2024

AP

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 2

☑ Scoring Guidelines

☑ Student Samples

☑ Scoring Commentary

Question 2: Experimental Design — 12 points

(a)	For measuring the mass of at least one cylinder with the digital scale	**1 point**
	For measuring the period of oscillation of the cylinder-spring system with the stopwatch	**1 point**
	For a procedure that indicates that the cylinder hung on the spring should be set into oscillatory motion	**1 point**
	For a procedure that indicates a method to reduce experimental uncertainty	**1 point**

Accept **one** of the following:

- For using multiple masses
- For doing multiple trials with a single mass
- For measuring multiple oscillations and dividing by the number of oscillations

Example Response

Place a cylinder on the digital scale and record the mass. Hang the cylinder from the spring and pull the cylinder down a small distance so that the spring is stretched. Release the cylinder. Use the stopwatch to measure the amount of time necessary for the cylinder to complete ten full cycles (from maximum stretch length back to maximum stretch length). Repeat the procedure for cylinders of different masses.

Total for part (a) **4 points**

(b)(i) For listing quantities that can be measured with a stopwatch and a digital scale and could be plotted to produce a linear graph whose slope can be used to determine k **1 point**

Accept **one** of the following:

- m vs. T^2
- T^2 vs. m
- $4\pi^2 m$ vs. T^2
- T^2 vs. $4\pi^2 m$
- $\frac{T^2}{4\pi^2}$ vs. m
- m vs. $\frac{T^2}{4\pi^2}$
- T vs. $\sqrt{m}$
- $\sqrt{m}$ vs. T
- $\frac{T}{2\pi}$ vs. $\sqrt{m}$
- $\sqrt{m}$ vs. $\frac{T}{2\pi}$
- T vs. $2\pi\sqrt{m}$
- $2\pi\sqrt{m}$ vs. T

Scoring Note: This point may be earned for any of the bullets above substituting $\frac{1}{f}$ for T.

Example Response

Vertical axis: m Horizontal axis: T^2

(b)(ii) For correctly relating the slope of the best-fit line to the value of k **1 point**

Example Response

Plotting the mass as a function of the period-squared would result in a graph whose slope could be used to find k by using the equation for the period of an oscillating cylinder-spring system.

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

$\text{slope} = \dfrac{k}{4\pi^2}$

$k = (\text{slope})4\pi^2$

Graph	**Slope**	k
m vs. T^2	$\text{slope} = \dfrac{k}{4\pi^2}$	$k = (\text{slope})4\pi^2$
T^2 vs. m	$\text{slope} = \dfrac{4\pi^2}{k}$	$k = \dfrac{4\pi^2}{\text{slope}}$
$4\pi^2 m$ vs. T^2	$\text{slope} = k$	$k = \text{slope}$
T^2 vs. $4\pi^2 m$	$\text{slope} = \dfrac{1}{k}$	$k = \dfrac{1}{\text{slope}}$
$\dfrac{T^2}{4\pi^2}$ vs. m	$\text{slope} = \dfrac{1}{k}$	$k = \dfrac{1}{\text{slope}}$
m vs. $\dfrac{T^2}{4\pi^2}$	$\text{slope} = k$	$k = \text{slope}$
T vs. $\sqrt{m}$	$\text{slope} = \sqrt{\dfrac{4\pi^2}{k}}$	$k = \dfrac{4\pi^2}{\text{slope}^2}$
$\sqrt{m}$ vs. T	$\text{slope} = \sqrt{\dfrac{k}{4\pi^2}}$	$k = \text{slope}^2 \times 4\pi^2$
$\dfrac{T}{2\pi}$ vs. $\sqrt{m}$	$\text{slope} = \sqrt{\dfrac{1}{k}}$	$k = \dfrac{1}{\text{slope}^2}$
$\sqrt{m}$ vs. $\dfrac{T}{2\pi}$	$\text{slope} = \sqrt{k}$	$k = \text{slope}^2$
T vs. $2\pi\sqrt{m}$	$\text{slope} = \sqrt{\dfrac{1}{k}}$	$k = \dfrac{1}{\text{slope}^2}$
$2\pi\sqrt{m}$ vs. T	$\text{slope} = \sqrt{k}$	$k = \text{slope}^2$

