2022

AP® | CollegeBoard

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 5

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

Question 5: Short Answer — 7 points

(a) For obtaining a period from the graph of 1.25 seconds — **1 point**

For substituting the values of period and mass into a valid equation for the spring constant — **1 point**

Example Response

$T = 1.25 \text{ s}$

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

$$k_0 = \frac{m}{\left(\frac{T}{2\pi}\right)^2} = \frac{0.50 \text{ kg}}{\left(\frac{1.25 \text{ s}}{2\pi}\right)^2} = 12.6 \text{ N/m}$$

Alternate Solution

For stating that the spring is stretched 0.40 m *to its equilibrium position (because the equilibrium height is* 60 cm *and the original height was* 100 cm*)* — 1 point

For substituting the amount of spring stretch and mass into a valid equation for the spring constant — 1 point

Alternate Example Response

The string is stretched 0.40 m *under a force of* $mg = 5 \text{ N}$. *Because* $F = -kx$, *we have*

$$k = \frac{mg}{x} = \frac{5}{0.4} \text{ N/m} = 12.5 \text{ N/m}$$

Total for part (a) 2 points

(b)(i) For a valid reason why the kinetic energy is the same at both times — **1 point**

Example Responses

The magnitude of the slope of the graph is the same at both times, this means the speed and, therefore, the kinetic energy is the same at both times.

OR

The object is the same distance from equilibrium at both times, so the kinetic energy must be the same.

(b)(ii) For a valid reason why the total potential energy is the same at both times — **1 point**

Example Responses

The total energy of the system is constant, so if K *is the same at both times,* U *must be also.*

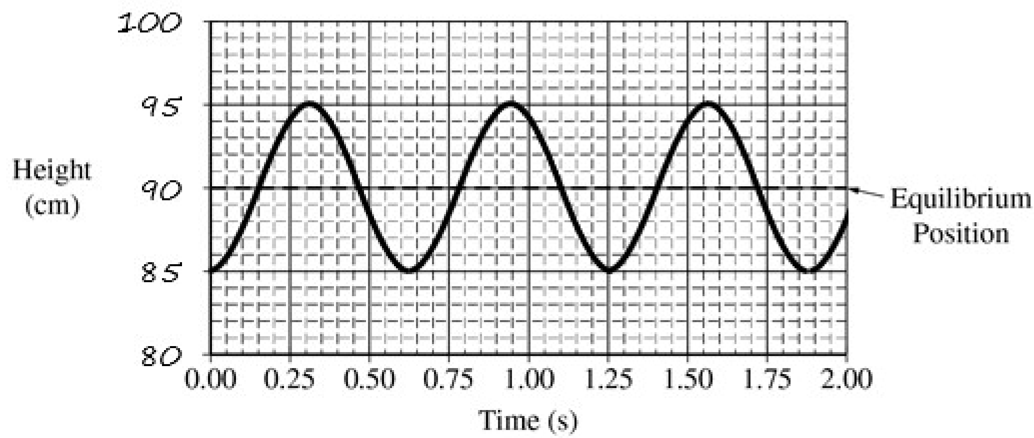
OR

The total energy of the system is constant, and equal energy is transferred from gravitational potential to spring potential.

Total for part (b) 2 points

(c)(i)	For writing 90 cm or 0.90 m	**1 point**
(c)(ii)	For **both** of the following: • a graph that has the same amplitude as the original graph • a graph that is centered on the new equilibrium value consistent with (c)(i)	**1 point**
	For a graph with half the period as the original graph	**1 point**

Example Response

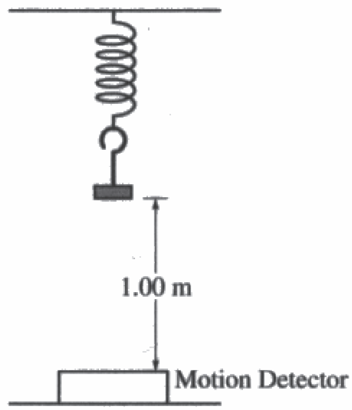


Total for part (c) 3 points

Total for question 5 7 points

Question 5

Begin your response to **QUESTION 5** on this page.



