2024

AP® Physics C: Mechanics

Sample Student Responses and Scoring Commentary Set 2

Inside:

Free-Response Question 1

- ☑ Scoring Guidelines
- ☑ Student Samples
- ☑ Scoring Commentary

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

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

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

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

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

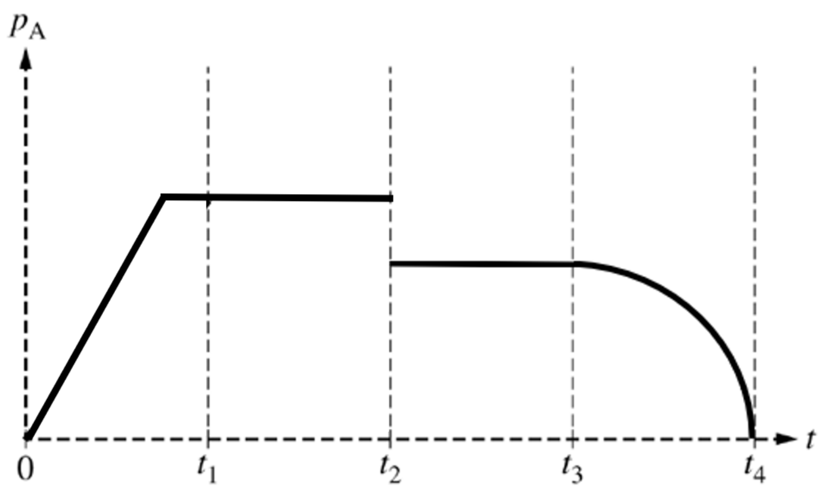
$$k = \frac{(3m)}{x_c^{\,2}}\left(\frac{2}{3}\sqrt{2gD(\sin\theta - \mu\cos\theta)}\right)^2$$

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

Total for part (a) 6 points

(b)(i)	For a sketch that increases linearly during the time interval $0 \le t < t_1$ **Scoring Note:** A sketch that only increases linearly from $t = 0$ to $t = t_1$ earns this point.	**1 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 **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.	**1 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: • 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.	**1 point**
	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 1

Begin your response to **QUESTION 1** on this page.

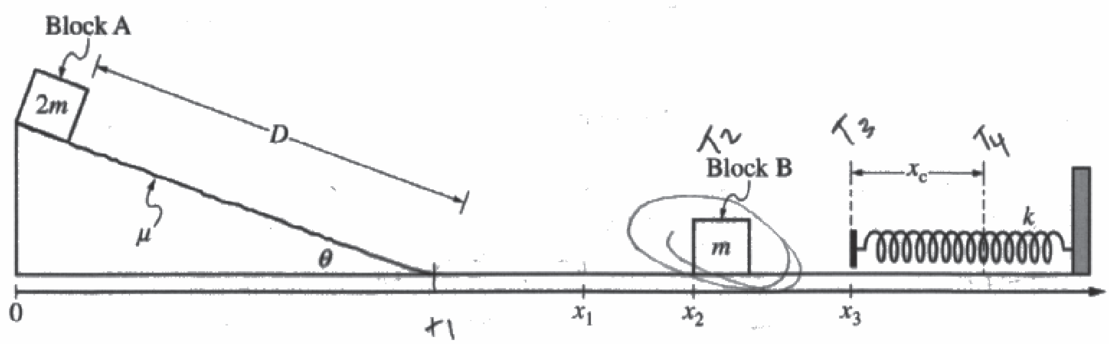
PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



Note: Figure not drawn to scale.

1. Blocks A and B of masses $2m$ and m, respectively, are arranged in a setup consisting of a ramp that makes an angle θ with a smooth horizontal table and an ideal spring of spring constant k fixed to a wall, as shown. Block A is held at rest a distance D up the ramp, and Block B is at rest on the horizontal table. The coefficient of kinetic friction between Block A and the rough ramp is μ in the region of length D, and there is negligible friction between the blocks and the smooth table.

Question 1

Continue your response to QUESTION 1 on this page.

At time $t = 0$, Block A is located at horizontal position $x = 0$ and is released from rest. After the block is released, the following occurs.

- At time $t = t_1$, Block A has traveled a distance D down the ramp, has transitioned to the table, and is moving with speed v at $x = x_1$.
- At time $t = t_2$, Block A is at $x = x_2$ when it collides with and sticks to Block B.
- At time $t = t_3$, the combined blocks A and B are at $x = x_3$ when they collide with and stick to the spring in its equilibrium position.
- At time $t = t_4$, the combined blocks A and B are instantaneously at rest and the spring is compressed a distance x_c from its equilibrium position.

