2023

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 1

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

Question 1: Short Answer — 7 points

(a) For an explanation that indicates that the maximum kinetic energy and maximum potential energy are the same due to energy conservation — **1 point**

Scoring Note: This point may be earned for only stating "conservation of energy."

Example Response

The maximum kinetic energy and maximum potential energy of the car-spring system are both 4 J, because energy is conserved in this system.

Total for part (a) 1 point

(b) For using the equation for frequency or period in a ratio — **1 point**

Example Responses

$$\frac{\frac{1}{2\pi}\sqrt{\frac{k}{m_2}}}{\frac{1}{2\pi}\sqrt{\frac{k}{m_1}}} \quad \textit{OR} \quad \frac{\frac{1}{2\pi}\sqrt{\frac{k}{m_1}}}{\frac{1}{2\pi}\sqrt{\frac{k}{m_2}}} \quad \textit{OR} \quad \frac{2\pi\sqrt{\frac{m_2}{k}}}{2\pi\sqrt{\frac{m_1}{k}}} \quad \textit{OR} \quad \frac{2\pi\sqrt{\frac{m_1}{k}}}{2\pi\sqrt{\frac{m_2}{k}}}$$

Scoring Note: Simplified versions of the above ratios also earn this point.

For substituting the total mass $4m_0$ into the correct ratio: $\frac{f_2}{f_1}$ or $\frac{T_1}{T_2}$ — **1 point**

Example Response

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

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$\frac{f_2}{f_1} = \frac{\frac{1}{2\pi}\sqrt{\frac{k}{4m_0}}}{\frac{1}{2\pi}\sqrt{\frac{k}{m_0}}}$$

$$\frac{f_2}{f_1} = \frac{1}{2}$$

Total for part (b) 2 points

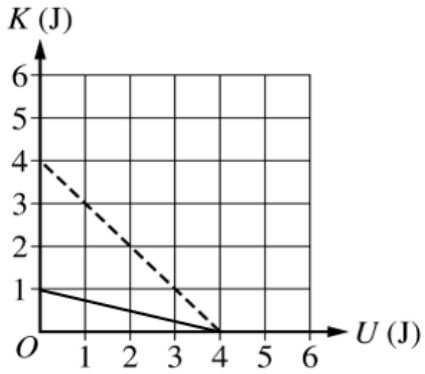
(c)(i)	For a valid explanation in terms of work or energy for why the systems' energies should be the same Accept **one** of the following: • No work is done on the system • The maximum spring potential energy is the same • The force exerted on the system is perpendicular to the direction of motion	**1 point**

Example Response

The maximum potential energy of the system does not depend upon the mass of the system, therefore there will be no change when the block is added.

(c)(ii)	For drawing a single straight line with a horizontal intercept that is the same as the horizontal intercept of the original graph of 4 J	**1 point**
	For drawing a line with a vertical intercept that is less than the vertical intercept in the original graph	**1 point**
	For drawing a line with the correct vertical intercept of 1 J	**1 point**

Example Response



Total for part (c)	**4 points**
Total for question 1	**7 points**

Question 1

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

PHYSICS 1

SECTION II

Time—1 hour and 30 minutes

5 Questions

Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

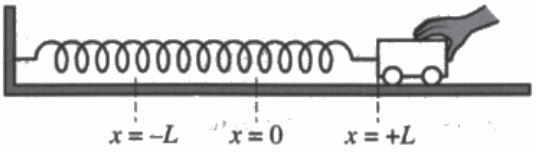


Figure 1

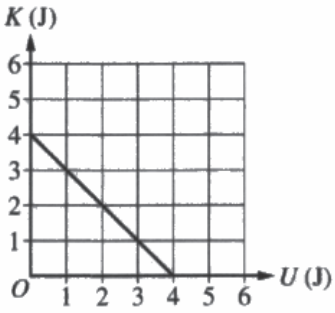


Figure 2

1. (7 points, suggested time 13 minutes)

A cart on a horizontal surface is attached to a spring. The other end of the spring is attached to a wall. The cart is initially held at rest, as shown in Figure 1. When the cart is released, the system consisting of the cart and spring oscillates between the positions $x = +L$ and $x = -L$. Figure 2 shows the kinetic energy of the cart-spring system as a function of the system's potential energy. Frictional forces are negligible.

(a) On the graph of kinetic energy K versus potential energy U shown in Figure 2, the values for the x-intercept and y-intercept are the same. Briefly explain why this is true, using physics principles.

The two values are the same since the system demonstrates the conservation of energy. When the cart has the most kinetic energy, U_s is at a minimum as $U_s = \frac{1}{2}kA^2$, and the peak of kinetic energy occurs when $x=0$. The same is true for kinetic energy in that it is at its minimum when potential energy is at its max.