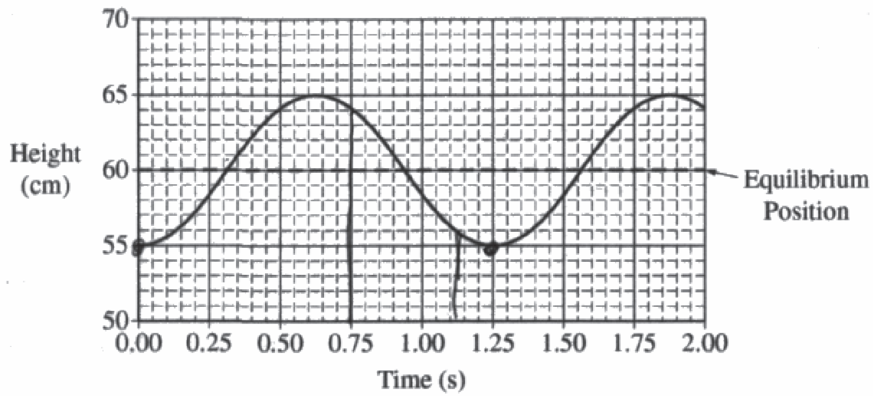
5. (7 points, suggested time 13 minutes)

A spring of unknown spring constant k_0 is attached to a ceiling. A lightweight hanger is attached to the lower end of the spring, and a motion detector is placed on the floor facing upward directly under the hanger, as shown in the figure above. The bottom of the hanger is 1.00 m above the motion detector.

A 0.50 kg object is placed on the hanger and allowed to come to rest at the equilibrium position. The spring is then stretched downward a distance d_0 from equilibrium and released at time $t = 0$. The motion detector records the height of the bottom of the hanger as a function of time. The output from the motion detector is shown in the graph on the following page.

Question 5

Continue your response to **QUESTION 5** on this page.



(a) Using the information given and information taken from the graph, calculate the spring constant.

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

Period = 1.25 (s)

$1.25\,s = 2\pi\sqrt{\frac{0.5\,kg}{K}}$ $K = 12.63\ kg \cdot s^{2}$

(b) At time 0.75 s, the object-spring-Earth system has a total kinetic energy K_0 and a total potential energy U_0. At 1.13 s, the object-spring-Earth system again has a total kinetic energy K_0 and a total potential energy U_0.

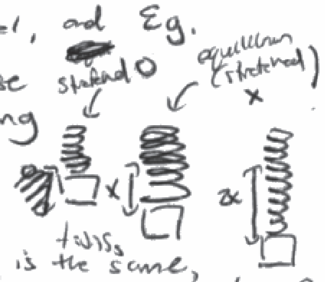
i. Explain how a feature of the graph indicates that the total kinetic energy of the system is the same at these two times.

The slopes of the graph at these two times are equal. This indicates that their vertical velocity (and speed) at that time is equal, making the kinetic energy of the system equal at both times.

ii. ~~Briefly~~ explain why the total potential energy of the system is the same at these two times.

2 potential energies at work → E_{el}, and E_g.

They add up to the same value at these times, as seen in the picture, at t = 1.13 the spring is stretched much more (more E_{el}), but has very little gravitational potential energy. At t = 0.75 s, there is significant gravitational potential energy but little elastic energy. Because kinetic energy is the same, and total E_{mech} is the same, these other 2 potential energies must add up to the same.



  GO ON TO THE NEXT PAGE.

Question 5

Continue your response to **QUESTION 5** on this page.

(c) The experiment is repeated with a spring of spring constant $4k_0$ and that has the same length as the original spring. The 0.50 kg object is hung from the new spring and allowed to come to rest at a new equilibrium position.

