Question 2: Translation Between Representations (TBR) — 12 points

A	For indicating that K_{block} is zero	**Point A1**
	For drawing bars with positive heights for U_{A} and U_{B}	**Point A2**
	For drawing a bar for U_{B} with a height that is twice the height of the bar drawn for U_{A} **Scoring Note:** This point may be earned regardless of the signs of either bar.	**Point A3**

Example Response

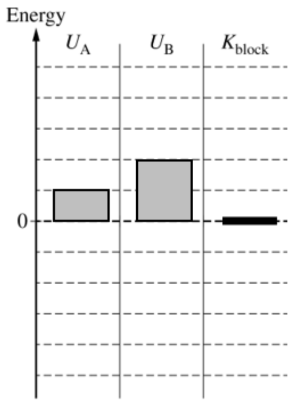

Figure 3

B	For a multistep derivation that includes energy conservation or simple harmonic motion	**Point B1**
	For relating the presence of both springs to the behavior of the system	**Point B2**
	For relating positions $x = x_1$ and $x = \frac{1}{2}x_1$ to the oscillation of the block	**Point B3**
	For a correct expression for v in terms of given quantities	**Point B4**

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Example Responses

$$E_{\text{tot},0} = U_{\text{A}}(x_1) + U_{\text{B}}(x_1) + K_{\text{block}}(x_1)$$
$$E_{\text{tot},f} = U_{\text{A}}\left(\frac{1}{2}x_1\right) + U_{\text{B}}\left(\frac{1}{2}x_1\right) + K_{\text{block}}\left(\frac{1}{2}x_1\right)$$

$$E_{\text{tot},0} = \frac{1}{2}(k)(x_1)^2 + \frac{1}{2}(2k)(x_1)^2 + 0$$
$$E_{\text{tot},f} = \frac{1}{2}(k)\left(\frac{1}{2}x_1\right)^2 + \frac{1}{2}(2k)\left(\frac{1}{2}x_1\right)^2 + K_{\text{block},\,\frac{1}{2}x_1}$$

$$E_{\text{tot},0} = E_{\text{tot},f}$$
$$\frac{1}{2}kx_1^2 + kx_1^2 = \frac{1}{8}kx_1^2 + \frac{1}{4}kx_1^2 + K_{\text{block},\,\frac{1}{2}x_1}$$
$$\frac{3}{2}kx_1^2 = \frac{3}{8}kx_1^2 + K_{\text{block},\,\frac{1}{2}x_1}$$

$$K_{\text{block},\,\frac{1}{2}x_1} = \frac{9}{8}kx_1^2$$
$$\frac{1}{2}mv^2 = \frac{9}{8}kx_1^2$$

$$v = \frac{3}{2}x_1\sqrt{\frac{k}{m}}$$

OR

$$x = x_{\max}\cos(\omega t + \phi)$$

$$x(t) = x_1\cos\omega t$$
$$v(t) = -x_1\omega\sin\omega t$$

$$k_{\text{eff}} = k + 2k = 3k$$
$$\omega = \sqrt{\frac{3k}{m}}$$

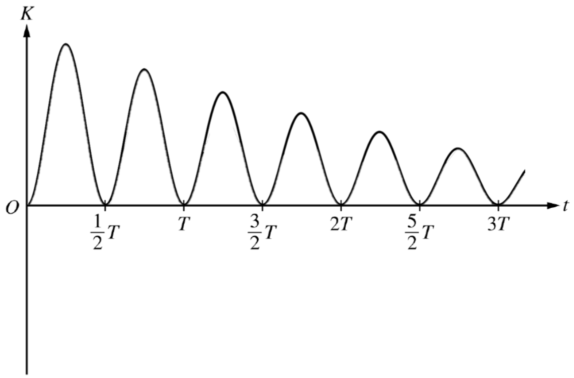
$$\frac{x_1}{2} = x_1\cos\omega t_{\frac{1}{2}x_1}$$
$$\cos\omega t_{\frac{1}{2}x_1} = \frac{1}{2}$$
$$t_{\frac{1}{2}x_1} = \frac{\pi}{3\omega}$$

$$v_{\frac{1}{2}x_1} = -x_1\omega\sin\omega t_{\frac{1}{2}x_1}$$
$$v_{\frac{1}{2}x_1} = -x_1\sqrt{\frac{3k}{m}}\sin\frac{\pi}{3}$$

$$v = \left|v_{\frac{1}{2}x_1}\right| = \frac{3}{2}x_1\sqrt{\frac{k}{m}}$$

C	For sketching a curve that starts at zero and is always positive or zero	**Point C1**
	For sketching a periodic curve with zeros that have a period of $\frac{1}{2}T$	**Point C2**
	For sketching a periodic curve with a decreasing amplitude	**Point C3**