(a) For parts (a)(i) and (a)(ii), express your answer in terms of m, θ, D, μ, x_c, and physical constants, as appropriate.

i. **Derive** an expression for the speed v of Block A at time t_1.

height = $D\sin\theta$

$\Sigma TE_i + W_{ext} = \Sigma TE_f$

$mgh + W_{F_f} = \frac{1}{2}mv^2$

$2mg(D\sin\theta) + |\mu 2mg\cos\theta||D|\cos 180° = \frac{1}{2}2mv^2$

$2gD\sin\theta - 2\mu gD\cos\theta = v^2$

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

$F_f = \mu F_N$

$\Sigma F_y = 0$

$F_g\cos\theta - F_N = 0$

$F_N = 2mg\cos\theta$

$F_f = \mu 2mg\cos\theta$

ii. **Derive** an expression for the spring constant k of the spring.

$\Sigma P_i = \Sigma P_f$

$2mv_A + mv_B = 3mv_f$

$2m\sqrt{2gD(\sin\theta - \mu\cos\theta)} + 0 = 3mv_f$

$v_f = \frac{2}{3}\sqrt{2gD(\sin\theta - \mu\cos\theta)}$

$\Sigma TE_i = \Sigma TE_f$

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

$(3m)\left(\frac{4(2gD(\sin\theta - \mu\cos\theta))}{9}\right) = kx_c^2$

$\frac{m4\ 8gD(\sin\theta - \mu\cos\theta)}{3} = k$

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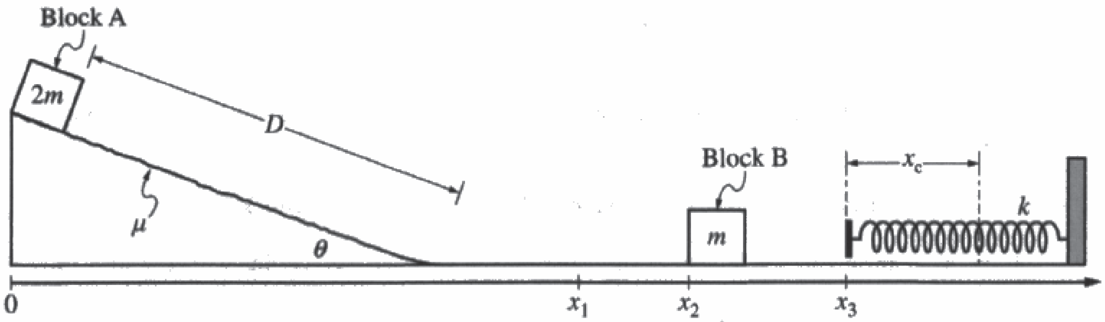
Question 1

Continue your response to **QUESTION 1** on this page.



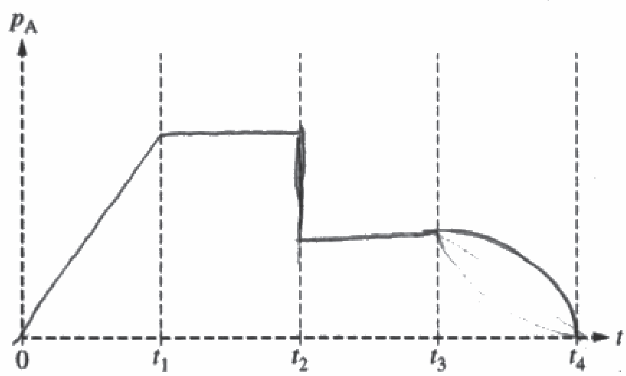
Note: Figure not drawn to scale.

(b)

i. On the following axes, **sketch** a graph of the magnitude of the momentum p_A of Block A as a function of time t from $t = 0$ to t_4.

$\frac{1}{2}mv^2 = \frac{1}{2}k(0.1)^2$

$12.5 = \frac{1}{2}kx^2$



ii. Use principles of forces to **justify** the graph drawn in part (b)(i) for the time interval $t = t_3$ to $t = t_4$. Explicitly reference features of the shape of the graph you drew in part (b)(i).

The force of the spring is not constant, thus acceleration changes with the distance covered. Therefore, the velo city is not decreasing at a constant rate As distance increases, the force of the spring increases greater, and thus the negative acceleration gets more negative.. as time /distance increase, the rate of velocity decreasing increases

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Question 1

Continue your response to **QUESTION 1** on this page.