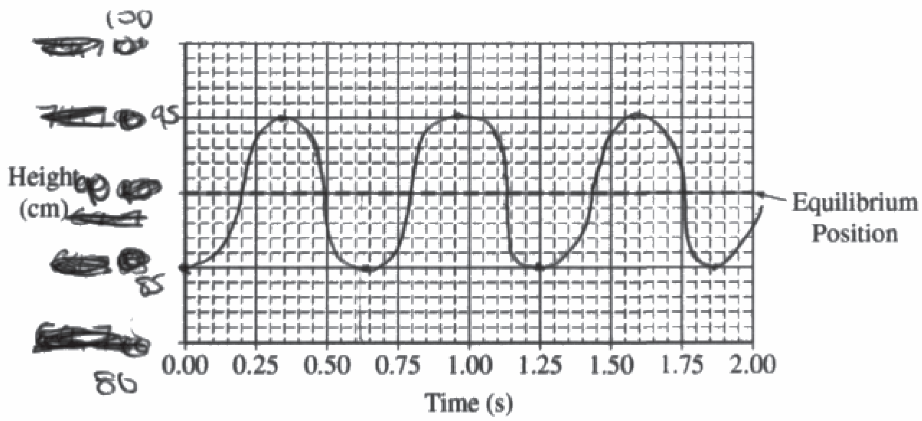
i. Determine the new equilibrium position above the motion detector.

$k_{new} = 4k_0 = 4(12.63) = 50.52\ kg/s^2$

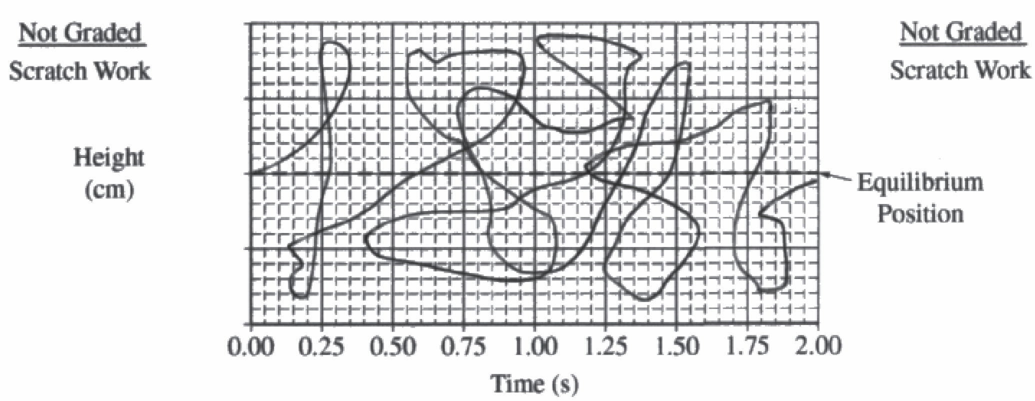
$F_{spring} = F_g = (0.5)(9.8) = (50.52)(\Delta x)$, $\Delta x = 0.097\ m$

$\Sigma F_y = F_g - F_{spring} = 0$, $F_g = F_{spring}$

ii. The object is again pulled down the same distance d_0 from the equilibrium position and released. On the following graph, draw a curve representing the motion of the object after it is released. Label the vertical axis with an appropriate numerical scale. A grid for scratch (practice) work is also provided.



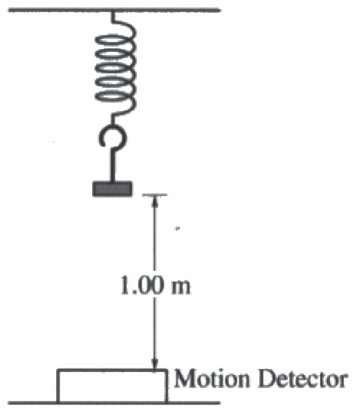
The following graph is provided for scratch work only and will not be graded.



GO ON TO THE NEXT PAGE.

Question 5

Begin your response to **QUESTION 5** on this page.



