2024

AP® Physics C: Mechanics

Scoring Guidelines
Set 1

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

$$E_{\text{initial}} = E_{\text{final}}$$
$$\frac{1}{2}k{x_c}^2 = \frac{1}{2}mv^2$$

For a correct solution for v — **1 point**

Example Response

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

Example Solution

$$E_{\text{initial}} = E_{\text{final}}$$
$$U_s = K$$
$$\frac{1}{2}k{x_c}^2 = \frac{1}{2}mv^2$$
$$v = \sqrt{\frac{k{x_c}^2}{m}}$$
$$v = x_c\sqrt{\frac{k}{m}}$$

(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

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

Example Solutions

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

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

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

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

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

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

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

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

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

OR

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

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

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

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

$$-\mu mg = ma$$

$$a = -\mu g$$

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

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

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

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

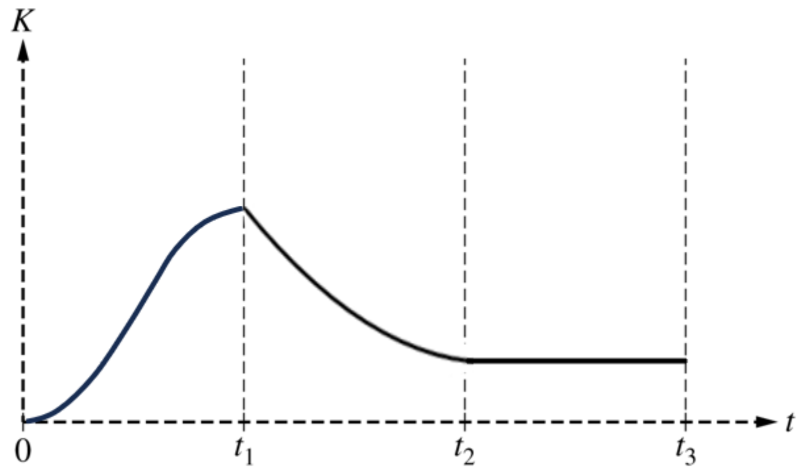
$$v_{A,B} = \frac{m\sqrt{\frac{kx_c^2}{m} - 2\mu gD}}{4m}$$

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

Total for part (a) 6 points

(b)(i)	For a nonlinear sketch that begins at zero and increases for the entire time interval $0 \le t \le t_1$	**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 2: Free-Response Question — 15 points

(a) For a multi-step derivation that includes Newton's second law of motion — **1 point**

For indicating that the net force exerted on the cylinder includes only the gravitational force and a drag force — **1 point**

Example Response

$F_{\text{net}} = F_g - F_{\text{drag}}$

For a correct differential equation that is in terms of the given variables — **1 point**

Scoring Note: Variables do not have to be separated for this point to be earned.

Example Response

$$m\frac{dv}{dt} = mg - bv^2$$

Example Solution

$$\Sigma F = ma$$
$$F_g - F_{\text{drag}} = ma_y$$
$$mg - bv^2 = ma_y$$
$$m\frac{dv}{dt} = mg - bv^2$$

Total for part (a) — 3 points

(b)(i) For a vertical line labeled t_1 at the approximate location at which the line becomes horizontal — **1 point**

Example Response

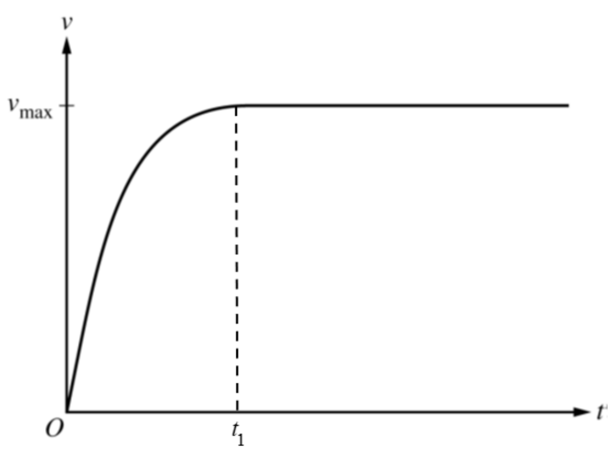


Figure 2

(b)(ii)	For relating t_1 to the time at which the velocity versus time graph is constant or the slope of the line is zero	**1 point**
	For indicating that a constant velocity indicates that the net force is zero	**1 point**

