2022

AP® CollegeBoard

AP® Physics C: Mechanics

Scoring Guidelines

Set 2

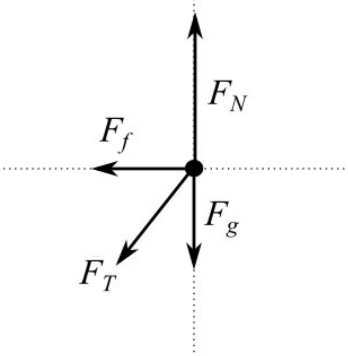
Question 1: Free-Response Question — 15 points

(a) For correctly drawing and labeling the force of gravity and the normal force on the sled — **1 point**

For correctly drawing and labeling the force of friction on the on the sled — **1 point**

For correctly drawing and labeling the force of tension on the on the sled — **1 point**

Example Response



Scoring Notes:

- 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," $F_{\text{Earth on block}}$, $F_{\text{E,Block}}$. The labels G and 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. F_{string}, F_s, F_T, $F_{Tension}$, T, "string force," "tension force," or similar labels may be used for the tension force exerted by the string.
- A response with extraneous forces or vectors can earn a maximum of two points.

Total for part (a) — 3 points

(b) For any correct trigonometric expression for θ in terms of the given quantities — **1 point**

$$\sin\theta = \frac{x}{\sqrt{y^2 + x^2}} \qquad \therefore \theta = \sin^{-1}\left(\frac{x}{\sqrt{y^2 + x^2}}\right)$$

OR

$$\cos\theta = \frac{y}{\sqrt{y^2 + x^2}} \qquad \therefore \theta = \cos^{-1}\frac{y}{\sqrt{y^2 + x^2}}$$

OR

$$\tan\theta = \frac{x}{y} \qquad \therefore \theta = \tan^{-1}\frac{x}{y}$$

Total for part (b) — 1 point

(c)(i) For beginning the derivation with Newton's second law to write an equation that is consistent with part (a). **1 point**

$$\Sigma F = ma$$
$$F_N - F_{T,y} - F_g = 0$$
$$F_N = F_{T,y} + F_g$$

Scoring Note: Derivation must start with a statement of Newton's second law to earn this point.

For correctly substituting the vertical component of the tension in terms of the given variables consistent with part (b) **1 point**

$$F_N = mg + F_T \cos\theta$$
$$F_N = mg + F_T\left(\frac{y}{\sqrt{y^2 + x^2}}\right)$$

(c)(ii) For summing the forces in the horizontal direction, consistent with parts (a) and (b) **1 point**

$$F_{net} = -F_{T,x} - F_f$$

For correctly substituting the horizontal component of the force of tension in terms of the given variables **1 point**

$$F_{net} = -F_T \sin\theta - F_f$$
$$F_{net} = -F_T\left(\frac{x}{\sqrt{y^2 + x^2}}\right) - F_f$$

For correctly substituting the expression for the normal force from part (c)(i) into the expression for the force of friction **1 point**

$$F_{net} = -F_T\left(\frac{x}{\sqrt{y^2 + x^2}}\right) - \mu_k F_N$$
$$F_{net} = -F_T\left(\frac{x}{\sqrt{y^2 + x^2}}\right) - \mu_k\left(mg + F_T\left(\frac{y}{\sqrt{y^2 + x^2}}\right)\right)$$

Total for part (c) 5 points

(d)	For using the integral definition of work to derive an expression for the work done by the force of tension $W = \int F \cdot dx$	**1 point**
	For any indication that the work done on the sled by the string is due only to the horizontal component of the tension in the string $W = \int F_{T,x} dx$	**1 point**
	For using the horizontal component of the force of tension consistent with part (b) or (c) $W = \int_{x=0}^{x=L} -F_T \left(\frac{x}{\sqrt{y^2 + x^2}} \right) dx$	**1 point**
	For correct limits of integration, x= 0 to x= L, and indicating that the work done is negative let $u = y^2 + x^2$, then $du = 2x\ dx$ $W = -F_T \int_{x=0}^{x=L} \frac{1}{2} \left(\frac{1}{\sqrt{u}} \right) du$ $W = -F_T \left(\sqrt{y^2 + x^2} \right) \Big|_{x=0}^{x=L}$ $W = -F_T \left(\sqrt{y^2 + L^2} - \sqrt{y^2} \right)$	**1 point**
	Total for part (d)	**4 points**
(e)	For selecting "$E_1 > E_2$" with an attempt at a relevant justification	**1 point**
	For a justification that correctly relates the force of friction to the normal force, and the normal force to the position or the angle	**1 point**
	Example Response *The vertical component of the string force is the largest when the string is more vertical* $(0 < x < L)$*. A larger vertical component of the string tension leads to a larger normal force and, hence, a larger friction force.*	
	Total for part (e)	**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**