Total for part (b) 2 points

(c)(i) For using the kinetic energy equation $K = \frac{1}{2}mv^2$ **1 point**

For substituting **one** of the following: **1 point**

- 0.25 kg as the mass
- 0.3 m/s as the initial velocity

For an answer that approximates the change in kinetic energy to be $\Delta K \approx -0.0113$ J **1 point**

Scoring Note: A correct response with no supporting work earns this point only.

Scoring Note: The unit and the negative sign are not required to earn this point.

Example Response

$$\Delta K = K_f - K_i$$
$$\Delta K = \frac{1}{2}mv_f{}^2 - \frac{1}{2}mv_i{}^2$$
$$\Delta K = \frac{1}{2}0.25(0)^2 - \frac{1}{2}0.25(0.3)^2$$
$$\Delta K = -0.0113 \text{ J}$$

(c)(ii) For indicating the magnitude of the change in momentum is zero **1 point**

For indicating the area under the force-time graph represents the value of the change in momentum **1 point**

Example Response

The area under the curve for a force vs time graph represents the impulse or change in momentum. The area under the curve for 0.5 s *to* 2.5 s *is zero.*

(c)(iii) For an explanation that compares the estimated value of the change in momentum from (c)(ii) to the data from the velocity-time graph **1 point**

Example Response

The velocity-time graph shows that velocity is 0.3 m/s *at both* 0.5 s *and* 2.5 s*, and momentum is mass times velocity, so the momentum is the same at both times. This agrees with my estimation from part (c)(ii) that the change in momentum is zero.*

Total for part (c) 6 points

Total for question 2 12 points

Question 2

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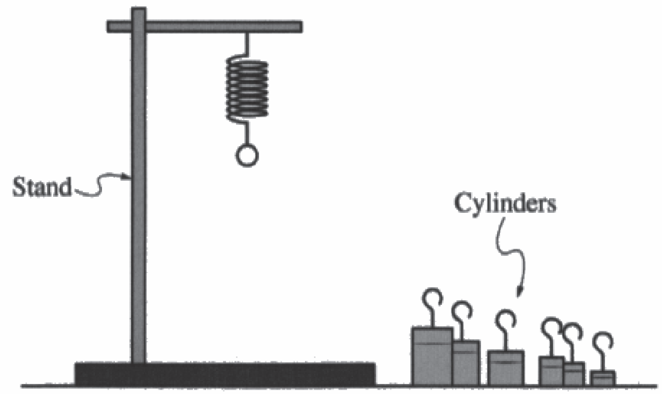


Figure 1

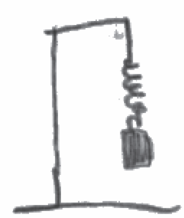
2. (12 points, suggested time 25 minutes)

A student hangs a spring of unknown spring constant k vertically by attaching one end to a stand, as shown in Figure 1. The other end of the spring has a small loop from which small cylinders can be hung. In addition to the spring, the student has access only to a variety of cylinders of unknown masses, a stopwatch, and a digital scale.

(a) Design an experimental procedure the student could use to determine the spring constant k of the spring.

In the following table, list the quantities that would be measured using only the provided equipment in your experiment. Define a symbol to represent each quantity.

In the space below the table, **describe** the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table. If needed, you may include a simple diagram of the setup with your procedure.