For times $t > t_4$, the two-block-spring system oscillates with period T_O. The procedure is then repeated using a new ramp, where there is negligible friction between Block A and the ramp.

(c) **Indicate** how the new period of oscillation T_N in the procedure that uses the new ramp compares with the period of oscillation T_O from the original procedure.

____ $T_N > T_O$ ____ $T_N < T_O$ __✓__ $T_N = T_O$

Briefly **justify** your answer.

negligible friction between Block A and ramp will lead to a larger velocity at t_3, which means x_c will be larger. This means that amplitude will be larger. However, amplitude does not change period, only changes in mass or spring constant affect period

[redacted]

Question 1

Begin your response to **QUESTION 1** on this page.

PHYSICS C: MECHANICS

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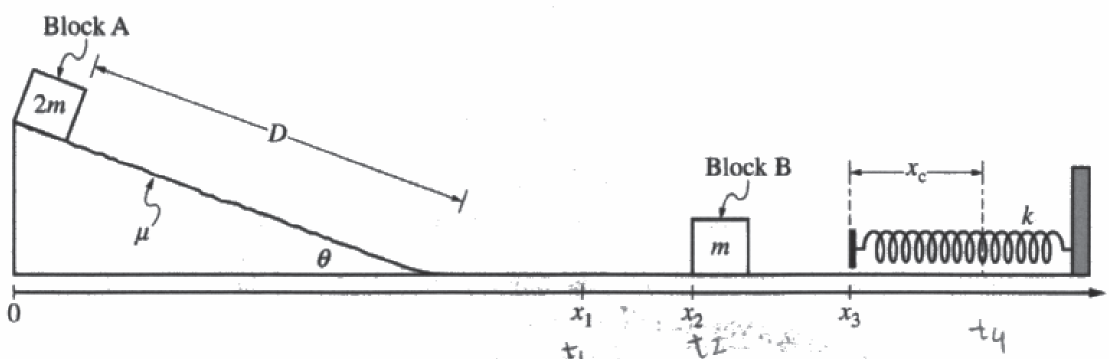

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- At time $t = t_4$, the combined blocks A and B are instantaneously at rest and the spring is compressed a distance x_c from its equilibrium position.

(a) For parts (a)(i) and (a)(ii), express your answer in terms of m, θ, D, μ, x_c, and physical constants, as appropriate.

i. **Derive** an expression for the speed v of Block A at time t_1.

~~$ME_i = ME_f$ conservation of energy~~

$W = \Delta E \Rightarrow W_{fr} = F_{fr} \cdot D = F_N \mu \cdot D = \mu 2mg\sin\theta$

$h =$

$\sin\theta = \frac{h}{D}$

$mgh - W_{fr} = \frac{1}{2}mv^2$

$2mgD\sin\theta - 2mg\mu\sin\theta = \frac{1}{2}(2m)v^2$

$2gD\sin\theta - 2\mu\sin\theta = v^2$

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

ii. **Derive** an expression for the spring constant k of the spring.

Conservation of p.

Find V_f:

$(2m)(v) + m(0) = 3m(V_f)$

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

$ME_i = ME_f$

$KE = U_s$

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

$\frac{1}{2}(3m)v_f^2 = \frac{1}{2}kx_c^2$

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

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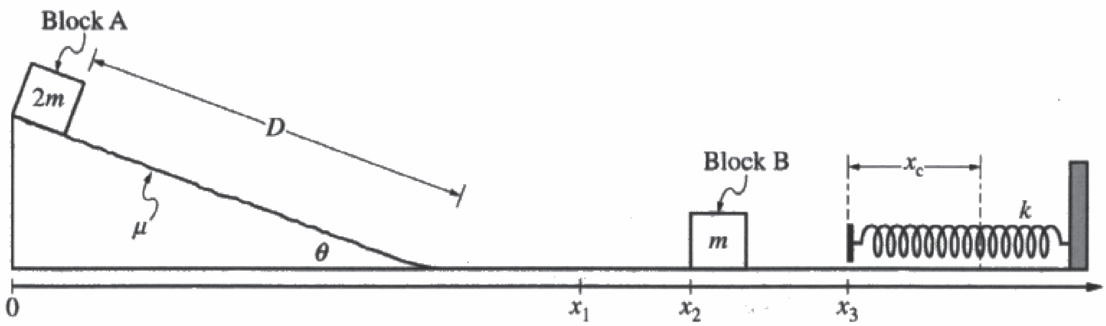
Question 1