Example Response



Scenario 2

Figure 5

D	For indicating **one** of the following: • The period increases. • The rate at which the graph approaches zero increases. • The maximum value of K over each period is less than the graph drawn.	**Point D1**
	For a correct justification relevant to the feature indicated	**Point D2**

Example Responses

The period of the graph increases. The period of a simple harmonic oscillator increases with increasing mass.

OR

The rate at which the graph approaches zero amplitude increases. Because the mass of the block is larger, the force of friction is greater, which causes the block to lose energy at a greater rate.

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

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

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

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

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

Example Response

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

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

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

Example Solutions

$E_{x_1} = E_{\text{before collision}}$

$K_{x_1} - \Delta E_{\text{friction}} = K_{\text{before collision}}$

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

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

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

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

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

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

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

OR

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

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

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

$\Sigma F_x = -F_f = ma$

$-\mu mg = ma$

$a = -\mu g$

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

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

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

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

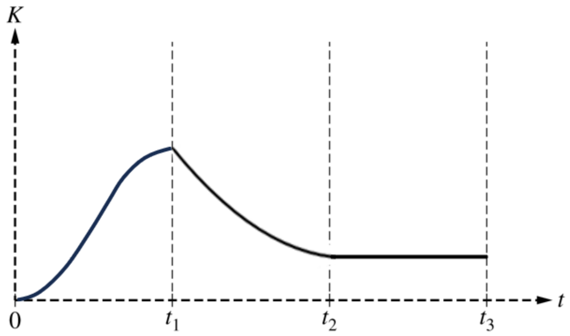
$v_{\text{A,B}} = \frac{m\sqrt{\frac{kx_c^2}{m} - 2\mu gD}}{4m}$

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

Total for part (a) 6 points

(b)(i)	For a nonlinear sketch that begins at zero and increases for the entire time interval $0 \le t \le t_1$	**1 point**
	For a sketch that decreases for the entire time interval $t_1 \le t \le t_2$ but does not go to zero	**1 point**
	For a sketch that is concave up for the time interval $t_1 \le t \le t_2$	**1 point**
	For a continuous function for the time interval $t_1 \le t \le t_3$ that has a horizontal line that is greater than zero for the time interval $t_2 \le t \le t_3$	**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: • 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.	**1 point**
	For a correct explanation for why the graph is nonlinear, such as **one** of the following: • 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.	**1 point**

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: • 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	**1 point**
	For **one** of the following that is consistent with the previous point: • An expression for the energy dissipated by friction, including the correct sign • A substitution of acceleration in a kinematics equation	**1 point**

Example Responses

$\Delta E_{\text{friction}} = -F_f D$ **OR** $v^2 = v_0^2 + 2\left(\dfrac{F_{g,x} - F_f}{2m}\right)\Delta x$

	For a correct expression for v	**1 point**

Example Response

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

Example Solutions

$$E_{\text{initial}} = E_{\text{final}}$$
$$U_g - \Delta E_{\text{friction}} = K$$
$$m_A gD\sin\theta - \mu m_A gD\cos\theta = \frac{1}{2}m_A v^2$$
$$gD\sin\theta - \mu gD\cos\theta = \frac{1}{2}v^2$$
$$v = \sqrt{2gD(\sin\theta - \mu\cos\theta)}$$

OR

$$a = \frac{F_{\text{net}}}{m}$$
$$2ma = F_{g,x} - F_f$$
$$2ma = 2mg\sin\theta - \mu(2m)g\cos\theta$$
$$a = g\sin\theta - \mu g\cos\theta$$
$$v^2 = v_0^2 + 2a\Delta x$$
$$v^2 = 0^2 + 2(g\sin\theta - \mu g\cos\theta)D$$
$$v = \sqrt{2gD(\sin\theta - \mu\cos\theta)}$$

(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

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

For indicating v before the collision between the blocks and the spring is equal to $v_{A,B}$ **1 point**