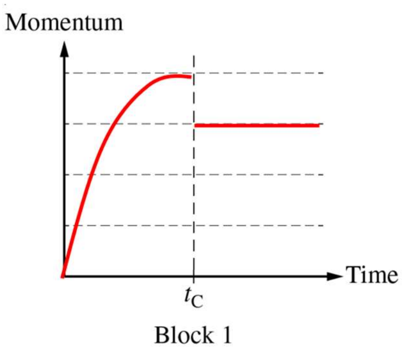
Example Response

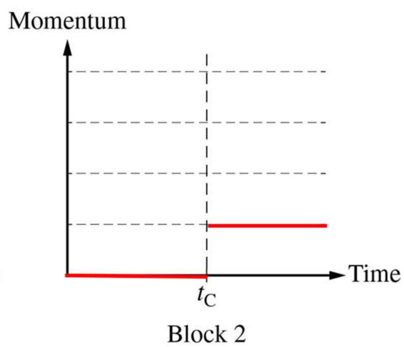
The impulse between the two blocks is the same, so because Block 1 is moving at the end, the impulse given by the spring must be greater than the impulse given to Block 2 by Block 1.

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





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

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

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

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

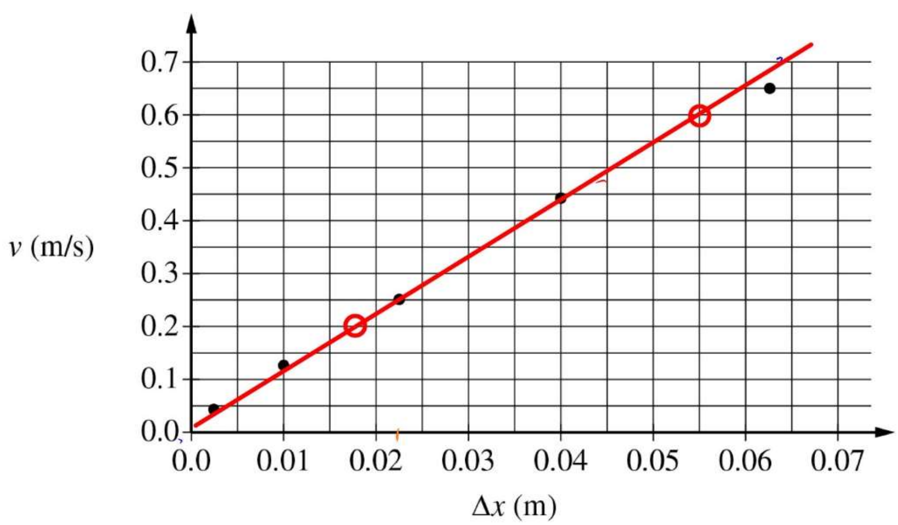
$$v = \frac{m_1 v_1}{m_1 + m_2}$$

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

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



(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

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

$$slope = \frac{\sqrt{km_1}}{m_1 + m_2}$$

$$m_2 = \frac{\sqrt{km_1}}{slope} - m_1$$

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

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

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

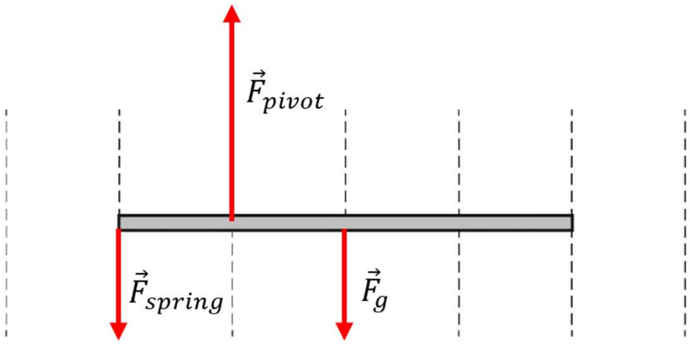
Question 3: Free-Response Question — 15 points

(a) For correct location and label of the force exerted on the board by the spring — **1 point**

For correct location and label of the force exerted on the board by gravity — **1 point**

For correct location and label of the force exerted on the board by the pivot — **1 point**

Example Response



Scoring Notes:

- 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," $F_{\text{Earth on block}}$, $F_{\text{E,Block}}$. The labels G and 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, which can be used instead of F_{pivot}. F_{spring}, F_S, "spring force," or similar labels may be used for the force exerted by the spring.
- A response with extraneous forces or vectors can earn a maximum of two points.

