2022

AP® | CollegeBoard

AP® Physics C: Mechanics

Sample Student Responses and Scoring Commentary Set 2

Inside:

Free-Response Question 2

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

Question 2: Free-Response Question — 15 points

(a)	For selecting "$J_S > J_2$" with an attempt at a relevant justification	**1 point**
	For a correct justification	**1 point**

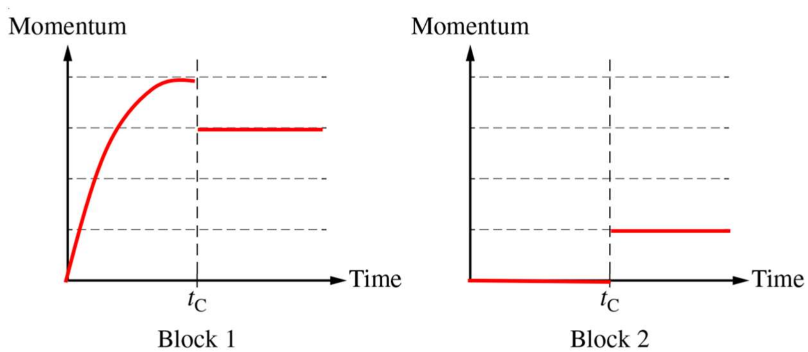
Example Response

The impulse between the two blocks is the same, so because Block 1 is moving at the end, the impulse given by the spring must be greater than the impulse given to Block 2 by Block 1.

Total for part (a) — 2 points

(b)	For correctly drawing the momentum for blocks 1 and 2 for the time interval $0 < t < t_C$: Block 1 shows an increasing curve with a decreasing slope (concave down) to highest value (technically a cosine curve) and Block 2 shows zero momentum up to t_C (a horizontal line along the time axis).	**1 point**
	For drawing a horizontal line for Block 1 when $t > t_C$ that is smaller in magnitude than the momentum of Block 1 at time $t = t_C$	**1 point**
	For drawing a horizontal line for Block 2 when $t > t_C$ that is smaller in magnitude than the momentum of Block 1 after time $t = t_C$	**1 point**
	For blocks 1 and 2 having a change in momentum that is equal in magnitude such that Block 1 loses momentum and Block 2 gains momentum	**1 point**

Example Response



Total for part (b) — 4 points

(c)	For using conservation of energy to find the speed of Block 1 at $x = 0$	**1 point**
	For using conservation of momentum to find the speed of the two-block system after the collision	**1 point**
	For combining correct equations from above	**1 point**