Example Solution

$$p_{\text{before collision}} = p_{\text{after collision}}$$
$$2mv = (2m + m)v_{A,B}$$
$$v_{A,B} = \frac{2m\sqrt{2gD(\sin\theta - \mu\cos\theta)}}{(3m)}$$
$$v_{A,B} = \frac{2}{3}\sqrt{2gD(\sin\theta - \mu\cos\theta)}$$

$$E_{\text{after collision}} = E_{\text{max compression of spring}}$$
$$K_{\text{after collision}} = U_{s,\,\max}$$
$$\frac{1}{2}(2m + m)\left(v_{A,B}\right)^2 = \frac{1}{2}kx^2$$
$$(3m)\left(\frac{2}{3}\sqrt{2gD(\sin\theta - \mu\cos\theta)}\right)^2 = kx_c^2$$
$$k = \frac{(3m)}{x_c^2}\left(\frac{2}{3}\sqrt{2gD(\sin\theta - \mu\cos\theta)}\right)^2$$
$$k = \frac{8}{3}\frac{mgD(\sin\theta - \mu\cos\theta)}{x_c^2}$$

Total for part (a) 6 points

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

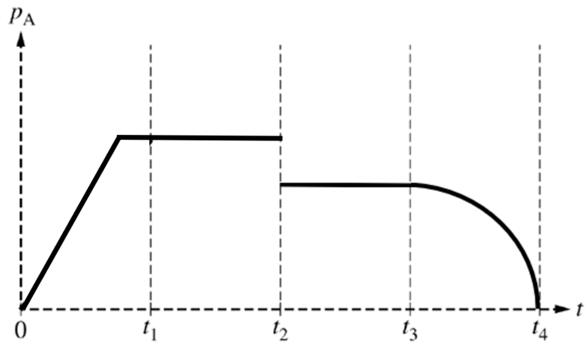
Scoring Note: A sketch that only increases linearly from $t = 0$ to $t = t_1$ earns this point.

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

For a horizontal line for the time interval $t_2 \le t \le t_3$ 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 $t_3 \le t < t_4$ 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

Question 2: Free-Response Question — 15 points

(a) For selecting "$J_S > J_2$" with an attempt at a relevant justification **1 point**

For a correct justification **1 point**

Example Response

The impulse between the two blocks is the same, so because Block 1 is moving at the end, the impulse given by the spring must be greater than the impulse given to Block 2 by Block 1.

Total for part (a) 2 points

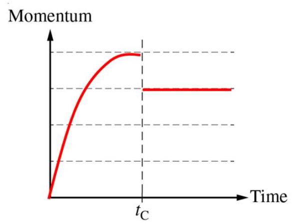
(b) For correctly drawing the momentum for blocks 1 and 2 for the time interval $0 < t < t_C$: Block 1 shows an increasing curve with a decreasing slope (concave down) to highest value (technically a cosine curve) and Block 2 shows zero momentum up to t_C (a horizontal line along the time axis). **1 point**

For drawing a horizontal line for Block 1 when $t > t_C$ that is smaller in magnitude than the momentum of Block 1 at time $t = t_C$ **1 point**

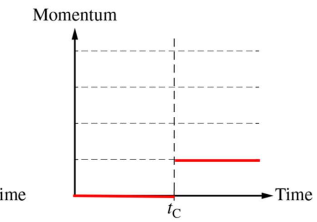
For drawing a horizontal line for Block 2 when $t > t_C$ that is smaller in magnitude than the momentum of Block 1 after time $t = t_C$ **1 point**

For blocks 1 and 2 having a change in momentum that is equal in magnitude such that Block 1 loses momentum and Block 2 gains momentum **1 point**

Example Response



Block 1



Block 2

Total for part (b) 4 points

(c)	For using conservation of energy to find the speed of Block 1 at $x = 0$	**1 point**
	For using conservation of momentum to find the speed of the two-block system after the collision	**1 point**
	For combining correct equations from above	**1 point**