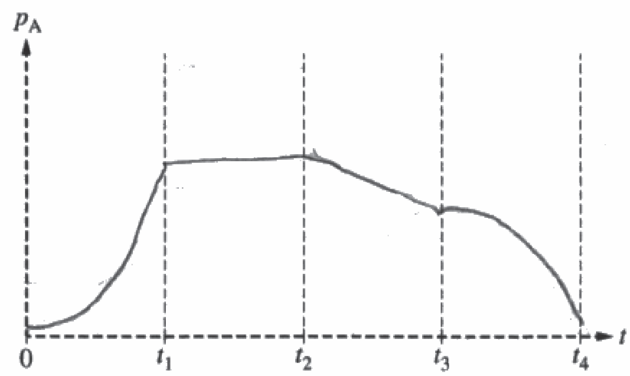
Continue your response to **QUESTION 1** on this page.



Note: Figure not drawn to scale.

* (b) $p = F \cdot t$

i. On the following axes, **sketch** a graph of the magnitude of the momentum p_A of Block A as a function of time t from $t = 0$ to t_4.



ii. Use principles of forces to **justify** the graph drawn in part (b)(i) for the time interval $t = t_3$ to $t = t_4$. Explicitly reference features of the shape of the graph you drew in part (b)(i).

From t_3 to t_4 the spring is compressed a distance x_c, meaning that the force acting on Block A and Block B is $F_s = kx_c$. This force opposes the direction of motion of the blocks so the graph depicts a gradual decrease in momentum as F_s decreases

Question 1

Continue your response to **QUESTION 1** on this page.

For times $t > t_4$, the two-block-spring system oscillates with period T_O. The procedure is then repeated using a new ramp, where there is negligible friction between Block A and the ramp.

(c) **Indicate** how the new period of oscillation T_N in the procedure that uses the new ramp compares with the period of oscillation T_O from the original procedure.

$T = 2\pi\sqrt{\frac{m}{k}}$

____ $T_N > T_O$ ____ $T_N < T_O$ __✓__ $T_N = T_O$

Briefly **justify** your answer.

The new period of oscillation T_N is equal to T_O because the period of a spring-pendulum is equal to $T_s = 2\pi\sqrt{\frac{m}{k}}$. The velocity of the system will increase due to negligible fiction sine there is no opposition to the block-system's motion. But since T_s is not dependent on velocity or compression distance (only mass m and k), T_N will be the same as To.

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Question 1

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PHYSICS C: MECHANICS

SECTION II

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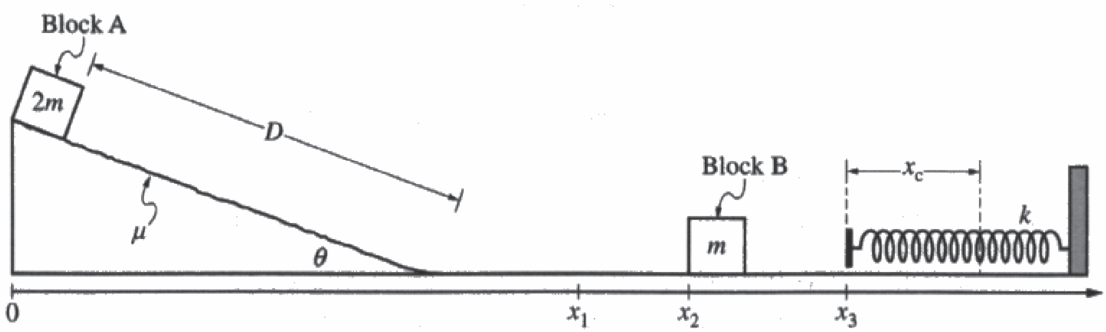

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Question 1

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At time $t = 0$, Block A is located at horizontal position $x = 0$ and is released from rest. After the block is released, the following occurs.

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- At time $t = t_3$, the combined blocks A and B are at $x = x_3$ when they collide with and stick to the spring in its equilibrium position.
- At time $t = t_4$, the combined blocks A and B are instantaneously at rest and the spring is compressed a distance x_c from its equilibrium position.

(a) For parts (a)(i) and (a)(ii), express your answer in terms of m, θ, D, μ, x_c, and physical constants, as appropriate.

i. **Derive** an expression for the speed v of Block A at time t_1.