Example Response

$$\frac{1}{2}k(\Delta x)^2 = \frac{1}{2}m_1 v_1^2$$

$$v_1 = \sqrt{\frac{k}{m_1}}\Delta x$$

$$m_1 v_1 = (m_1 + m_2)v$$

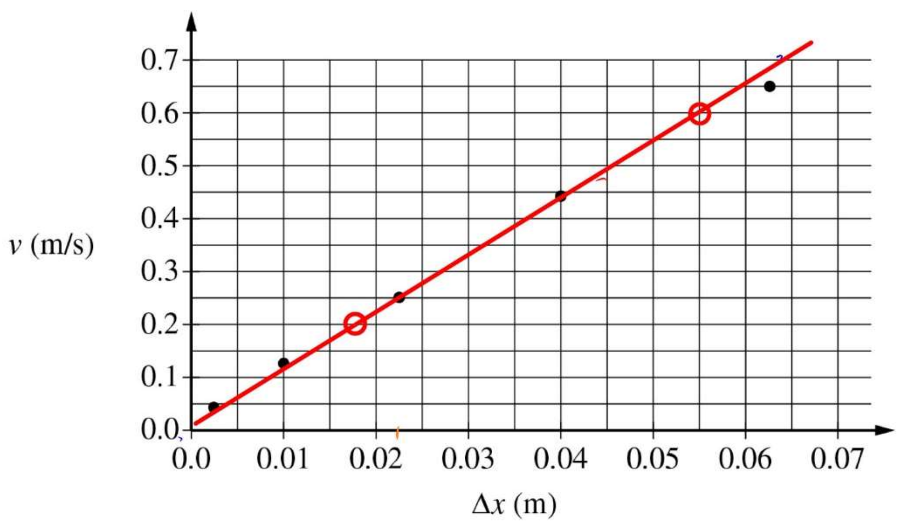
$$v = \frac{m_1 v_1}{m_1 + m_2}$$

$$\therefore v = \frac{\Delta x\sqrt{k m_1}}{m_1 + m_2}$$

Total for part (c) **3 points**

(d)(i)	For drawing an appropriate best-fit line including approximately the same number of points above and below the line	**1 point**

Example Response



(d)(ii)	For calculating the slope using two points on the line	**1 point**
	For correctly relating the slope of the best-fit line to the mass of Block 2	**1 point**
	For a correct mass of Block 2	**1 point**

Example Response

$$slope = \frac{(0.60 - 0.02)\text{ m/s}}{(0.055 - 0.0175)\text{ m}} = 10.67\text{ s}^{-1}$$

$$slope = \frac{\sqrt{km_1}}{m_1 + m_2}$$

$$m_2 = \frac{\sqrt{km_1}}{slope} - m_1$$

$$m_2 = \frac{\sqrt{\left(150\,\frac{\text{N}}{\text{m}}\right)(0.50\text{ kg})}}{10.67\text{ s}^{-1}} - 0.50\text{ kg}$$

$$m_2 = 0.31\text{ kg}$$

Scoring Note: Acceptable responses for mass are $0.27\text{ kg} - 0.37\text{ kg}$.

Total for part (d) 4 points

(e)	For selecting "$k' > 150\text{ N/m}$" with an attempt at relevant justification	**1 point**
	For a correct justification	**1 point**

Example Response

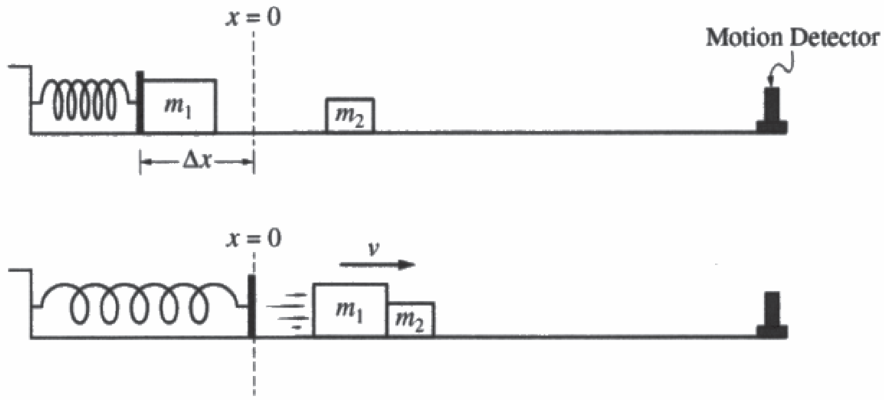
A greater m_2 indicates the spring constant k' should be greater than 150 N/m. *The slope of the graph is the same so as m_2 increases k must be smaller.*

Total for part (e) 2 points

Total for question 2 15 points

Question 2

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



2. Block 1 of mass m_1 is held at rest while compressing an ideal spring an amount Δx. The spring constant of the spring is k. Block 2 has mass m_2, where $m_2 < m_1$. At time $t = 0$, Block 1 is released. At time t_C, the spring is no longer compressed and Block 1 immediately collides with and sticks to Block 2. The blocks stick together and the two-block system moves with constant speed v, as shown. Frictional effects are negligible.

   (a) The impulse on Block 1 from the spring during the time interval $0 < t < t_C$ is J_S. The impulse on Block 1 from Block 2 during the collision is J_2. Which of the following expressions correctly compares the magnitudes of J_S and J_2?

✓ $J_S > J_2$ ____ $J_S < J_2$ ____ $J_S = J_2$

Justify your answer.

$J = \int F\,dt$ $J = \Delta p$

J_S causes the ~~mor~~ p_1 to increase from 0 to the total momentum of the system immediately before the collision.