Example Response

$$\frac{1}{2}k(\Delta x)^2 = \frac{1}{2}m_1 v_1^2$$

$$v_1 = \sqrt{\frac{k}{m_1}}\Delta x$$

$$m_1 v_1 = (m_1 + m_2)v$$

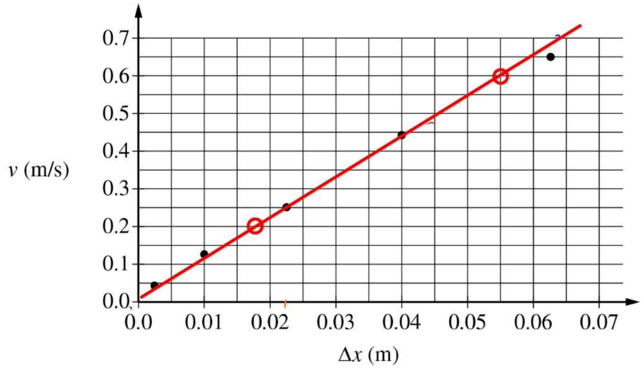
$$v = \frac{m_1 v_1}{m_1 + m_2}$$

$$\therefore v = \frac{\Delta x\sqrt{k m_1}}{m_1 + m_2}$$

Total for part (c) 3 points

(d)(i)	For drawing an appropriate best-fit line including approximately the same number of points above and below the line	**1 point**

Example Response



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(d)(ii)	For calculating the slope using two points on the line	**1 point**
	For correctly relating the slope of the best-fit line to the mass of Block 2	**1 point**
	For a correct mass of Block 2	**1 point**

Example Response

$$slope = \frac{(0.60 - 0.02)\text{ m/s}}{(0.055 - 0.0175)\text{ m}} = 10.67\text{ s}^{-1}$$

$$slope = \frac{\sqrt{k m_1}}{m_1 + m_2}$$

$$m_2 = \frac{\sqrt{k m_1}}{slope} - m_1$$

$$m_2 = \frac{\sqrt{\left(150\,\frac{\text{N}}{\text{m}}\right)(0.50\text{ kg})}}{10.67\text{ s}^{-1}} - 0.50\text{ kg}$$

$$m_2 = 0.31\text{ kg}$$

Scoring Note: Acceptable responses for mass are $0.27\text{ kg} - 0.37\text{ kg}$.

Total for part (d) 4 points

(e)	For selecting "$k' > 150$ N/m" with an attempt at relevant justification	**1 point**
	For a correct justification	**1 point**

Example Response

A greater m_2 indicates the spring constant k' should be greater than 150 N/m. *The slope of the graph is the same so as m_2 increases k must be smaller.*

Total for part (e) 2 points

Total for question 2 15 points

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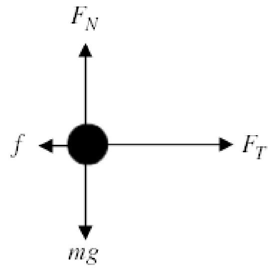
Question

15 points total | **Distribution of points**

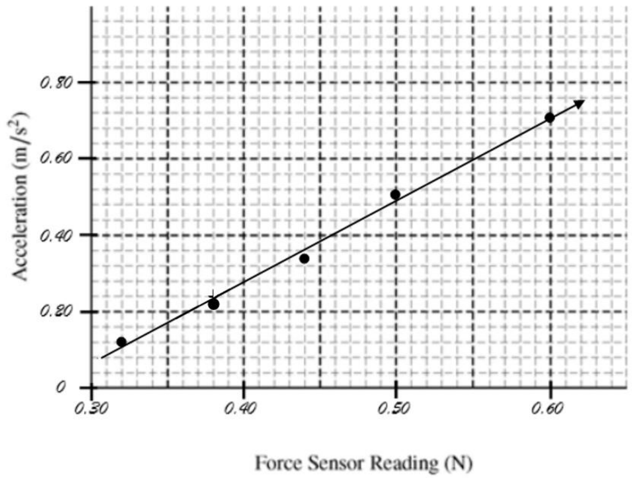
3 points



For correctly drawing and labeling the force of tension	1 point
For correctly drawing and labeling the force of friction	1 point
For correctly drawing and labeling both forces in the vertical direction	1 point

Note: A maximum of two points may be earned if there are any extraneous vectors.

3 points



For a correct scale that uses more than half the grid	1 point
For correctly plotting the given data	1 point
For drawing a straight line consistent with the given data	1 point

Note: Full credit can be earned if the axes are switched.

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Question 1 (continued)

Distribution of points

2 points

For correctly calculating slope using the best-fit straight line and not data points — 1 point

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(0.70 - 0.16)}{(0.60 - 0.35)}\text{kg}^{-1} = 2.16\ \text{kg}^{-1}$$

Note: Linear regression gives slope $= 2.12\ \text{kg}^{-1}$.