$E_0 = E_f$

$GPE = KE$

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

$v = \sqrt{2gh}$

$v = \sqrt{-2\frac{a}{\mu}h}$

$F = ma$

$-F_f = ma$

$-\mu mg = ma$

$-\mu g = a$

$g = \frac{a}{-\mu}$

$v^2 = v_0^2 + 2a\Delta x$

@ t = 1

ii. **Derive** an expression for the spring constant k of the spring.

$F = ma$

$F_k = ma$

$kx = ma$

$kx = 3ma$

$k = \frac{3ma}{x}$

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Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

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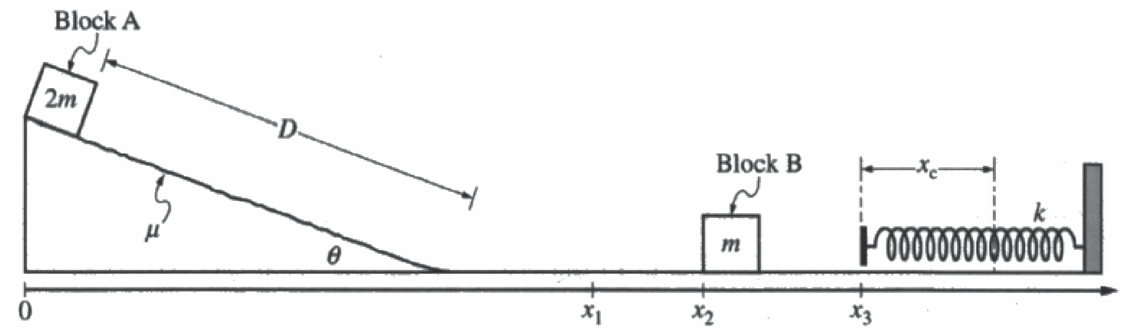
Question 1

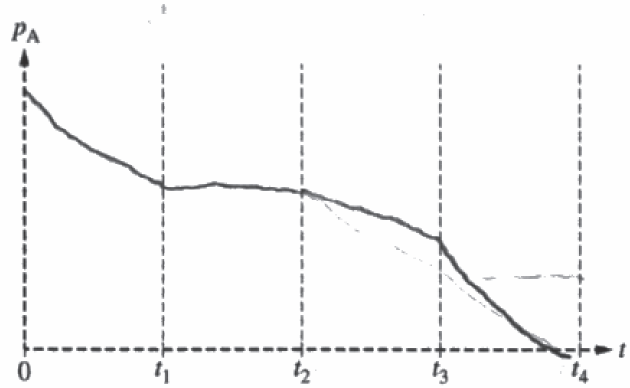
Continue your response to QUESTION 1 on this page.



Note: Figure not drawn to scale.

(b)

i. On the following axes, **sketch** a graph of the magnitude of the momentum p_A of Block A as a function of time t from $t = 0$ to t_4.



ii. Use principles of forces to **justify** the graph drawn in part (b)(i) for the time interval $t = t_3$ to $t = t_4$. Explicitly reference features of the shape of the graph you drew in part (b)(i).

k compresses and ~~mass~~/velocity decrease until zero

Question 1

Continue your response to **QUESTION 1** on this page.

For times $t > t_4$, the two-block-spring system oscillates with period T_O. The procedure is then repeated using a new ramp, where there is negligible friction between Block A and the ramp.

(c) **Indicate** how the new period of oscillation T_N in the procedure that uses the new ramp compares with the period of oscillation T_O from the original procedure.

X $T_N > T_O$ ____ $T_N < T_O$ ____ $T_N = T_O$

Briefly **justify** your answer.

greater initial velocity with a
smooth ramp will increase
the period of oscillation
less loss of energy
since there is
no friction on
the ramp

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Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

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Q5270/5

Question 1

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses were expected to demonstrate the ability to:

- Derive an expression using conservation of energy, including energy dissipated by friction.
- Apply conservation of momentum during a collision.
- Analyze and interpret a graphical representation of momentum as a function of time.
- Identify patterns on a momentum-time graph using force principles.
- Identify factors that affect the period of an oscillating spring system.