J_2 causes the p_1 to decrease to some nonzero value (since $v_f \neq 0$) slightly less.

The increase from 0 to p_1 is larger than the decrease from p_1 to some nonzero value

GO ON TO THE NEXT PAGE.

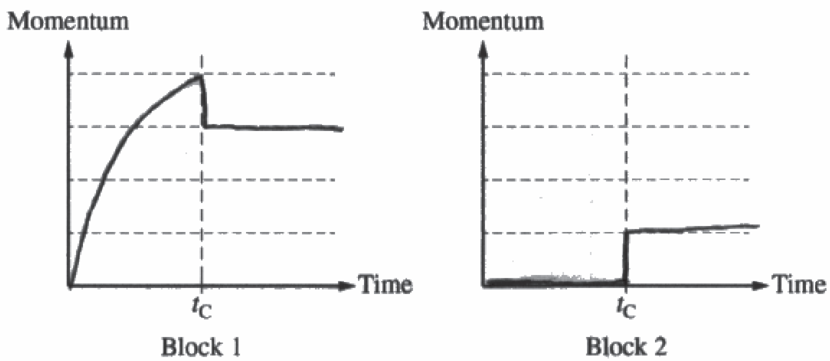
Question 2

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

(b) On the following axes, draw graphs of the magnitude of the momentum of each block as a function of time, before and after t_C. The collision occurs in a negligible amount of time. The grid lines on each graph are drawn to the same scale.

$F = \frac{\partial p}{\partial t}$

$p = \int F \partial t$



(c) Show that the velocity v of the two-block system after the collision is given by the equation $v = \frac{\sqrt{km_1}}{m_1 + m_2}\Delta x$.

Cons of E

$U_i = K_f \quad \frac{1}{2}k(\Delta x)^2 = \frac{1}{2}m_1 v_1^2 \quad m_1 v_1 = \sqrt{km_1}\,\Delta x$

$m_1 k(\Delta x)^2 = (m_1 v_1)^2$

Cons of p

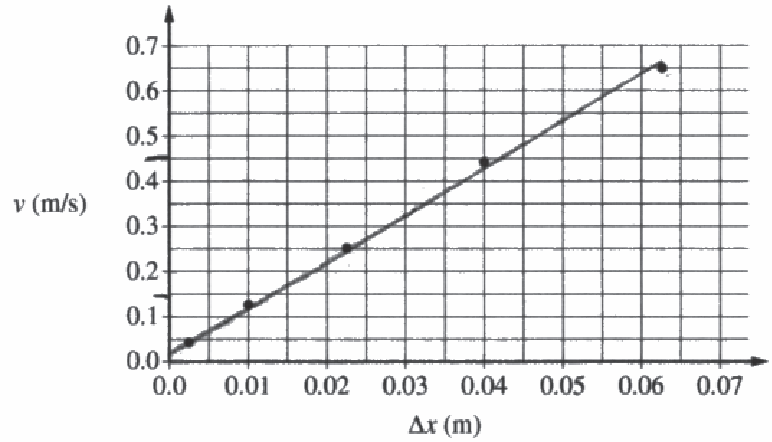
$p_i = p_f \quad m_1 v_1 = (m_1 + m_2)v$

$v = \frac{m_1 v_1}{m_1 + m_2} = \frac{\sqrt{km_1}}{m_1 + m_2}\Delta x$

Question 2

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

(d) A group of students use the setup to perform an experiment. They measure the mass of Block 1 to be $m_1 = 0.500$ kg, and the spring constant k of the spring to be 150 N/m. The mass of Block 2 is unknown. They perform several trials and in each trial the spring is compressed a different distance Δx and the final velocity v of the two-block system is measured. They graph v as a function of Δx, as shown below.



i. Draw a line that represents the best fit to the data points shown.

ii. Use the best-fit line to calculate the mass of Block 2.