For correctly calculating the mass of the cart using the slope — 1 point

$$m = \frac{1}{\text{slope}} = \frac{1}{\left(2.16\ \text{kg}^{-1}\right)}$$

Correct answer:

$m = 0.463\ \text{kg}$ (Note: linear regression gives $m = 0.472\ \text{kg}$)

1 point

For an answer with correct units consistent with the x-intercept of the graph from (b) i. — 1 point

$f = 0.272\ \text{N}$

(

1 point

ɔlying Newton's second law and substituting the values from part (b)

$$\sum F = ma = F_a - f$$

$$a = \frac{F_a - f}{m} = \frac{0.45\ \text{N} - 0.272\ \text{N}}{0.463\ \text{kg}}$$

For an answer with correct units consistent with part (b), either from the graph or calculated using the mass and frictional force. — 1 point

$a = 0.376\ \text{m/s}^2$

;CORING GUIDELINES

Question 1 (continued)

Distribution of points

3 points

For using a correct equation to solve for the speed of the cart when the string breaks, with an acceleration consistent with part (c) i. — 1 point

$v_2 = v_1 + at$

$v_2 = 0 + \left(0.376\ \text{m/s}^2\right)(2.0\ \text{s})$

$v_2 = 0.752\ \text{m/s}$

For recognizing that the acceleration of the cart after the string breaks is due to the frictional force determined in part (b) — 1 point

Use a correct equation to solve for the time for the cart to stop after the string breaks

$v_2 = v_1 + at$

$0 = v_1 - \frac{f}{m}t$

For using the final velocity before the string breaks as the initial velocity for the cart stopping in the correct equation for time — 1 point

$$t = \frac{mv_1}{f}$$

$$t = \frac{(0.463\ \text{kg})(0.752\ \text{m/s})}{(0.272\ \text{N})}$$

Correct answer

$t = 1.28\ \text{s}$

Alternate solution — *Alternate points*

For setting the magnitude of the impulse before the string breaks equal to the magnitude of the impulse after the string breaks — *1 point*

$F_1 t_1 = F_2 t_2$

For correctly using the proper force (e.g., the tension force minus the friction force) for F_1 — *1 point*

For correctly using the proper force (e.g., the friction force) for F_2 — *1 point*

Correct answer

$t = 1.28\ \text{s}$

1 point

For selecting "Equal to" — 1 point

1 point

For selecting "Greater than" — 1 point

SCORING GUIDELINES

Question

15 points total | **Distribution of points**

2 points

For correctly drawing and labeling vectors on the block of mass $2M$ — 1 point

For correctly drawing and labeling vectors on the block of mass $3M$ using symbols for the vectors that are physically correct and different from those on the block of mass $2M$ — 1 point

Note: A maximum of one point can be earned if there are any extraneous vectors.

2 points

Using a proper expression for conservation of momentum

$p_1 = p_2$

For correctly substituting into the above equation — 1 point

$3Mv_0 = (3M + 2M)v_f$

For a correct answer — 1 point

$v_f = \frac{3}{5}v_0$

(1 point

Using a proper expression for kinetic energy of the two-block system

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

$K = \frac{1}{2}(5M)\left(\frac{3}{5}v_0\right)^2$

For an answer consistent with part (b) — 1 point

$K = \frac{9}{10}Mv_0^2$

SCORING GUIDELINES

Question continued)

Distribution of points

4 points

For a correct expression of the conservation of energy — 1 point

$\Delta K_{\text{system}} + \Delta U_{\text{system}} = 0$

$K_0 = U_{\text{final}}$

For attempting to integrate the spring force equation — 1 point

$\frac{9}{10}Mv_0^2 = -\int_{x_1}^{x_2} -Bx^3 dx$

$\frac{9}{10}Mv_0^2 = \int_{x_1}^{x_2} Bx^3 dx$

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

$\frac{9}{10}Mv_0^2 = \int_0^D Bx^3 dx$

$\frac{9}{10}Mv_0^2 = \left[\frac{Bx^4}{4}\right]_0^D$

For an answer consistent with the speed from (b) or the kinetic energy from part (c) — 1 point

$D = \sqrt[4]{\frac{18Mv_0^2}{5B}}$

2 points

For selecting the correct answer "Right" with a reasonable attempt at a justification — 1 point

If the incorrect selection is made, no points are earned for the justification.