Example Response

Because the sketched line is horizontal after t_1, the velocity is constant. If the velocity is constant, then the acceleration is zero. Therefore, the net force is zero, which means that the gravitational and drag forces are equal in magnitude.

Total for part (b) 3 points

(c)	For selecting "Equal to" with an attempt at a relevant justification	**1 point**
	For a correct justification	**1 point**

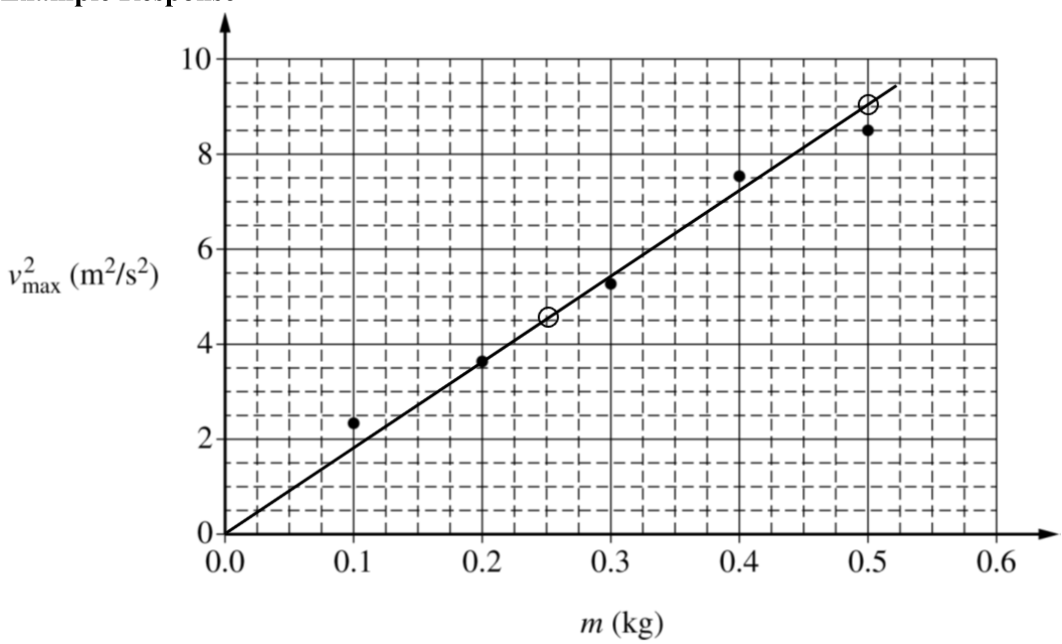
Example Response

At its peak, the cylinder will have a speed of $0\ \text{m/s}$. *Therefore, the cylinder would reach the same v_{max} as if the student had dropped the cylinder from rest at that height. Because the cylinder reached v_{max} from the initial drop, the two max speeds are equal.*

Total for part (c) 2 points

(d)(i)	For drawing an appropriate line of best fit that approximates the data	**1 point**

Example Response



(d)(ii) For calculating a value for the slope of the line using two points on the best-fit line **1 point**

Scoring Note: Using data points that fall on the best-fit line is acceptable.