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{0.45 - 0.15}{0.0425 - 0.0125} = 10.$$

$$v = \frac{\sqrt{k m_1}}{m_1 + m_2}\Delta x$$

$$\text{slope} = \frac{\sqrt{k m_1}}{m_1 + m_2}$$

$$m_2 = \frac{\sqrt{k m_1}}{\text{slope}} - m_1 = \frac{\sqrt{(150\ \text{N/m})(0.500\ \text{kg})}}{10\ \text{s}^{-1}} - 0.500\ \text{kg} = \boxed{0.37\ \text{kg}}$$

Question 2

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

(e) After the experiment, the students use a balance to measure the mass of Block 2 and find it to be greater than what was determined in part (d). To explain this discrepancy, one of the students proposes that the spring constant was incorrectly measured at the beginning of the experiment. The students measure the spring constant again and record a new value, k'.

Should the students expect that k' be greater than 150 N / m, less than 150 N / m, or equal to 150 N / m ?

✓ $k' > 150$ N / m ____ $k' < 150$ N / m ____ $k' = 150$ N / m

Justify your answer.

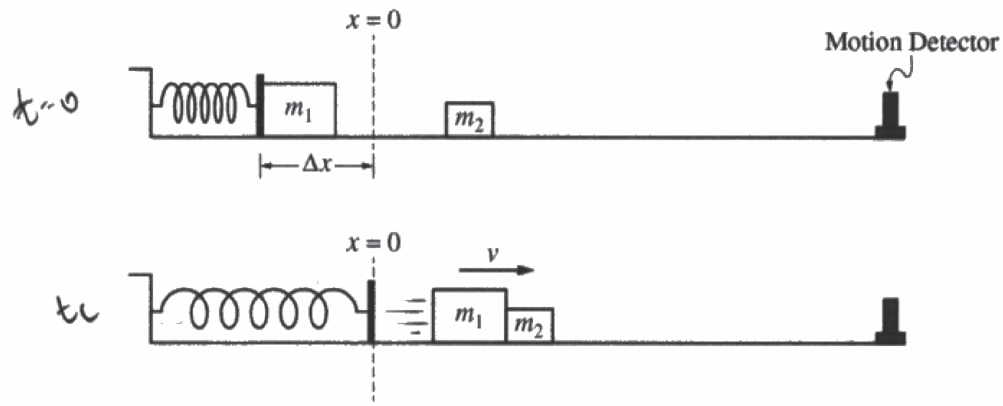
My ~~m~~ m_2 from d was too small,

from the relation $m_2 = \frac{\sqrt{km_1}}{slope} - m_1$, m_2 too small could be caused by the k value of 150 N/m being too small.

So, the new k' will be larger than k

Question 2

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



2. Block 1 of mass m_1 is held at rest while compressing an ideal spring an amount Δx. The spring constant of the spring is k. Block 2 has mass m_2, where $m_2 < m_1$. At time $t = 0$, Block 1 is released. At time t_C, the spring is no longer compressed and Block 1 immediately collides with and sticks to Block 2. The blocks stick together and the two-block system moves with constant speed v, as shown. Frictional effects are negligible.

(a) The impulse on Block 1 from the spring during the time interval $0 < t < t_C$ is J_S. The impulse on Block 1 from Block 2 during the collision is J_2. Which of the following expressions correctly compares the magnitudes of J_S and J_2?

__ $J_S > J_2$ __ $J_S < J_2$ X $J_S = J_2$

Justify your answer.

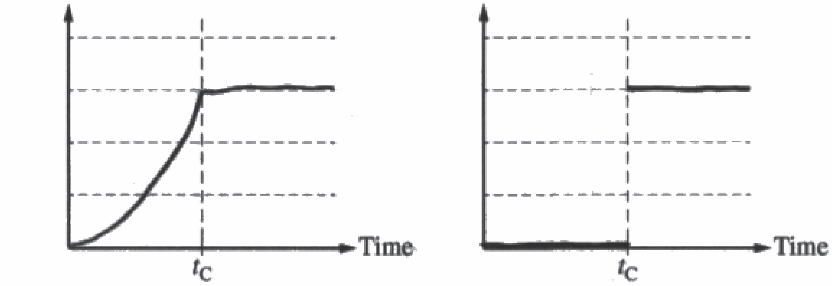
conservation of momentum → change in Block 1's momentum would equal change in Block 2's.