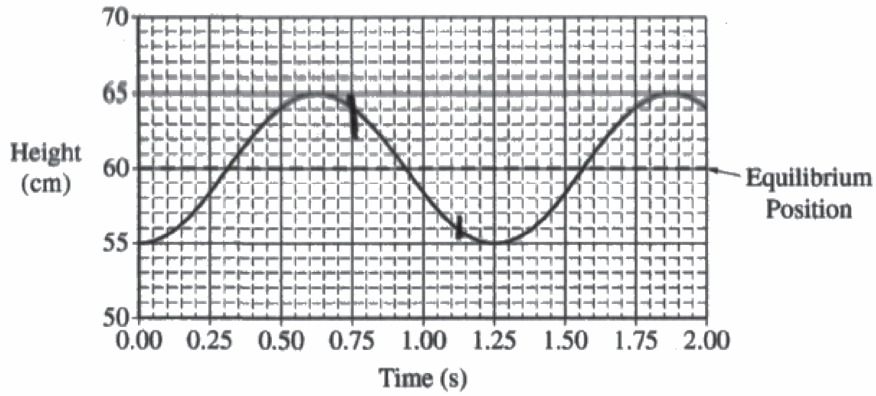
5. (7 points, suggested time 13 minutes)

A spring of unknown spring constant k_0 is attached to a ceiling. A lightweight hanger is attached to the lower end of the spring, and a motion detector is placed on the floor facing upward directly under the hanger, as shown in the figure above. The bottom of the hanger is 1.00 m above the motion detector.

A 0.50 kg object is placed on the hanger and allowed to come to rest at the equilibrium position. The spring is then stretched downward a distance d_0 from equilibrium and released at time $t = 0$. The motion detector records the height of the bottom of the hanger as a function of time. The output from the motion detector is shown in the graph on the following page.

Question 5

Continue your response to **QUESTION 5** on this page.



(a) Using the information given and information taken from the graph, calculate the spring constant.

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

$\left(\frac{1.25\ \text{sec}}{2\pi}\right)^2 = \frac{m}{k} \Rightarrow k = \frac{0.50\ \text{kg}}{\left(\frac{1.25\ \text{sec}}{2\pi}\right)^2} = 12.6\ \frac{\text{kg}}{\text{sec}^2}$.

(b) At time 0.75 s, the object-spring-Earth system has a total kinetic energy K_0 and a total potential energy U_0. At 1.13 s, the object-spring-Earth system again has a total kinetic energy K_0 and a total potential energy U_0.

i. Explain how a feature of the graph indicates that the total kinetic energy of the system is the same at these two times.

At time 0.75 s and 1.13 s, the slope of the graph is equal. The slope on a height vs time graph shows the velocity of the object. When the velocity is equal, the kinetic energy, $\frac{1}{2}mv^2$, is equal as well. The slope of the graph is its tangent line at that point.

ii. Briefly explain why the total potential energy of the system is the same at these two times.

At these times the total potential energy is equal due to conservation of energy. The system has GPE, TKE, and SPE. The sum of these energies is conserved throughout. Since TKE is equal at the two times, the sum of gravitational potential and spring potential energy is ~~the~~ the same in order to maintain cons. of energy.

Question 5

Continue your response to QUESTION 5 on this page.

(c) The experiment is repeated with a spring of spring constant $4k_0$ and that has the same length as the original spring. The 0.50 kg object is hung from the new spring and allowed to come to rest at a new equilibrium position.

i. Determine the new equilibrium position above the motion detector.