Example Response

$$\text{slope} = \frac{9\ \text{m}^2/\text{s}^2 - 4.5\ \text{m}^2/\text{s}^2}{0.5\,\text{kg} - 0.25\,\text{kg}}$$

For using the correct relationship between the slope of the best-fit line and the value of b **1 point**

Example Response

$$\text{slope} = \frac{g}{b}$$

For a calculated value of b that is $0.45\ \text{kg/m} \le b \le 0.75\ \text{kg/m}$ **1 point**

Example Response

$b = 0.544\ \text{kg/m}$

Example Solution

$$mg - bv^2 = 0$$
$$bv^2 = mg$$
$$\frac{v^2}{m} = \frac{g}{b}$$
$$\text{slope} = \frac{g}{b}$$
$$b = \frac{g}{\text{slope}}$$
$$b = \frac{9.8\ \text{m/s}^2}{\dfrac{9\ \text{m}^2/\text{s}^2 - 4.5\ \text{m}^2/\text{s}^2}{0.5\ \text{kg} - 0.25\ \text{kg}}}$$

$$b = 0.544\ \text{kg/m}$$

Total for part (d) 4 points

(e)(i)	For indicating that the length of the cylinder should be graphed	**1 point**
	For indicating that the maximum velocity of the cylinder should be graphed	**1 point**
(e)(ii)	For describing how the quantities graphed are related to the conclusions of the experiment	**1 point**

Example Response

The slope of the length vs. maximum velocity graph can be used to determine if length affects terminal velocity.

Total for part (e) 3 points

Total for question 2 15 points

Question 3: Free-Response Question — 15 points

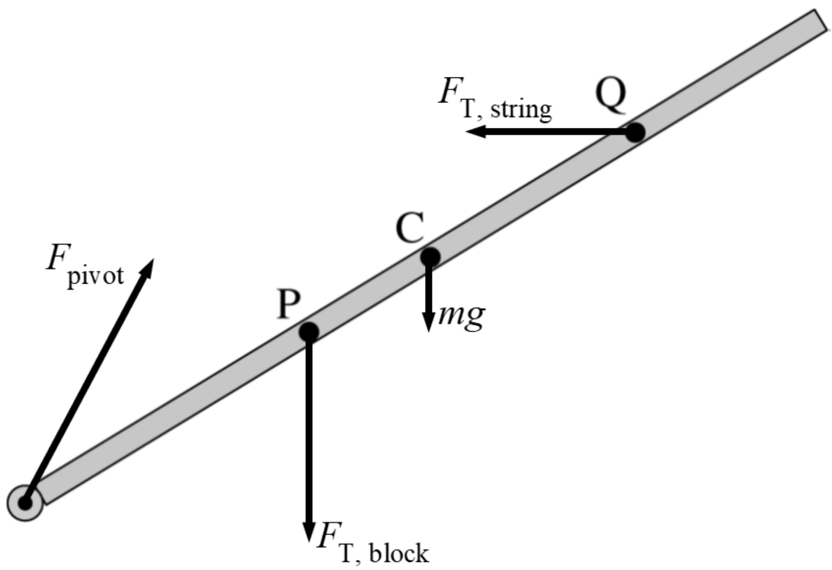
(a) For drawing and appropriately labeling the downward forces that are exerted on the rod at points P and C — **1 point**

Scoring Note: Labeling the downward force of tension as F_{block}, $3mg$, or similar, may earn this point.

For drawing and appropriately labeling a leftward force that is exerted on the rod at Point Q — **1 point**

For drawing and appropriately labeling a force that is directed up and to the right that is exerted on the rod at the pivot, and no extraneous forces are present — **1 point**

Example Response



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," $F_{\text{Earth on block}}$, $F_{\text{E,Block}}$. The labels G and g are not appropriate labels for the force due to gravity.

Scoring Note: Examples of appropriate labels for the force from the pivot include: F_p, F_{pivot}, F_n, F_N, N, "normal force," "pivot force."

Scoring Note: Examples of appropriate labels for the tension force include F_t, F_T, T, F_{string}, and "Force from string."