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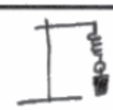
Question 2

Continue your response to **QUESTION 2** on this page.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement
time/period	t/T	Stopwatch
mass of cylinders	m	Digital scale

Procedure (and diagram, if needed)

1) weigh the mass of the cylinder + record it
2) attach a cylinder to the spring on the stand
3) release it from rest + allow the spring-cylinder system to oscillate
4) as the system oscillates, start the stopwatch + record the time for 5 oscillations + record
5) repeat ~~[illegible]~~ for several trials + using multiple cylinders w/ different masses to reduce experimental uncertainty + error



$T_s = 2\pi\sqrt{\frac{m}{k}}$ $T^2 = 4\pi^2 \cdot \frac{m}{k}$ $T^2 = 4\pi^2 m \cdot \frac{1}{k}$ $T^2 k = 4\pi^2 m$ $y = mx + b$ $\frac{T}{2\pi} = \sqrt{\frac{m}{k}}$ $\frac{T^2}{4\pi^2} = \frac{m}{k}$

(b)

i. **Indicate** the quantities that could be plotted to produce a linear graph whose slope can be used to determine the spring constant k of the spring.

Vertical axis:____________ Horizontal axis:____________

ii. Briefly **describe** how the slope of the graph would be analyzed to determine the spring constant k of the spring.

Calculating the $\frac{\text{rise}}{\text{run}}$ of a point on the line of the graph would get the spring constant value as the slope would be = to K

Question 2

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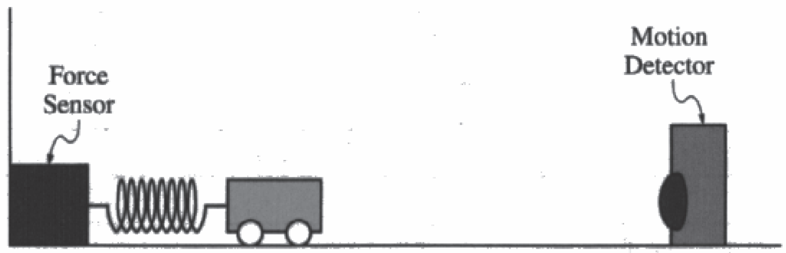
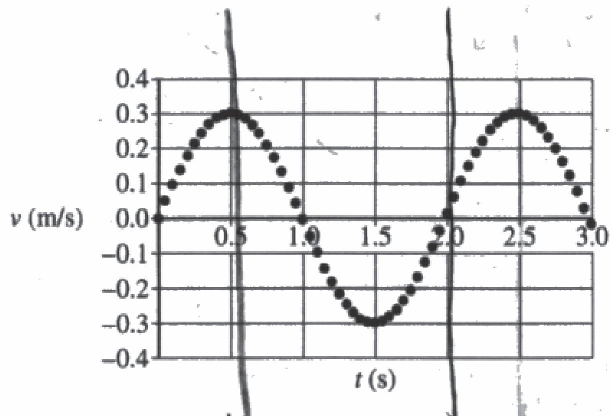
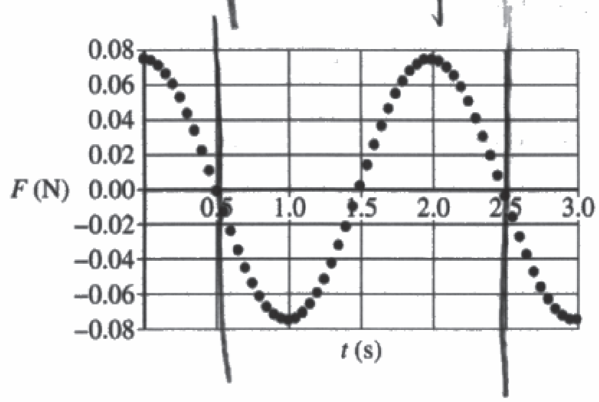


Figure 2

In a different experiment, the student attaches one end of a spring to a force sensor that is attached to a wall. The other end of the spring is attached to a cart with mass $m = 0.25$ kg. The student places a motion detector to the right of the cart, as shown in Figure 2, and pulls the cart to the right a small distance so that the spring is stretched. The student releases the cart from rest, and the cart-spring system oscillates.

The following graphs show the velocity v of the cart and the force F exerted on the cart by the spring as functions of time t.