GO ON TO THE NEXT PAGE.

Question 2

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

(b) On the following axes, draw graphs of the magnitude of the momentum of each block as a function of time, before and after t_C. The collision occurs in a negligible amount of time. The grid lines on each graph are drawn to the same scale.



(c) Show that the velocity v of the two-block system after the collision is given by the equation $v = \frac{\sqrt{km_1}}{m_1 + m_2}\Delta x$.

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

$$\not{\frac{1}{2}}kx^2 = \not{\frac{1}{2}}(m_1)v_1^2$$

$$v_1 = \sqrt{\frac{kx^2}{m_1}}$$

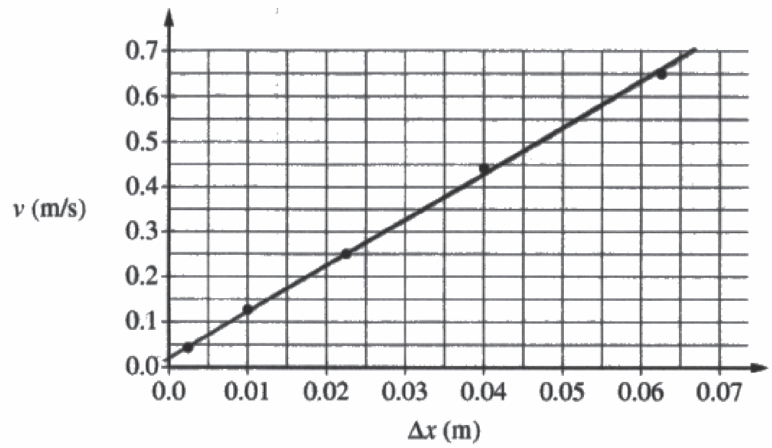
$$m_1v_1 = (m_1 + m_2)v$$

$$v = \frac{m_1v_1}{m_1 + m_2} = \frac{m_1\sqrt{\frac{kx^2}{m_1}}}{m_1 + m_2} = \frac{\sqrt{km_1}}{m_1 + m_2}x$$

Question 2

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

(d) A group of students use the setup to perform an experiment. They measure the mass of Block 1 to be $m_1 = 0.500$ kg, and the spring constant k of the spring to be 150 N/m. The mass of Block 2 is unknown. They perform several trials and in each trial the spring is compressed a different distance Δx and the final velocity v of the two-block system is measured. They graph v as a function of Δx, as shown below.



i. Draw a line that represents the best fit to the data points shown.

ii. Use the best-fit line to calculate the mass of Block 2.

$m_1 = 0.500$ kg , $m_2 = ?$, $k = 150$ N/m

$$v = \frac{\sqrt{km_1}}{m_1+m_2}\Delta x$$

$$\frac{v}{\Delta x} = \frac{\sqrt{km_1}}{m_1+m_2} = \text{slope of line} = \frac{0.45-0.25}{0.04-0.023} \approx \frac{0.2}{0.02} \approx 10$$

$$\frac{\sqrt{150 \cdot 0.500}}{0.500+m_2} = 10 \; , \quad m_2 = \boxed{0.366 \text{ kg}}$$

Question 2

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

(e) After the experiment, the students use a balance to measure the mass of Block 2 and find it to be greater than what was determined in part (d). To explain this discrepancy, one of the students proposes that the spring constant was incorrectly measured at the beginning of the experiment. The students measure the spring constant again and record a new value, k'.

Should the students expect that k' be greater than 150 N / m, less than 150 N / m, or equal to 150 N / m ?