Total for part (a) — 3 points

(b) For indicating that the sum of the torques equals zero — **1 point**

$\Sigma\tau = 0$

For substituting mg for the force of gravity and $k\Delta x$ for the spring force into a torque equation — **1 point**

$$\frac{L}{4}k\Delta x - \frac{L}{4}mg = 0$$

For a correct expression for Δx — **1 point**

$$\Delta x = \frac{mg}{k}$$

Example Response

$\Sigma\tau = 0$

$F_{\text{spring}}d_{\text{spring}} - F_{\text{weight}}d_{\text{weight}} = 0$

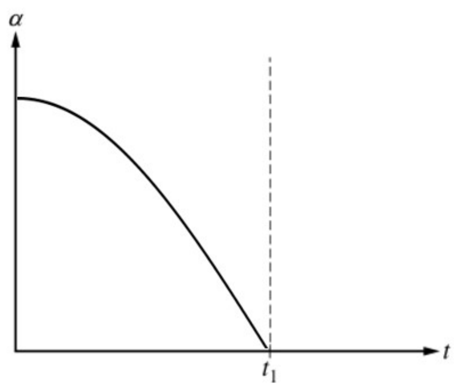
$\frac{L}{4}k\Delta x - \frac{L}{4}mg = 0$

$\Delta x = \frac{mg}{k}$

Scoring Note: This point can be earned regardless of whether a negative sign is present.

	Total for part (b)	**3 points**
(c)(i)	For a sketch that begins at a maximum value and monotonically decreases to a minimum of zero at $t = t_1$	**1 point**
	For a sketch that is concave down between $t = 0$ and $t = t_1$	**1 point**

Example Response



Scoring Note: Any part of the graph beyond t_1 is not considered in scoring.

(c)(ii)	For indicating that the torques are in opposite directions in the rotational form of Newton's second law $\tau_{\text{spring}} - \tau_g = I\alpha$	**1 point**
	For including $\sin(90 - \theta_0)$, $\sin(90 + \theta_0)$, or $\cos\theta_0$ in an expression for the net torque exerted on the rod $F_{spring}d_{spring}(\cos\theta) - F_g d_g(\cos\theta) = I_B\alpha_0$	**1 point**
	For substituting mg for the force due to gravity and substituting $k\Delta x_2$ for the spring force in an expression for the net torque exerted on the rod $d_{spring}k\Delta x_2(\cos\theta_0) - d_g mg(\cos\theta_0) = I_B\alpha_0$	**1 point**
	For substituting correct lever arms in an expression for the net torque exerted on the rod $\frac{L}{4}(\cos\theta_0)k\Delta x_2 - \frac{L}{4}(\cos\theta_0)mg = I_B\alpha_0$	**1 point**

Example Response

$\tau_{\text{spring}} - \tau_g = I\alpha$

$F_{spring} d_{spring} (\cos\theta_0) - F_g d_g (\cos\theta_0) = I_B \alpha_0$

$l_{spring} (\cos\theta_0) k\Delta x_2 - l_g (\cos\theta_0) mg = I_B \alpha_0$

$\frac{L}{4}(\cos\theta_0) k\Delta x_2 - \frac{L}{4}(\cos\theta_0) mg = I_B \alpha_0$

$\alpha_0 = \frac{L}{4I_B}(k\Delta x_2 \cos\theta_0 - mg\cos\theta_0)$

Total for part (c) 6 points

(d)	For selecting “$\alpha' < \alpha_0$” with an attempt at a relevant justification	**1 point**
	For indicating that the net torque does not change	**1 point**
	For indicating the rotational inertia increases	**1 point**

Example Response

The net torque on the system is the same (the spring and the person exert the same force and the additional torques from the gravitational forces on the masses cancel) but the rotational inertia of the system is now larger. This means that the angular acceleration of the system is now smaller than it was before.

Total for part (d) 3 points

Total for question 3 15 points