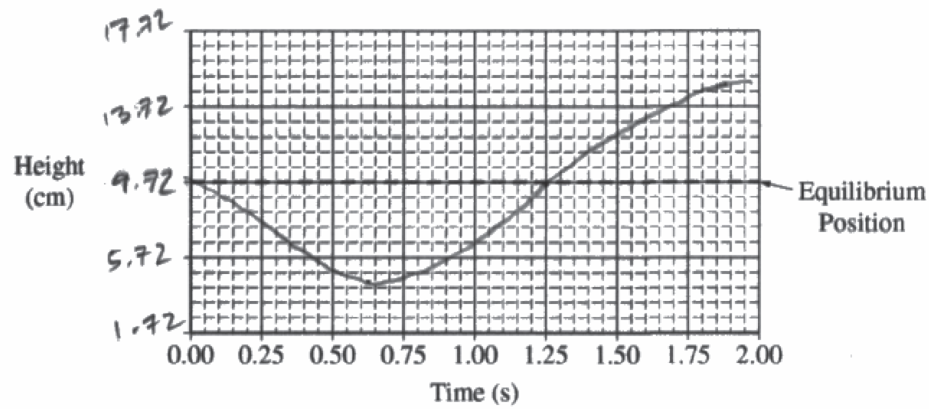
$mg = K\Delta x$

$(0.50\,kg)(9.8\,\frac{m}{s^2}) = 4(12.6\,\frac{kg}{s^2})\Delta x$

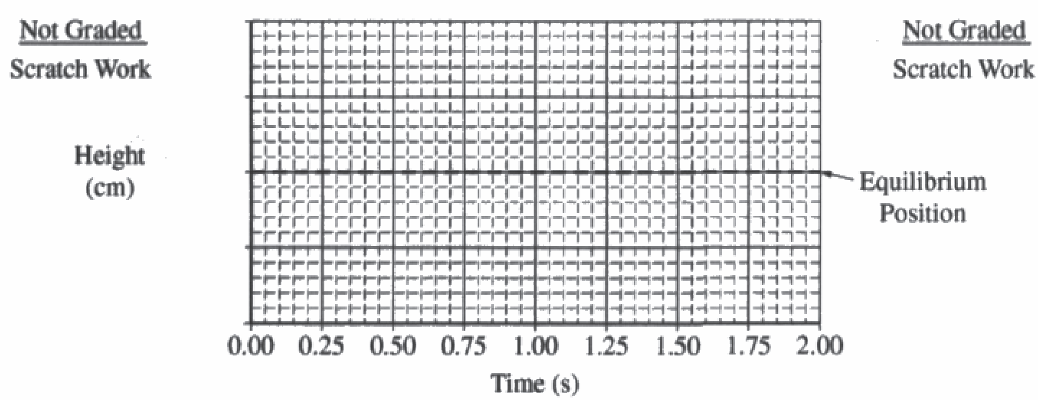
$\Delta x = 0.0972\ m$

$= 9.72\ cm$

ii. The object is again pulled down the same distance d_0 from the equilibrium position and released. On the following graph, draw a curve representing the motion of the object after it is released. Label the vertical axis with an appropriate numerical scale. A grid for scratch (practice) work is also provided.



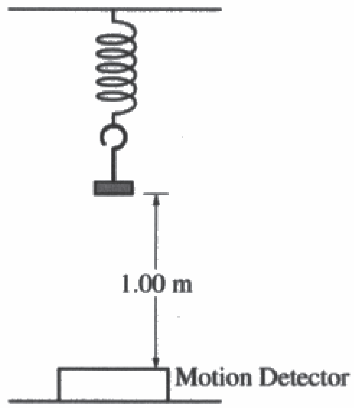
The following graph is provided for scratch work only and will <u>not</u> be graded.



GO ON TO THE NEXT PAGE.

Question 5

Begin your response to **QUESTION 5** on this page.



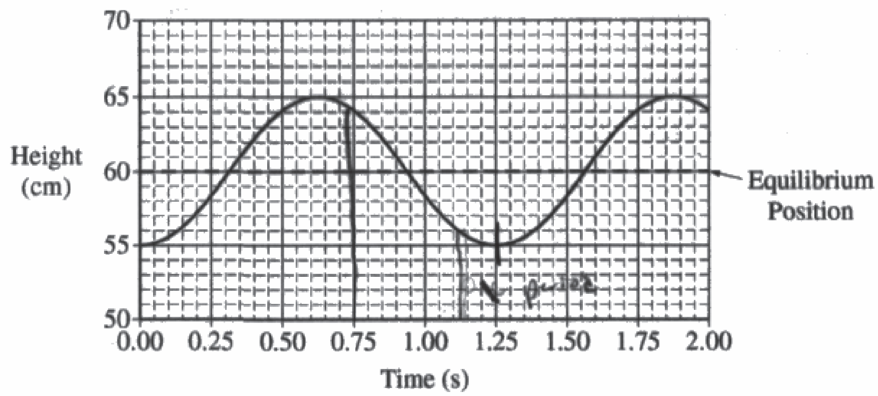
5. (7 points, suggested time 13 minutes)

A spring of unknown spring constant k_0 is attached to a ceiling. A lightweight hanger is attached to the lower end of the spring, and a motion detector is placed on the floor facing upward directly under the hanger, as shown in the figure above. The bottom of the hanger is 1.00 m above the motion detector.