_X_ $k' > 150\,\text{N/m}$ ____ $k' < 150\,\text{N/m}$ ____ $k' = 150\,\text{N/m}$

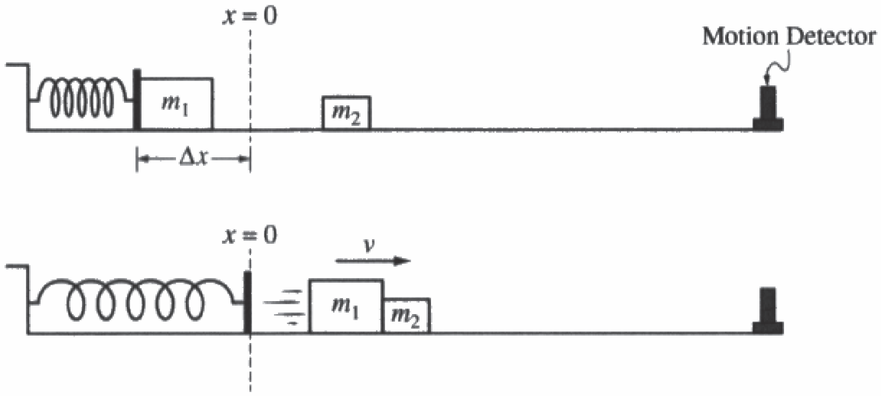
Justify your answer.

According to the equation $\frac{v}{\Delta x} = \frac{\sqrt{km_1}}{m_1+m_2}$, $m_2 = \frac{\sqrt{km_1}}{v}\Delta x - m_1$.

As k increases, m_2 increases. So $k' > 150$ N/m since m_2 was found to be greater.

Question 2

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



2. Block 1 of mass m_1 is held at rest while compressing an ideal spring an amount Δx. The spring constant of the spring is k. Block 2 has mass m_2, where $m_2 < m_1$. At time $t = 0$, Block 1 is released. At time t_C, the spring is no longer compressed and Block 1 immediately collides with and sticks to Block 2. The blocks stick together and the two-block system moves with constant speed v, as shown. Frictional effects are negligible.

(a) The impulse on Block 1 from the spring during the time interval $0 < t < t_C$ is J_S. The impulse on Block 1 from Block 2 during the collision is J_2. Which of the following expressions correctly compares the magnitudes of J_S and J_2 ?

✓ $J_S > J_2$ ___ $J_S < J_2$ ___ $J_S = J_2$

$J = \Delta p = mv$

Justify your answer.

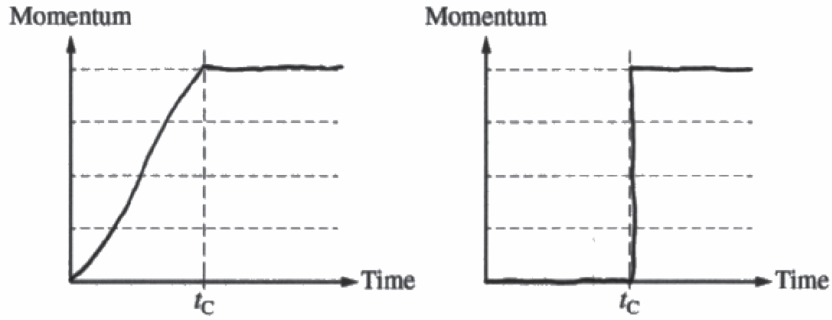
~~The Js~~ J is greater for block 1 since it has a much larger mass and the velocity is constant or the same for block 1 and 2 so the Js has to be larger than J_2.

Question 2

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

(b) On the following axes, draw graphs of the magnitude of the momentum of each block as a function of time, before and after t_C. The collision occurs in a negligible amount of time. The grid lines on each graph are drawn to the same scale.

pencil



Block 1 Block 2

(c) Show that the velocity v of the two-block system after the collision is given by the equation $v = \frac{\sqrt{km_1}}{m_1 + m_2} \Delta x$.