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Question 1

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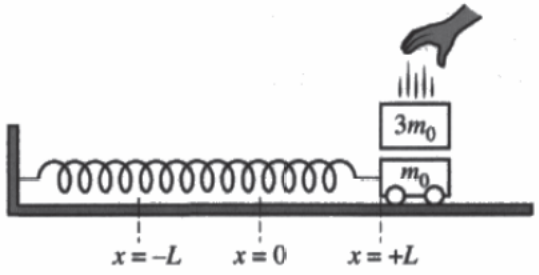

Figure 3

When the cart is at $+L$ and momentarily at rest, a block is dropped onto the cart, as shown in Figure 3. The block sticks to the cart, and the block-cart-spring system continues to oscillate between $-L$ and $+L$. The masses of the cart and the block are m_0 and $3m_0$, respectively.

(b) The frequency of oscillation before the block is dropped onto the cart is f_1. The frequency of oscillation after the block is dropped onto the cart is f_2. Calculate the numerical value of the ratio $\frac{f_2}{f_1}$.

$T_s = 2\pi\sqrt{\frac{m}{k}}$ $\quad f_s = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

$f_1 = \frac{1}{2\pi}\sqrt{\frac{k}{m_0}}$

$f_2 = \frac{1}{2\pi}\sqrt{\frac{k}{3m_0+m_0}} = \frac{1}{2\pi}\sqrt{\frac{k}{4m_0}}$

$= \frac{1}{2\pi}\sqrt{\frac{1}{4}\cdot\frac{k}{m_0}}$

$= \frac{1}{4\pi}\sqrt{\frac{k}{m_0}}$

$\frac{f_2}{f_1} = \frac{\frac{1}{4\pi}\sqrt{\frac{k}{m_0}}}{\frac{1}{2\pi}\sqrt{\frac{k}{m_0}}} = \frac{2}{4} = \boxed{\frac{1}{2} = \frac{f_2}{f_1}}$

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Question 1

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

(c) The dashed line in Figure 4 shows the kinetic energy K versus potential energy U of the block-cart-spring system after the block is dropped onto the cart. This graph is identical to the graph shown in Figure 2 for the cart-spring system before the block is dropped onto the cart.

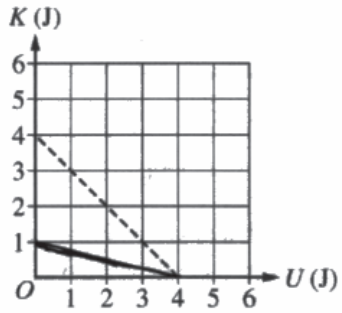

Figure 4

i. Briefly explain why the two graphs must be the same, using physics principles.

The two graphs must be the same since $U_S = \frac{1}{2}kx^2$. When the block is dropped on the cart, the spring is still stretched the same distance, so the potential and kinetic energy remain the same.

ii. After the block is dropped onto the cart, consider a system that consists only of the cart and the spring. On Figure 4, sketch a solid line that shows the kinetic energy of the system that consists of the cart and the spring but not the block after the block is dropped onto the cart.

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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.

Question 1

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

PHYSICS 1

SECTION II

Time—1 hour and 30 minutes

5 Questions

Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

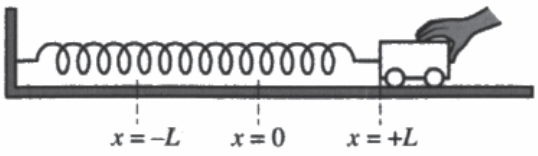

Figure 1

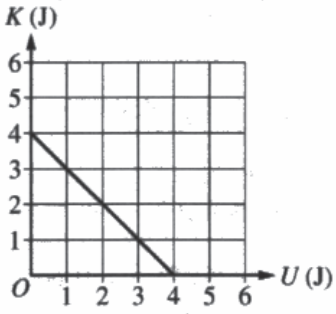

Figure 2

1. (7 points, suggested time 13 minutes)

A cart on a horizontal surface is attached to a spring. The other end of the spring is attached to a wall. The cart is initially held at rest, as shown in Figure 1. When the cart is released, the system consisting of the cart and spring oscillates between the positions $x = +L$ and $x = -L$. Figure 2 shows the kinetic energy of the cart-spring system as a function of the system's potential energy. Frictional forces are negligible.

(a) On the graph of kinetic energy K versus potential energy U shown in Figure 2, the values for the x-intercept and y-intercept are the same. Briefly explain why this is true, using physics principles.