A 0.50 kg object is placed on the hanger and allowed to come to rest at the equilibrium position. The spring is then stretched downward a distance d_0 from equilibrium and released at time $t = 0$. The motion detector records the height of the bottom of the hanger as a function of time. The output from the motion detector is shown in the graph on the following page.

Question 5

Continue your response to **QUESTION 5** on this page.



(a) Using the information given and information taken from the graph, calculate the spring constant.

$T_s = 2\pi\sqrt{\frac{m}{k}}$ $\quad$ $1.25 = 2\pi\sqrt{\frac{.5}{k}} \cdot k$ $\quad$ $K = 3.55$ Nm

$T = 1.25s$ $\quad$ $1.25k = 2\pi\sqrt{.5}$

$\frac{1.25k}{1.25} = \frac{4.44}{1.25}$

(b) At time 0.75 s, the object-spring-Earth system has a total kinetic energy K_0 and a total potential energy U_0. At 1.13 s, the object-spring-Earth system again has a total kinetic energy K_0 and a total potential energy U_0.

i. Explain how a feature of the graph indicates that the total kinetic energy of the system is the same at these two times.

These two times on the graph show ~~dis~~ downwards slope which tells us that because distance ~~is~~ on the y axis the height is going down which causes Kinetic energy to grow in most situations.

ii. Briefly explain why the total potential energy of the system is the same at these two times.

The potential energy of the system is the same at these times because PE_c is the main source of potential energy not PE_g. It also goes through a similar process like KE does in part (b)(i)

Question 5

Continue your response to **QUESTION 5** on this page.

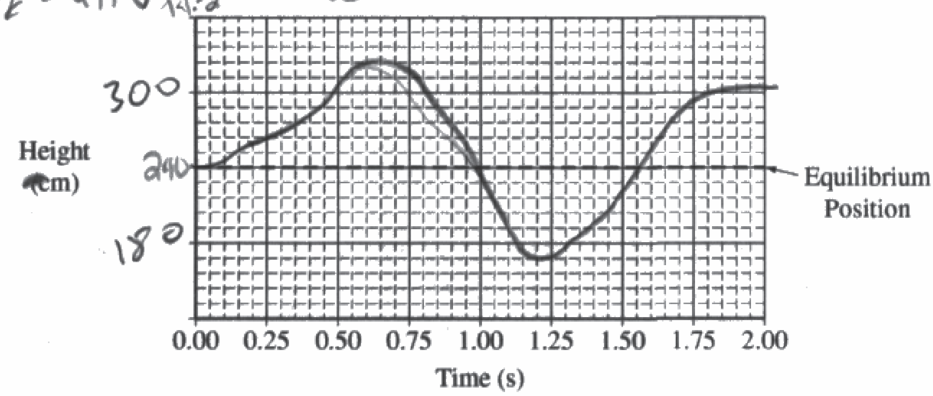
(c) The experiment is repeated with a spring of spring constant $4k_0$ and that has the same length as the original spring. The 0.50 kg object is hung from the new spring and allowed to come to rest at a new equilibrium position.

i. Determine the new equilibrium position above the motion detector.