Total for part (a) — 3 points

(b)	For indicating that the net torque exerted on the rod is equal to zero	**1 point**

Example Response

$\Sigma\tau = 0$

For a correct expression for the torque exerted on the rod by the hanging mass **1 point**

Example Response

$3mg\sin\theta\left(\frac{3L}{8}\right)$

For a correct expression for the torque exerted on the rod by the gravitational force **1 point**

Example Response

$mg\sin\theta\left(\frac{4L}{8}\right)$

For a correct expression for the torque exerted on the rod by the string **1 point**

Example Responses

$F_T\sin(90° - \theta)\left(\frac{6L}{8}\right)$ **OR** $F_T\cos\theta\left(\frac{6L}{8}\right)$

Example Solution

$\Sigma\tau = 0$

$$3mg\sin\theta\left(\frac{3L}{8}\right) + mg\sin\theta\left(\frac{4L}{8}\right) - F_T\sin(90° - \theta)\left(\frac{6L}{8}\right) = 0$$

$$3mg\sin\theta\left(\frac{3L}{8}\right) + mg\sin\theta\left(\frac{4L}{8}\right) - F_T\cos\theta\left(\frac{6L}{8}\right) = 0$$

$$\left(\frac{9}{8}\right)mg\sin\theta + \left(\frac{4}{8}\right)mg\sin\theta = \left(\frac{6}{8}\right)F_T\cos\theta$$

$$13mg\sin\theta = 6F_T\cos\theta$$

$$F_T = \frac{13}{6}mg\tan\theta$$

Scoring Note: A maximum of three points may be earned if the trigonometric functions ($\sin$ and $\cos$) are reversed for all three torque terms.

Total for part (b) 4 points

(c)	For indicating that the torque exerted on the rod by the string is always the same	**1 point**
	For stating that as the angle between the string and the rod increases, the force exerted on the rod by the string decreases	**1 point**

Example Response

Because the torque exerted on the rod by the string is always the same, as the angle between the string and the rod increases, the tension $F_{T,\text{new}}$ *must decrease.*

Total for part (c) 2 points

(d)(i)	For indicating the total mass is the sum of differentiable masses along the length of the rod	**1 point**

Example Response

$$M = \int dm$$

For correctly writing dm in terms of x **1 point**

Example Response

$$M = \int_0^{1.2} (6 + 10x)\, dx$$

For a correct numeric answer with correct units **1 point**

Example Response

$M = 14.4$ kg

Example Solution

$$M = \int dm$$

$$M = \int \lambda \, dx$$

$$M = \int_0^{1.2} (6 + 10x)\, dx$$

$$M = \left(6x + \frac{10x^2}{2}\right)\Bigg|_0^{1.2\text{ m}}$$

$$M = 6\text{ kg/m}(1.2\text{ m}) + \frac{10\text{ kg/m}^2 (1.2\text{ m})^2}{2}$$

$$M = 14.4\text{ kg}$$

(d)(ii) For a correct substitution of λ into an integral expression of rotational inertia **1 point**

Example Response

$$I = \int_0^{1.2\text{ m}} (A + Bx)x^2 dx$$

For a correct integration **1 point**

Example Response

$$I = \left(\frac{Ax^3}{3} + \frac{Bx^4}{4}\right)\Bigg|_0^{1.2\text{ m}}$$

For a correct numeric answer with correct units **1 point**

Example Response

$$I = 8.64\text{ kg}\cdot\text{m}^2$$

Example Solution

$$I = \int r^2 dm \qquad dm = \lambda dr \text{ and } r = x$$

$$I = \int_0^{1.2\text{ m}} \lambda x^2 dx$$

$$I = \int_0^{1.2\text{ m}} (A + Bx)x^2 dx$$

$$I = \left(\frac{Ax^3}{3} + \frac{Bx^4}{4}\right)\Bigg|_0^{1.2\text{ m}}$$

$$I = \frac{(6.0\text{ kg/m})(1.2\text{ m})^3}{3} + \frac{\left(10.0\text{ kg/m}^2\right)(1.2\text{ m})^4}{4}$$

$$I = 8.64\text{ kg}\cdot\text{m}^2$$

Total for part (d) 6 points

Total for question 3 15 points