Conservation of Energy means that the total energy of a closed system will remain constant.
$K_{max} = U_{max}$

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Question 1

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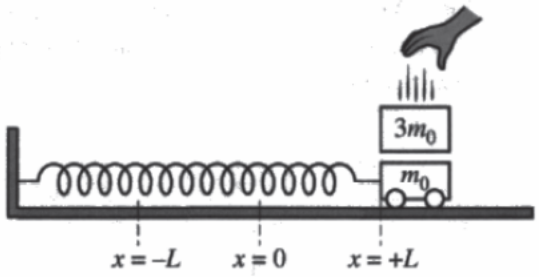

Figure 3

When the cart is at $+L$ and momentarily at rest, a block is dropped onto the cart, as shown in Figure 3. The block sticks to the cart, and the block-cart-spring system continues to oscillate between $-L$ and $+L$. The masses of the cart and the block are m_0 and $3m_0$, respectively.

(b) The frequency of oscillation before the block is dropped onto the cart is f_1. The frequency of oscillation after the block is dropped onto the cart is f_2. Calculate the numerical value of the ratio $\frac{f_2}{f_1}$.

$T_s = 2\pi\sqrt{\frac{m}{k}} \qquad F = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

$f_1 = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

$f_2 = \frac{1}{2\pi}\sqrt{\frac{k}{4m}}$

$\frac{\frac{1}{2\pi}\sqrt{\frac{k}{4m}}}{\frac{1}{2\pi}\sqrt{\frac{k}{m}}}$

$\frac{f_2}{f_1} = \frac{\frac{1}{\sqrt{4}}f_1}{f_1}$

$\frac{f_2}{f_1} = \frac{1}{\sqrt{4}} = \frac{1}{2}$

Question 1

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

(c) The dashed line in Figure 4 shows the kinetic energy K versus potential energy U of the block-cart-spring system after the block is dropped onto the cart. This graph is identical to the graph shown in Figure 2 for the cart-spring system before the block is dropped onto the cart.

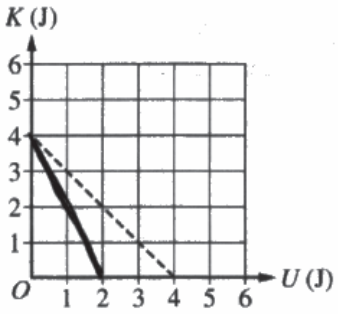

Figure 4

i. Briefly explain why the two graphs must be the same, using physics principles.

Since the block is part of the system, it is still a closed-system so energy is still conserved. No work is done.

ii. After the block is dropped onto the cart, consider a system that consists only of the cart and the spring. On Figure 4, sketch a solid line that shows the kinetic energy of the system that consists of the cart and the spring but not the block after the block is dropped onto the cart.

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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.

Question 1

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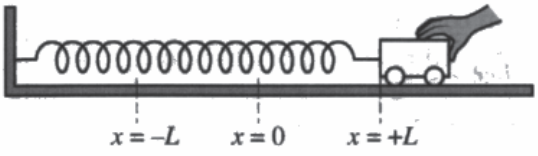

Figure 1

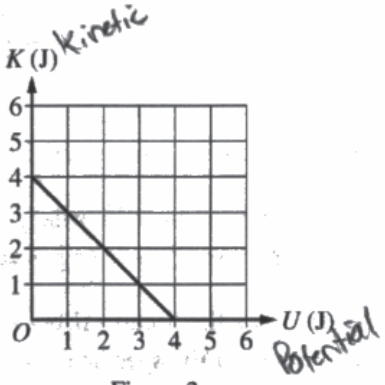

Figure 2

1. (7 points, suggested time 13 minutes)

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(a) On the graph of kinetic energy K versus potential energy U shown in Figure 2, the values for the x-intercept and y-intercept are the same. Briefly explain why this is true, using physics principles.

$E_{mechanical} = KE + U_g + kse$ $\quad E_{mech\,A} = E_{mech\,B}$

$E_{mech_A} = U_g$ (+L) $\quad E_{mech_B} = KE\left(\frac{1}{2}mv^2\right)$ (–L)

Since frictional forces are negligible, energy is conserved. The total mechanical energy is equal at all points, so the intercepts for kinetic and potential energy are equal.

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Question 1

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

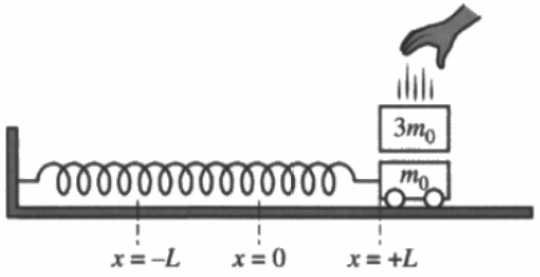

Figure 3

When the cart is at $+L$ and momentarily at rest, a block is dropped onto the cart, as shown in Figure 3. The block sticks to the cart, and the block-cart-spring system continues to oscillate between $-L$ and $+L$. The masses of the cart and the block are m_0 and $3m_0$, respectively.