Sample: 1A
Score: 15

Part (a) earned 6 points. The first point was earned for correctly applying conservation of energy in a multi-step derivation and including U_g as the initial mechanical energy. The second point was earned for including energy dissipated by friction and using the correct sign. The third point was earned for correctly showing the expression for v. The fourth point was earned for using conservation of momentum to find $v_{\text{A,B}}$ written as v_f. The fifth point was earned for equating the kinetic energy after the collision to the maximum elastic potential energy of the compressed spring. The sixth point was earned for indicating that v before the collision between the blocks and the spring is equal to $v_{\text{A,B}}$. Part (b) earned 7 points. The first point was earned for showing a sketch that increases linearly during the time interval $0 \leq t \leq t_1$. The second point was earned for showing a horizontal line for the time interval $t_1 \leq t \leq t_2$ that is continuous at t_1. The third point was earned for showing a horizontal line for the time interval $t_2 \leq t \leq t_3$ that has a smaller magnitude than the previous time interval. The fourth point was earned for showing a concave down curve, continuous at t_3, in the interval $t_3 \leq t \leq t_4$ that reaches zero at t_4. The fifth point was earned for writing a statement about the change in momentum consistent with the graph drawn in part (b)(i). The sixth point was earned for indicating the force exerted on Block A is in a direction opposite to the motion of Block A. "The force of the spring increases greater, and thus the negative acceleration gets more negative." The seventh point was earned for relating the change in momentum (velocity) to the magnitude of the force exerted on Block A. Part (c) earned 2 points. The first point was earned for selecting "$T_{\text{N}} = T_{\text{O}}$" with a relevant justification. The second point was earned for correctly stating that "only changes in mass and spring constant affect period."

Question 1 (continued)

Sample: 1B
Score: 11

Part (a) earned 5 points. The first point was earned for correctly applying conservation of energy in a multi-step derivation and including U_g as the initial mechanical energy. The second point was earned for including the energy dissipated by friction and using the correct sign. The third point was not earned because the response does not correctly solve the expression for v. The fourth point was earned for using conservation of momentum to find $v_{A,B}$ written as v_f. The fifth point was earned for equating the kinetic energy after the collision to the maximum elastic potential energy of the compressed spring. The sixth point was earned for indicating that v before the collision between the blocks and the spring is equal to $v_{A,B}$. Part (b) earned 4 points. The first point was not earned because the response shows a sketch of a concave up curve during the time interval $0 \le t \le t_1$. The second point was earned for showing a horizontal line for the time interval $t_1 \le t \le t_2$ that is continuous at t_1. The third point was not earned because the response shows a linearly decreasing line for the time interval $t_2 \le t \le t_3$. The fourth point was earned for showing a concave down curve, continuous at t_3, in the interval $t_3 \le t \le t_4$ that reaches zero at t_4. The fifth point was earned for writing a statement about the change in momentum consistent with the graph drawn in part (b)(i). The sixth point was earned for indicating the force exerted on Block A is in a direction opposite to the motion of Block A. The seventh point was not earned because the response does not relate the change in momentum to the magnitude of the force exerted on Block A. Part (c) earned 2 points. The first point was earned for selecting "$T_N = T_O$" with a relevant justification. The second point was earned for showing a correct justification by stating that velocity increases but is independent of the period.

Question 1 (continued)

Sample: 1C
Score: 3

Part (a) earned 1 point for correctly applying conservation of energy in a multi-step derivation and including U_g as the initial mechanical energy. The second point was not earned because the response does not include the energy dissipated by friction but rather the friction force with the correct sign. The third point was not earned because the response does not correctly solve the expression for v. The fourth point was not earned because the response does not use conservation of momentum to find $v_{A,B}$. The fifth point was not earned because the response does not equate the kinetic energy after the collision to the maximum elastic potential energy of the compressed spring. The sixth point was not earned because the response does not use the correct v from after the collision. Part (b) earned 2 points. The first point was not earned because the response shows a sketch of a linearly decreasing line during the time interval $0 \le t \le t_1$. The second point was earned for showing a sketch of a horizontal line during the time interval $t_1 \le t \le t_2$. The third point was not earned because the response shows a sketch of a linearly decreasing line during the time interval $t_2 \le t \le t_3$. The fourth point was not earned because the response shows a linearly decreasing line, continuous at t_3, in the interval $t_3 \le t \le t_4$ that reaches zero at t_4. The fifth point was earned for writing a statement about the change in momentum (velocity) consistent with the graph drawn in part (b)(i). The sixth point was not earned because the response does not indicate the force exerted on Block A is in a direction opposite to the motion of Block A. The seventh point was not earned because the response does not relate the change in momentum to the magnitude of the force exerted on Block A. Part (c) did not earn any points. The first point was not earned because "$T_N > T_O$" was selected. The second point was not earned because the response mentions that the new block has increased velocity but then states that this will increase the oscillation period.