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

$mv^2 = kx^2 + m_1v^2 + m_2v^2$

$m_1v = \frac{kx^2 + m_1v + m_2v}{m_1}$

$v = \frac{kx^2 + m_1v + m_2v}{m_1}$

$v = \frac{\sqrt{kx^2 + m_1}}{m_1 + m_2}$

$v = \frac{\sqrt{kx + m_1}}{m_1 + m_2} x$

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

$\frac{1}{2}kx^2 + \frac{1}{2}mv^2 + 0 = \frac{1}{2}kx^2 + \frac{1}{2}mv^2 + \frac{1}{2}mv^2$

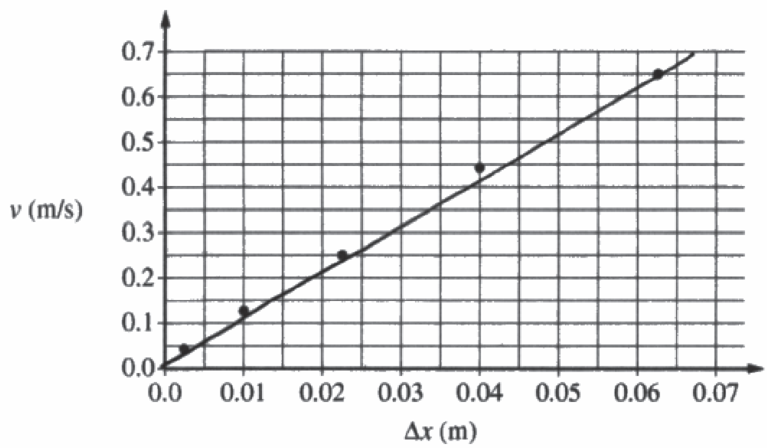
$\frac{1}{2}kx^2 + \frac{1}{2}mv^2 + \frac{1}{2}mv^2$

$kx^2 + mv^2$

Question 2

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

(d) A group of students use the setup to perform an experiment. They measure the mass of Block 1 to be $m_1 = 0.500$ kg, and the spring constant k of the spring to be 150 N/m. The mass of Block 2 is unknown. They perform several trials and in each trial the spring is compressed a different distance Δx and the final velocity v of the two-block system is measured. They graph v as a function of Δx, as shown below.



i. Draw a line that represents the best fit to the data points shown.

ii. Use the best-fit line to calculate the mass of Block 2.

$$v = \frac{\sqrt{km_1}}{m_1 + m_2} x$$

$$\frac{vm_1 + m_2 = \sqrt{km_1} \cdot x}{vm_1}$$

$$m_2 = \frac{\sqrt{km_1}\, x}{vm_1}$$

$$m_2 = \frac{\sqrt{150(0.5)}\ 0.0225}{0.25}$$

$$\boxed{m_2 = 0.779 \text{ kg}}$$

GO ON TO THE NEXT PAGE.

Question 2

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

(e) After the experiment, the students use a balance to measure the mass of Block 2 and find it to be greater than what was determined in part (d). To explain this discrepancy, one of the students proposes that the spring constant was incorrectly measured at the beginning of the experiment. The students measure the spring constant again and record a new value, k'.

Should the students expect that k' be greater than 150 N / m, less than 150 N / m, or equal to 150 N / m ?

✓ $k' > 150\ \text{N/m}$ ____ $k' < 150\ \text{N/m}$ ____ $k' = 150\ \text{N/m}$

Justify your answer.

When you plug in a larger value into the equation of $m_2 = \frac{\sqrt{km_1}\, x}{v m_1}$ you will receive a larger mass value for m_2.

GO ON TO THE NEXT PAGE.

Question 2

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

Overview

The responses were expected to demonstrate the ability to:

- Indicate that impulse changes momentum.
- Graph the individual momenta of two objects of different masses before and after an inelastic collision.
- Use the conservation of energy for objects on springs.
- Use momentum conservation to derive the speed of two objects after a collision.
- Draw a best-fit line when given a set of plotted data points.
- Calculate the slope of the best-fit line drawn and relate the slope of the best-fit line to a given equation.
- Analyze the functional dependence between two variables to determine how a change in one variable will affect the other variable.