Question 2

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(c)

i. Using the data in the velocity-time graph, **calculate** the change in kinetic energy of the cart from $t = 0.5$ s to $t = 2.0$ s. Show your steps and substitutions.

m = .25kg
K = ½mv²
t = .5s, v = .3 m/s
t = 2s, v = 0 m/s

½(.25)(.3²) = .01125J
½(.25)(0²) = 0J
ΔKE = .01125J

ii. Using the data in the force-time graph, **estimate** the change in momentum of the cart from $t = 0.5$ s to $t = 2.5$ s. Briefly **explain** how you arrived at your estimation.

The Δp of the cart from t=.5s to t=2.5s would be 0Ns.
Change in momentum is equal to F·Δt which if you calculate using the area under the curve, ~~the~~ it's equal to 0 b/c the area from .5-1.5s is equal to the area from 1.5-2.5s so when you add them it is equal to 0 since they have the same magnitude but opposite directions.

iii. Do the data from the velocity-time graph confirm your estimation from part (c)(ii) ? Briefly **explain**.

Yes it does. At t=.5s, v=.3 m/s and t=2.5s, v=.3 m/s. The mass of the cart doesn't change + is .25kg, so using the momentum equation p=mv, the momentum at t=.5s is .075kgm/s + is .075kg m/s at t=2s, ~~so the~~ + since there is no change in momentum, as it stays the same, this confirms my estimation.

Question 2

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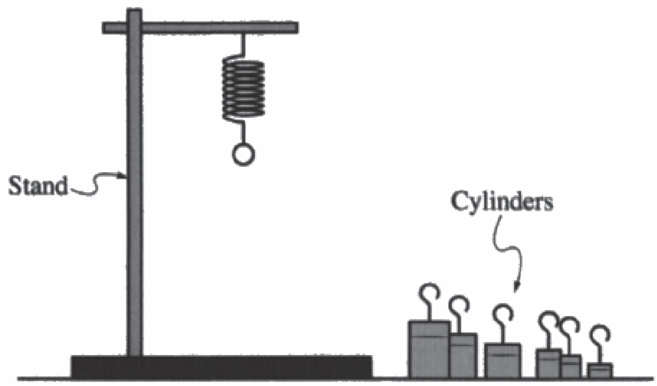

Figure 1

2. (12 points, suggested time 25 minutes)

A student hangs a spring of unknown spring constant k vertically by attaching one end to a stand, as shown in Figure 1. The other end of the spring has a small loop from which small cylinders can be hung. In addition to the spring, the student has access only to a variety of cylinders of unknown masses, a stopwatch, and a digital scale.

(a) Design an experimental procedure the student could use to determine the spring constant k of the spring.

In the following table, list the quantities that would be measured using only the provided equipment in your experiment. Define a symbol to represent each quantity.

In the space below the table, **describe** the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table. If needed, you may include a simple diagram of the setup with your procedure.

The first step is to use the digital scale to measure the masses of each cylinder. Once the mass of each cylinder is known, I would attach each cylinder one by one to the spring and measure the displacement of the spring. I would record the mass of the cylinder next to the displacement of the spring. $\vec{x}$ represents the displacement. m represents the mass of each cylinder.

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Q5238/6

Question 2

Continue your response to **QUESTION 2** on this page.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement
time	t	Stopwatch
mass	m	Digital scale

Procedure (and diagram, if needed)

The first step is to use the digital scale and measure the masses of each cylinder. Once the mass of each cylinder is known, I would attach each cylinder one by one to the spring. Once a cylinder is attached, I will let it go and start the stopwatch, measuring the amount of time it takes for the cylinder to touch the ground and stretch the spring all the way until it touches the ground. I'd record the mass of the cylinder next to the time it took for the cylinder to hit the ground.

(b)

i. **Indicate** the quantities that could be plotted to produce a linear graph whose slope can be used to determine the spring constant k of the spring.

Vertical axis: mass Horizontal axis: time

ii. Briefly **describe** how the slope of the graph would be analyzed to determine the spring constant k of the spring.