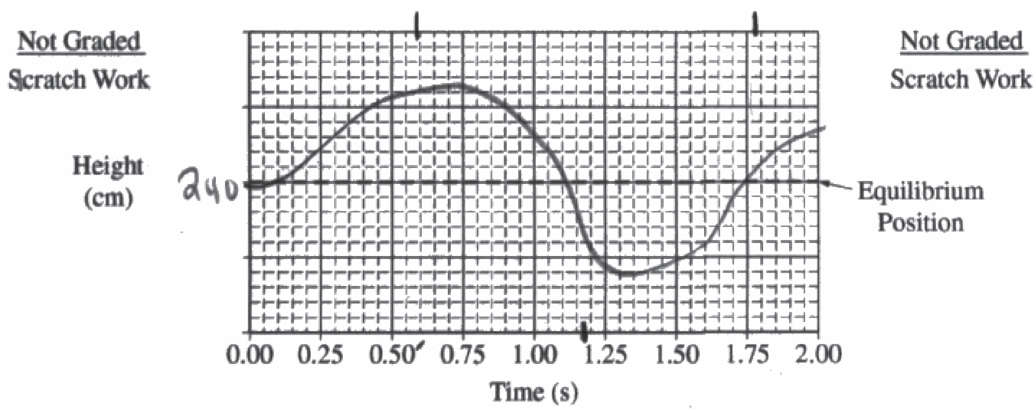
K=3.55 N/m from part (a), so 4K is equal to 14.2. With this new value of K the equilibrium position will be 4×60 = 240

ii. The object is again pulled down the same distance d_0 from the equilibrium position and released. On the following graph, draw a curve representing the motion of the object after it is released. Label the vertical axis with an appropriate numerical scale. A grid for scratch (practice) work is also provided.

$T_s = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{.5}{14.2}} = 1.18s$



The following graph is provided for scratch work only and will not be graded.



Question 5

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

Overview

The responses were expected to demonstrate the ability to:

- Use models to analyze an oscillator and to identify the period.
- Reference the graphical relationship between velocity and a position versus time graph to make a claim.
- Manipulate equations to substitute quantities and arrive at an answer.
- Apply functional dependence to determine the new equilibrium position and the new period for the graph.
- Make connections between the graph and energy concepts.
- Use argumentation skills to justify reasoning.
- Analyze the graph and diagram to address the relationships between the types of and movement of energy in the system.
- Graph the position versus time for simple harmonic motion of a mass on a spring with changes in the spring constant.

Sample: 5A
Score: 7

Part (a) earned 2 points. The first point was earned for a response that identifies the correct value for the period. The second point was earned for a response that correctly substitutes both mass and period into a valid equation.
Part (b)(i) earned 1 point for a response that identifies that the slopes of the graph at the two times are the same and, thus, kinetic energy is the same. Part (b)(ii) earned 1 point for a response that applies conservation of energy by explaining the exchange between spring and gravitational potential energy and indicating that kinetic energy is the same. Part (c)(i) earned 1 point for a response that identifies that the new equilibrium is 90 cm. Part (c)(ii) earned 2 points. The first point was earned for a response that uses the equilibrium in part (c)(i) and an amplitude of $\pm 5\text{ cm}$ from the original graph. The second point was earned for a response that uses the correct period to create the new graph.

Sample: 5B
Score: 4

Part (a) earned 2 points. The first point was earned for a response that identifies the correct value for the period. The second point was earned for a response that correctly substitutes both mass and period into a valid equation.
Part (b)(i) earned 1 point for a response that identifies that the slopes of the graph at the two times are the same and, thus, kinetic energy is the same. Part (b)(ii) earned 1 point for a response that applies conservation of energy by explaining the exchange between spring and gravitational potential energy and indicating that kinetic energy is the same. Part (c)(i) earned 0 points because the response incorrectly identifies the new stretch as the new equilibrium at 9.72 cm. Part (c)(ii) earned 0 points. The first point was not earned because the response uses the correct equilibrium from part (c)(i), but the amplitude is not consistent with the original graph. The second point was not earned because the response applies an incorrect period on the graph.

Question 5 (continued)

Sample: 5C
Score: 2

Part (a) earned 2 points. The first point was earned for a response that identifies the correct value for the period. The second point was earned for a response that correctly substitutes both mass and period into a valid equation.
Part (b)(i) earned 0 points because the response applies an incorrect application of slope and height as related to kinetic energy. Part (b)(ii) earned 0 points because the response does not explain why the potential energy was the same at both locations. Part (c)(i) earned 0 points because the response applies an incorrect equilibrium of 240 cm.
Part (c)(ii) earned 0 points. The first point was not earned because the response indicates a correct equilibrium value from part (c)(i), but the amplitude is not $\pm 5\text{ cm}$ as shown in the original graph. The second point was not earned because the response indicates an incorrect period for the new spring constant.