Sample: 2A
Score: 15

Part (a) earned 2 points. The first point was earned for correctly selecting "$J_s > J_2$" with an attempt at a relevant justification. The second point was earned for providing a valid justification by stating that the change in momentum from the spring is larger than the change in momentum from the collision because Block 1 is not brought back to a speed of zero. Part (b) earned 4 points. The first point was earned because the response has an increasing concave down curve to max value for Block 1 and zero indicated momentum for Block 2 before the indicated collision time. The second point was earned because the response indicates a horizontal line clearly below the peak value at the indicated collision time for Block 1. The third point was earned because the response indicates a horizontal line clearly below Block 1's horizontal line at and after the indicated collision time. The fourth point was earned because the response shows the decrease in momentum of Block 1 has the same magnitude as the increase in momentum of Block 2. Part (c) earned 3 points. The first point was earned because the response indicates the use of conservation of energy. The second point was earned because the response indicates the use of conservation of momentum. The third point was earned because the response combines two correct equations to obtain the given equation. Part (d)(i) earned 1 point because the response draws a correct best-fit line for the data. Part (d)(ii) earned 3 points. The first point was earned because the response calculates a slope using points on the line of best fit. The second point was earned because the response correctly relates slope to the mass of Block 2. The third point was earned because the response calculates a mass for Block 2 within the acceptable range. Part (e) earned 2 points. The first point was earned because the response correctly selects "$k' > 150\ \text{N/m}$" with an attempt at a relevant justification. The second point was earned because the response provides a valid justification by stating the equation and the mathematical relationship between the mass of Block 2 and the spring constant.

Question 2 (continued)

Sample: 2B
Score: 8

Part (a) earned 0 points. The first point was not earned because the response does not select "$J_s > J_2$" with an attempt at a relevant justification. The second point cannot be earned without earning the first point. Part (b) earned 0 points. The first point was not earned because the response draws an incorrect curve for Block 1 before the indicated collision time. The second point was not earned because the response does not indicate the momentum of Block 1 decreases after the collision. The third point was not earned because the response does not indicate a horizontal line clearly below Block 1's horizontal line at and after the indicated collision time. The fourth point was not earned because the response shows a magnitude of change in momentum of Block 2 greater than that of Block 1. Part (c) earned 3 points. The first point was earned because the response indicates the use of conservation of energy. The second point was earned because the response indicates the use of conservation of momentum. The third point was earned because the response combines two correct equations to obtain the given equation. Part (d)(i) earned 1 point because the response draws a correct best-fit line for the data. Part (d)(ii) earned 2 points. The first point was not earned because the response calculates a slope using points that are not on the line of best fit. The second point was earned because the response correctly relates slope to the mass of Block 2. The third point was earned because the response calculates a mass for Block 2 within the acceptable range. Part (e) earned 2 points. The first point was earned because the response correctly selects "$k' > 150 \text{ N/m}$" with an attempt at a relevant justification. The second point was earned because the response provides a valid justification by stating the equation and the mathematical relationship between the mass of Block 2 and the spring constant.

Sample: 2C
Score: 3

Part (a) earned 1 point. The first point was earned because the response correctly selects "$J_s > J_2$" with an attempt at a relevant justification. The second point was not earned because the response does not provide a valid justification. Part (b) earned 0 points. The first point was not earned because the response does not have the correct curve for Block 1 before the indicated collision time. The second point was not earned because the response does not indicate a horizontal line clearly below the peak value at the indicated collision time. The third point was not earned because the response does not indicate a horizontal line clearly below Block 1's horizontal line at and after the indicated collision time. The fourth point was not earned because the response does not show the decrease in momentum of Block 1 having the same magnitude as the increase in momentum of Block 2. Part (c) earned 1 point. The first point was earned because the response indicates the use of conservation of energy. The second point was not earned because the response does not indicate the use of conservation of momentum. The third point was not earned because the response does not combine two correct equations to obtain the given equation. Part (d)(i) earned 0 points because the response does not draw a correct straight best-fit line for the data. Part (d)(ii) earned 0 points. The first point was not earned because the response does not calculate a slope. The second point was not earned because the response does not relate the slope to the mass of Block 2. The third point was not earned because the response provides a mass for Block 2 that is not within the acceptable range. Part (e) earned 1 point. The first point was earned because the response correctly selects "$k' > 150 \text{ N/m}$" with an attempt at a relevant justification. The second point was not earned because the response does not provide a valid justification. An attempt is made but does not state clear mathematical reasoning.