The slope of the graph would show the time taken for the cylinder to hit the floor as a function of the mass, meaning the time is the dependent variable and mass is independent. Therefore, the slope would reflect this relationship.

The equation is: $\frac{1}{2}kx^2$ is equal to $\Delta U_g = mg\Delta y$. Therefore, $\frac{1}{2}kx^2 = mg\Delta y$, which is shown on the graph and k is the displacement and slope.

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Question 2

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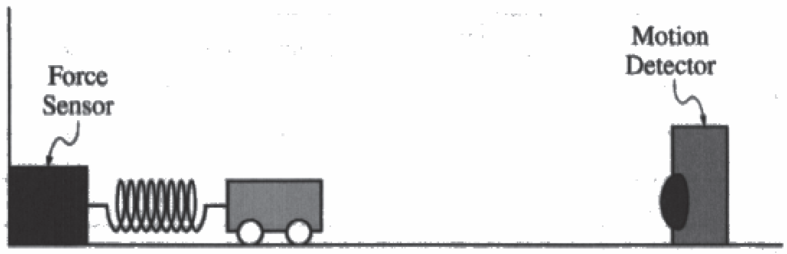
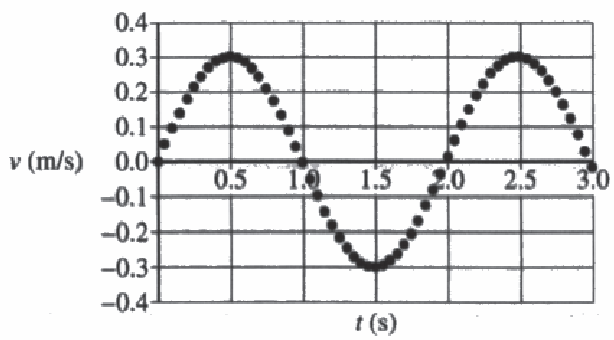
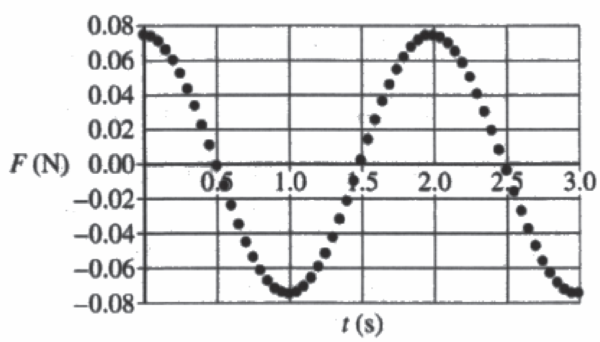


Figure 2

In a different experiment, the student attaches one end of a spring to a force sensor that is attached to a wall. The other end of the spring is attached to a cart with mass $m = 0.25$ kg. The student places a motion detector to the right of the cart, as shown in Figure 2, and pulls the cart to the right a small distance so that the spring is stretched. The student releases the cart from rest, and the cart-spring system oscillates.

The following graphs show the velocity v of the cart and the force F exerted on the cart by the spring as functions of time t.





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Question 2

Continue your response to **QUESTION 2** on this page.

(c)

i. Using the data in the velocity-time graph, **calculate** the change in kinetic energy of the cart from $t = 0.5$ s to $t = 2.0$ s. Show your steps and substitutions.

$V_1 = .3$

$K = \frac{1}{2}mv^2$ $m = .25kg$ $V_2 = 0$

$K_1 = \frac{1}{2}mv^2$ $K_2 = \frac{1}{2}mv^2$

$K_1 = \frac{1}{2}.25v_1^2$ $K_2 = \frac{1}{2}.25v_2^2$

$K_1 = \frac{1}{2}(.25)(.3)^2$ $K_2 = \frac{1}{2}(.25)(0)^2$

$K_1 = .01125$ $K_2 = 0$

$K_2 - K_1 = \Delta K$

$0 - .01125 = \Delta K$

$\Delta K = -.01125$

$\Delta K = .01125$

ii. Using the data in the force-time graph, **estimate** the change in momentum of the cart from $t = 0.5$ s to $t = 2.5$ s. Briefly **explain** how you arrived at your estimation.

