous at t_3 , in the interval $t_3 \leq t < t_4$ that reaches zero at t_4 1 point

Example Response



(b)(ii) For a statement about the change in momentum that is consistent with the graph drawn in the response for part (b)(i) 1 point

For indicating that a decreasing graph means that the force exerted on Block A is in a direction opposite to the motion of Block A 1 point

Scoring Note: A response that indicates that an increasing graph means that the force exerted on Block A is in the same direction as the motion of Block A also earns this point.

For relating the change in momentum to the magnitude of the force exerted on Block A 1 point

Example Response

The momentum of Block A decreases between t_3 and t_4 because the spring exerts a force on the blocks in the opposite direction of the velocity of the blocks, causing the blocks to slow to a stop. The spring force increases the more the spring compresses, so the momentum of Block A decreases at an increasing rate, which is shown in the slope of the curve becoming steeper with time.

Total for part (b) 7 points

(c) For selecting $T_N = T_O$ with an attempt at a relevant justification 1 point

For a correct justification that includes **one** of the following: 1 point

- The period of a spring-block oscillator is only dependent on the mass on the spring and spring constant, which do not change.
- The period of a spring-block oscillator is not dependent on increasing amplitude, velocity, or compression distance.

Example Response

Repeating the experiment on a smooth ramp will only affect the compression distance of the spring. The period of oscillation of a spring-block system depends only on mass and the spring constant, therefore the period of oscillation will not change.

Total for part (c) 2 points

Total for question 1 15 points

2017

AP[®] CollegeBoard

AP Physics C: Mechanics Scoring Guidelines

**AP® PHYSICS
2017 SCORING GUIDELINES**

General Notes About 2017 AP Physics Scoring Guidelines

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

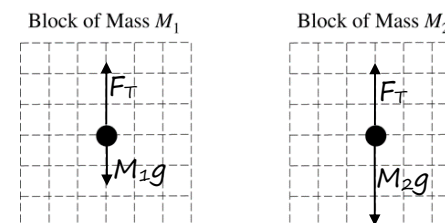
SCORING GUIDELINES

Question 1

15 points total

**Distribution
of points**

(a) 3 points



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

$$F_T - M_1g = M_1a$$

For correctly applying Newton's second law to block 2

1 point

$$M_2g - F_T = M_2a$$

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

1 point

$$M_2g - M_1g = (M_1 + M_2)a$$

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

(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

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

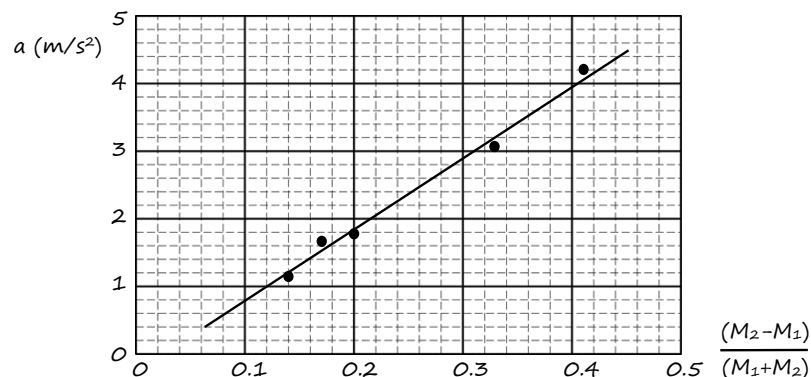
Note: Full credit is earned if axes are reversed, or if the student uses another acceptable combination.

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

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

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.

SCORING GUIDELINES

15 points total	Question	Distribution of points
(a)		
i. 2 points	For correctly using conservation of energy for the block moving down the incline $U_g = K$ $mgh = \frac{1}{2}mv^2$ For a correct answer $v = \sqrt{2gh}$	1 point 1 point
ii. 1 point	Correct answer: “Greater than” For a correct justification 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.	 1 point
(b) 1 point	For correctly using conservation of energy, consistent with part (a), for the block compressing the spring $U_g = U_s$ $mgh = \frac{1}{2}kx_{\max}^2$ $x_{\max} = \sqrt{\frac{2mgh}{k}}$	1 point
(c) 2 points	For indicating a simple harmonic motion approach For a correct answer $t = \frac{1}{4}T = \left(\frac{1}{4}\right)\left(2\pi\sqrt{\frac{m}{k}}\right) = \frac{\pi}{2}\sqrt{\frac{m}{k}}$	1 point 1 point

2017 SCORING GUIDELINES

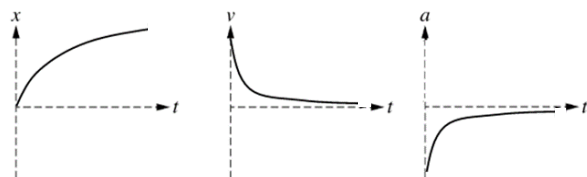
Question continued)		Distribution of points
(d)		
i.	3 points	
	For correctly applying Newton's second law for the horizontally sliding block	1 point
	For correctly indicating that the direction of F_{net} is opposite the direction of motion	1 point
	$F_{net} = ma$	
	$-\beta v^2 = ma$	
	For expressing 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

$$U_{g_top} = K_{table}$$

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

For a correct answer with units

1 point

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

(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

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

(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

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

For substituting into the above equation

1 point

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

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

2017 SCORING GUIDELINE

Question 3 (continued)

Distribution
of points

(c) (continued)

Alternate Solution

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

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

For substituting into the above equation

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

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

Alternate Points

1 point

1 point

(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.