For an indication that at maximum compression the block of mass $2M$ has an acceleration to the right due to the forces acting on the block of mass $2M$ or an acceleration to the right due to the external spring force acting on the system of blocks — 1 point

Example: At maximum compression the two-block system is instantaneously at rest. The only horizontal external force acting on the system is due to the spring. This force is directed to the right. The system and therefore the block of mass $2M$ is accelerated to the right, which implies that the net force acting on the block of mass $2M$ is also to the right.

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Question continued)

Distribution of points

2 points

ə magnitude of the net force is greater on the block of mass $3M$.

If the incorrect selection is made, no points are earned for the justification.

For an indication that both blocks will have the same acceleration — 1 point

For a correct justification for why the net force is greater on the block of mass $3M$ — 1 point

Example:

Because the blocks stick together, both blocks must have the same acceleration. Because the block of mass $3M$ has more mass, the net force on it must be greater than the net force on the block of mass $2M$.

2 points

For selecting the correct answer "No," with a reasonable attempt at a justification — 1 point

If the incorrect selection is made, no points are earned for the justification.

If the correct answer is selected without any justification, the point is not earned for the selection.

For an indication that the spring does not apply a linear force and that simple harmonic motion is the resulting motion of a linear restoring force — 1 point

$$\left(a = -\frac{k}{m}\Delta x\right)$$

Example:

Because the blocks are sticking together and are attached to the spring, the spring will apply a restoring force to the blocks. However, because the restoring force exerted by a nonlinear spring is not proportional to the blocks' displacement from equilibrium, the blocks do not exhibit simple harmonic motion.

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Question

15 points total

Distribution of points

3 points

For an indication that the spring force equals the mass times the centripetal acceleration — 1 point

$F_S = F_C = ma_C$

$kx = mr\omega^2$

correct substitution for x in the equation — 1 point

For a correct substitution for r in the equation that can be used to solve for k — 1 point

$k\left(\frac{d}{2}\right) = m(2d)\omega^2$

rect answer:

$k = 4m\omega^2$

1 point

Substitute values for the block into the equation for rotational inertia

$I = \sum mr^2 = m(2d)^2$

For a correct answer or an answer consistent with the radius used in part (a) — 1 point

$I = 4md^2$

2 points

For an indication that the rotational inertia of the system must include the platform, the rod, and the object — 1 point

$I = I_P + I_R + I_O$

$I = \frac{m_P R^2}{2} + \frac{m_R d^2}{3} + mr^2$

For correctly substituting into the equation the rotational inertia of the platform, the rod, and the object consistent with (b) i. — 1 point

$I = \frac{5m(2d)^2}{2} + \frac{3m\,d^2}{3} + 4md^2$

$I = (10 + 1 + 4)md^2$

rect answer:

$I = 15md^2$

1 point

Using a correct expression of angular momentum

$L = I\omega$

For an answer consistent with the answer from part (b) ii. — 1 point

$L = 15md^2\omega$

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Question continued)

Distribution of points

3 points

For indicating that the spring force equals the mass times the centripetal acceleration — 1 point

$F_S = F_C = ma_C$

$kx = mr\omega^2$

For a correct substitution for k, or a substitution consistent with part (a), in the equation — 1 point

For a correct substitution for r in the equation that can be used to solve for x — 1 point

$\left(4m\omega^2\right)x = m(d + x)\omega^2$

$4x = d + x$

$3x = d$

Correct answer:

$x = d/3$

2 points

electing "Decreasing" — 1 point

the wrong selection is made, no points are earned for the justification.

For a correct justification — 1 point

Example: The rotational inertia I of the system decreases while the angular velocity w stays the same. Because the angular momentum is Iw, it decreases.

2 points

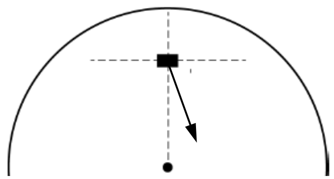
For selecting "Negative" — 1 point

If the wrong selection is made, no points are earned for the justification.

For a correct justification — 1 point

Example: Because the angular velocity is constant and the rotational inertia has decreased, the rotational kinetic energy has decreased. Therefore, work must be negative.

1 point



n arrow starting on the box and pointing down and to the right — 1 point