p=momentum

$\vec{p} = m\vec{v}$

$\Delta\vec{p} = \vec{F}\Delta t$

$t_1 = .5s$

$t_2 = 2.5s$

F at t = .5 = 0

F at t = 2.5 = 0

$\Delta t = 2.5 - .5 = 2 = \Delta t$

$\Delta p = (0)(2)$

$\Delta p = 0$

My estimation is that there will be no change in momentum because the force (N) at .5 seconds is zero and the force at 2.5 seconds is also zero, therefore theres no change in force

iii. Do the data from the velocity-time graph confirm your estimation from part (c)(ii) ? Briefly **explain**.

$\vec{p}_1 = m\vec{v}$ $\vec{p}_2 = m\vec{v}$ m=.25kg

V=velocity

V_1 at .5s = .3m/s

V_2 at 2.5 secs = .3m/s

$\vec{p}_1 = .25(3) = .75$

$\vec{p}_2 = .25(3) = .75$

$\Delta p = \vec{p}_2 - \vec{p}_1$

$\vec{p}_2 = .75$ $\vec{p}_1 = .75$

$\Delta\vec{p} = .75 - .75 = 0$

The data from the velocity versus time graph confirms my estimation because the speed at .5seconds and 2.5 seconds is the same, it is .3m/s. The velocity is the same at both times. When calculating momentum at both times, using the equation $\vec{p} = m\vec{v}$, since at both times the mass is also .25kg, the momentum is the same at both times. Therefore, the change in momentum is zero. (.3)(.25) = .75. See above for the work in calculating $\Delta\vec{p}$.

Question 2

Begin your response to **QUESTION 2** on this page.

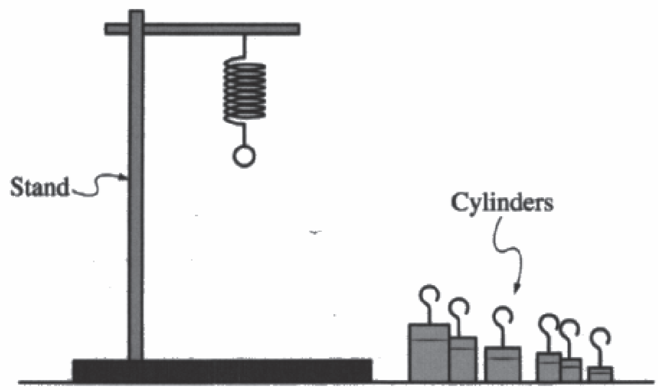

Figure 1

2. (12 points, suggested time 25 minutes)

A student hangs a spring of unknown spring constant k vertically by attaching one end to a stand, as shown in Figure 1. The other end of the spring has a small loop from which small cylinders can be hung. In addition to the spring, the student has access only to a variety of cylinders of unknown masses, a stopwatch, and a digital scale.

(a) Design an experimental procedure the student could use to determine the spring constant k of the spring.

In the following table, list the quantities that would be measured using only the provided equipment in your experiment. Define a symbol to represent each quantity.

In the space below the table, **describe** the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table. If needed, you may include a simple diagram of the setup with your procedure.

Question 2

Continue your response to **QUESTION 2** on this page.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement
time it takes	s	Stopwatch
mass of cylinder	m	Digital scale

Procedure (and diagram, if needed)

1, weigh each cylinder on the scale then mark it with it's weight.
2, Attach the lightest cylinder to the bottom of the scale
3, time how long it takes the spring to settle at a length then chart the mass of the cylinder and the time it took
4, repeat 2 and 3, working up in weight until all cylinders have been measured.
5, graph the data

(b) i. **Indicate** the quantities that could be plotted to produce a linear graph whose slope can be used to determine the spring constant k of the spring.