(b) The frequency of oscillation before the block is dropped onto the cart is f_1. The frequency of oscillation after the block is dropped onto the cart is f_2. Calculate the numerical value of the ratio $\frac{f_2}{f_1}$.

f_1 f_2 $|\vec{F}_S| = k|\vec{x}|$

m_0 $4m_0$

$f_2 = \frac{1}{4} f_1$

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

Question 1

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

(c) The dashed line in Figure 4 shows the kinetic energy K versus potential energy U of the block-cart-spring system after the block is dropped onto the cart. This graph is identical to the graph shown in Figure 2 for the cart-spring system before the block is dropped onto the cart.

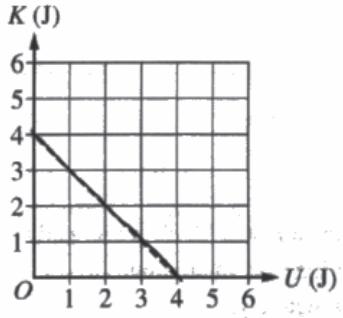

Figure 4

i. Briefly explain why the two graphs must be the same, using physics principles.

Since friction is negligible, there is no loss of energy when the block is dropped onto the spring. The total mechanical energy before the block is added = total mechanical energy after block is added.

ii. After the block is dropped onto the cart, consider a system that consists only of the cart and the spring. On Figure 4, sketch a solid line that shows the kinetic energy of the system that consists of the cart and the spring but not the block after the block is dropped onto the cart.

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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.

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:

- Recognize and apply the principle of conservation of energy.
- Identify the relationship between period and frequency for oscillatory motion.
- Manipulate fundamental equations to apply to a specific situation.
- Apply the relationship between work and energy in a defined system.
- Graphically represent the relationship between the kinetic and potential energy in a defined system.

Sample: 1A
Score: 7

Part (a) earned 1 point for explaining that the maximum kinetic energy and maximum potential energy are the same due to energy conservation. Part (b) earned 2 points. One point was earned for using the equation for frequency or period in a ratio. One point was earned for substituting the total mass $4m_0$ into the correct ratio: $\frac{f_2}{f_1}$ or $\frac{T_1}{T_2}$.
Part (c)(i) earned 1 point for explaining in terms of work or energy why the systems' energies should be the same. Part (c)(ii) earned 3 points. One point was earned for showing a straight line with a horizontal intercept that is the same as the horizontal intercept of the original graph of $4\ \text{J}$. One point was earned for showing a vertical intercept that is less than the vertical intercept in the original graph. One point was earned for a correct vertical intercept of $1\ \text{J}$.

Sample: 1B
Score: 4

Part (a) earned 1 point for an explanation that indicates that the maximum kinetic energy and maximum potential energy are the same due to energy conservation. Part (b) earned 2 points. One point was earned for using the equation for frequency or period in a ratio. One point was earned for substituting the total mass $4m_0$ into the correct ratio: $\frac{f_2}{f_1}$ or $\frac{T_1}{T_2}$. Part (c)(i) earned 1 point for explaining in terms of work or energy why the systems' energies should be the same. Part (c)(ii) earned no points because the response does not contain a straight line with a horizontal intercept that is the same as the horizontal intercept of the original graph, it does not contain a vertical intercept that is less than the vertical intercept in the original graph, and it does not contain a correct vertical intercept of $1\ \text{J}$.

Question 1 (continued)

Sample: 1C
Score: 2

Part (a) earned 1 point for explaining that the maximum kinetic energy and maximum potential energy are the same due to energy conservation. Part (b) earned no points because the equation for frequency or period was not used in a ratio. The response also does not substitute the total mass $4m_0$ into the correct ratio: $\frac{f_2}{f_1}$ or $\frac{T_1}{T_2}$. Part (c)(i) earned no points because the response does not explain in terms of work or energy why the systems' energies should be the same. The response states that no energy is lost because there is no friction. The response needs to address the fact that no work is done on the system. Part (c)(ii) earned 1 point for a straight line with a horizontal intercept that is the same as the horizontal intercept of the original graph of $4\ \text{J}$. The second and third points were not earned because the response does not contain a vertical intercept that is less than the vertical intercept in the original graph, and it does not contain a correct vertical intercept of $1\ \text{J}$.