Vertical axis: s Horizontal axis: m

ii. Briefly **describe** how the slope of the graph would be analyzed to determine the spring constant k of the spring.

The line of best fit through these points will show the average amount of time it would take for the spring to return to rest based off of the mass of the object attached to it.

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Question 2

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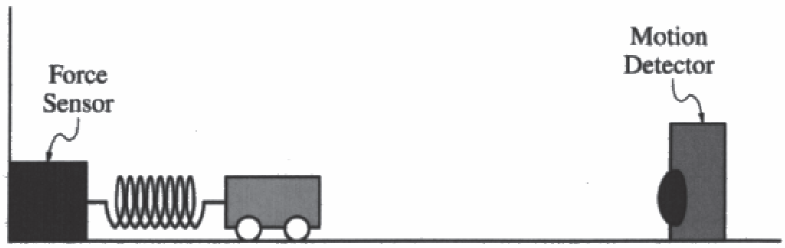
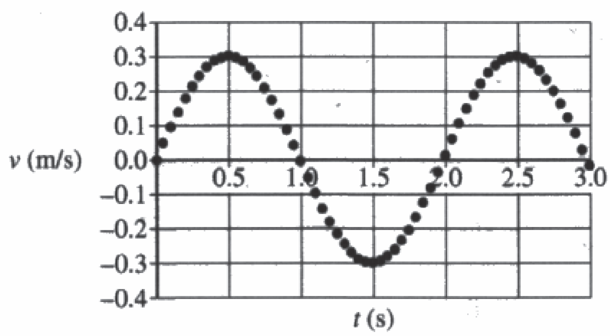
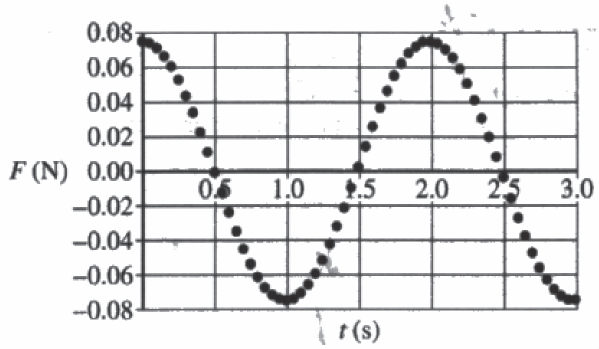


Figure 2

In a different experiment, the student attaches one end of a spring to a force sensor that is attached to a wall. The other end of the spring is attached to a cart with mass $m = 0.25$ kg. The student places a motion detector to the right of the cart, as shown in Figure 2, and pulls the cart to the right a small distance so that the spring is stretched. The student releases the cart from rest, and the cart-spring system oscillates.

The following graphs show the velocity v of the cart and the force F exerted on the cart by the spring as functions of time t.





Question 2

Continue your response to **QUESTION 2** on this page.

(c)

i. Using the data in the velocity-time graph, **calculate** the change in kinetic energy of the cart from $t = 0.5$ s to $t = 2.0$ s. Show your steps and substitutions.

$\Delta K = t_2 - t_{.5}$

$\Delta K = 0 - .3$

$\Delta K = -0.3\ m/s^2$

ii. Using the data in the force-time graph, **estimate** the change in momentum of the cart from $t = 0.5$ s to $t = 2.5$ s. Briefly **explain** how you arrived at your estimation.

$\Delta F_N = t_{2.5} - t_{0.5}$

$\Delta F_N = 0 - 0$

$\Delta F_N = 0\ N$

Since there is equal amounts of positive change and negative change the change of momentum is equal to zero.

iii. Do the data from the velocity-time graph confirm your estimation from part (c)(ii) ? Briefly **explain**.

It does because in this time period, the amount of negative force applied to the system is equal to the amount of positive force. This means that although there are changes within the time, there are overall no changes.

Question 2

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

Overview

Responses were expected to demonstrate the ability to:

- Communicate a procedure to measure a quantity using a specified set of equipment.
- Identify a pair of variables that could be plotted to create a linear graph whose slope would help determine the spring constant (e.g., mass and the square of period).
- Calculate the change in kinetic energy of an oscillating object from a velocity versus time graph.
- Estimate the change in momentum from a force versus time graph using the area under the graph.
- Calculate the change in momentum from a velocity versus time graph using speeds at specific times.
- Demonstrate consistency between different representations of motion.

Sample: 2A
Score: 10

Part (a) earned 4 points. The first point was earned for indicating that "mass of cylinders" should be measured with the digital scale. The second point was earned for indicating that "time / period" should be measured with a stopwatch. The third point was earned for indicating that the system will be oscillating in steps 3 and 4. The fourth point was earned for indicating both that five oscillations will be recorded and that those oscillations will be repeated with multiple cylinders. Part (b) did not earn any points. The first point was not earned because the response does not indicate quantities that should be graphed on the vertical and horizontal axes. The second point was not earned because the response does not describe a way to find the spring constant using the slope of a graph. Part (c) earned 6 points. The first point was earned for using the kinetic energy equation. The second point was earned for showing the substitution of both a correct mass and a correct velocity into an equation. The third point was earned for stating that the change in kinetic energy is 0.01125 J. The fourth point was earned for indicating that the change in momentum is zero. The fifth point was earned for explaining the change in momentum in terms of the area under the force-time graph. The sixth point was earned for using data from the velocity-time graph to calculate the momentum at the beginning of the time interval and indicating that the momenta are the same.

Sample: 2B
Score: 7

Part (a) earned 2 points. The first point was earned for stating to "use the digital scale and measure the masses of each cylinder." The second point was not earned because the response states to measure time with a stopwatch and indicates that the time being measured is "the amount of time it takes for the cylinder to touch the ground and stretch the spring all the way until it touches the ground." This is not the period, nor is it sufficient to determine the period. The third point was not earned because the response does not indicate that the system is set into oscillatory motion. The fourth point was earned for stating to "attach each cylinder one by one to the spring," which is an indication of performing multiple trials. Part (b) did not earn any points. The first point was not earned because the response indicates that mass should be graphed as a function of time, quantities that would not produce a linear graph. The second point was not earned because the response does not indicate how the slope of the graph could be used to find k. Part (c) earned 5 points. The first point was earned for using the kinetic energy equation. The second point was earned for showing the substitution of both a correct mass and a correct velocity into the equation. The third point was earned for stating that the change in kinetic energy is 0.01125. The fourth point was earned for indicating that the change in momentum is zero. The fifth point was not earned because the response indicates that the force at the beginning and end of the time interval is zero but does not discuss the area under the graph. The sixth point was earned for using data from the velocity-time graph to calculate that the momentum at the beginning and end of the time interval is the same and stating that the change in momentum is zero.

Question 2 (continued)

Sample: 2C
Score: 3

Part (a) earned 2 points. The first point was earned for stating to "weigh each cylinder on the scale." The second point was not earned because the response states to "take how long it takes the spring to settle," which cannot be used to find the period. The third point was not earned because the response does not indicate that the mass-spring system will be oscillating. The fourth point was earned for clearly indicating that the procedure should be repeated with all cylinders. Part (b) did not earn points. The first point was not earned because the response does not list quantities that could be plotted to produce a linear graph whose slope can be used to find k. The second point was not earned because the response does not correctly describe how the spring constant can be found using a best-fit line. Part (c) earned 1 point. The first point was not earned because the response does not use the kinetic energy equation. The second point was not earned because, while the response does include the value 0.3 m/s, it does not demonstrate that this value is being substituted into an equation. The third point was not earned because the response does not indicate the correct value for the change in kinetic energy. The fourth point was earned for indicating "the change of momentum is equal to zero." The fifth point was not earned because the response does not indicate that the area under the force-time graph represents the value of the change in momentum. The sixth point was not earned because the response does not compare the change in momentum to the data from the velocity-time graph.