2023

AP

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 3

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

AP Central is the official online home for the AP Program: apcentral.collegeboard.org.

Question 3: Quantitative/Qualitative Translation — 12 points

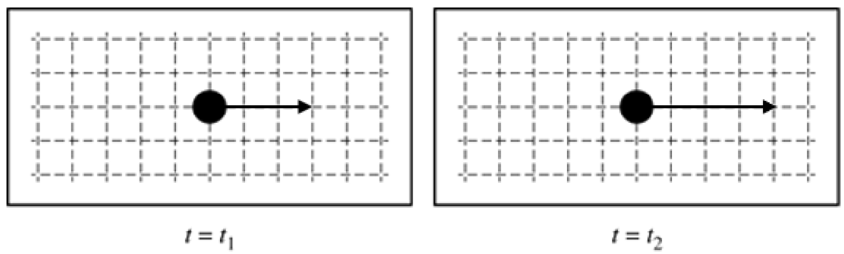
(a)(i) For drawing rightward arrows in both diagrams — **1 point**

For the length of the arrow at $t = t_2$ being longer than the arrow at $t = t_1$ — **1 point**

Scoring Notes:

- A maximum of 1 point can be earned if extraneous unlabeled arrows are drawn.
- A maximum of 1 point can be earned if incorrect labeled forces are drawn.

Example Response



(a)(ii) For an explanation that refers to the difference in the stretch length and indicates that the magnitude of the spring force is (or is not) related to the stretch length, consistent with the force diagram drawn in part (a)(i) — **1 point**

Example Response

The spring force arrow drawn at $t = t_2$ is longer because the spring is stretched a greater distance at that time and the spring force is related to the stretch distance.

(a)(iii)	For a correct selection with an attempt at a relevant justification, or a selection and justification consistent with the response in part (a)(ii)	**1 point**
	For indicating that the spring force is the net force **Scoring Note:** Stating $F = kx$ earns this point.	**1 point**
	For indicating that the net force is related to the speed (or acceleration) **Scoring Note:** The relationship does not need to be defined to earn this point.	**1 point**

Example Response

_____ $v_1 > v_2$ __X__ $v_1 < v_2$ _____ $v_1 = v_2$

The net force is the spring force. When the spring is stretched a greater length, the spring force is greater, so the net force is greater, and therefore the tangential speed is greater at $t = t_2$.

Total for part (a) 6 points

(b)(i) For the correct answer: $F_{\text{net}} = k_0 d$ **1 point**

Scoring Notes:

- An answer of kx does not earn this point.
- Points for part (b)(i) may be earned if correct in (b)(ii).

Example Response

$F_{\text{net}} = \Sigma F = F_s$
$F_{\text{net}} = \Sigma F = k_0 d$

(b)(ii) For a multistep derivation that begins with Newton's second law: $\Sigma F = ma$ **1 point**

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

- Substituting kx for force into Newton's second law
- Substituting $\frac{v^2}{r}$ for acceleration into Newton's second law
- Substituting $(L + d)$ for the radius

For the consistent answer in terms of the given variables: $v = \sqrt{\frac{k_0 d(L + d)}{m_0}}$ **1 point**

Scoring Notes:

- Subscripts for m and k are not required to earn this point.
- Points in (b)(ii) can be earned if correct in (b)(i).

Example Response

$\Sigma F = ma_c$

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

$k_0 d = \frac{m_0 v^2}{L + d}$

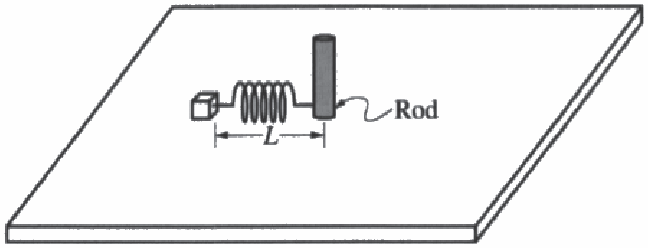
$v = \sqrt{\frac{k_0 d(L + d)}{m_0}}$

Total for part (b) 4 points

(c)	For an answer that attempts to use functional dependence to relate the tangential speed with stretched distance **Scoring Note:** It is not necessary to use the functional dependence correctly to earn this point.	**1 point**
	For a correct explanation for why the derived equation in part (b)(ii) does or does not support the reasoning in part (a)	**1 point**
	Example Response *My equation from part (b)(ii) agrees with my reasoning in part (a). The tangential speed of the block as it travels in a horizontal circle is related to the distance the spring is stretched. The greater the tangential speed of the block, the greater distance the spring is stretched. The equation shows this because the d is in the numerator.*	
	Total for part (c)	**2 points**
	Total for question 3	**12 points**

Question 3

Begin your response to **QUESTION 3** on this page.



3. (12 points, suggested time 25 minutes)

A small block of mass m_0 is attached to the end of a spring of spring constant k_0 that is attached to a rod on a horizontal table. The rod is attached to a motor so that the rod can rotate at various speeds about its axis. When the rod is not rotating, the block is at rest and the spring is at its unstretched length L, as shown. All frictional forces are negligible.

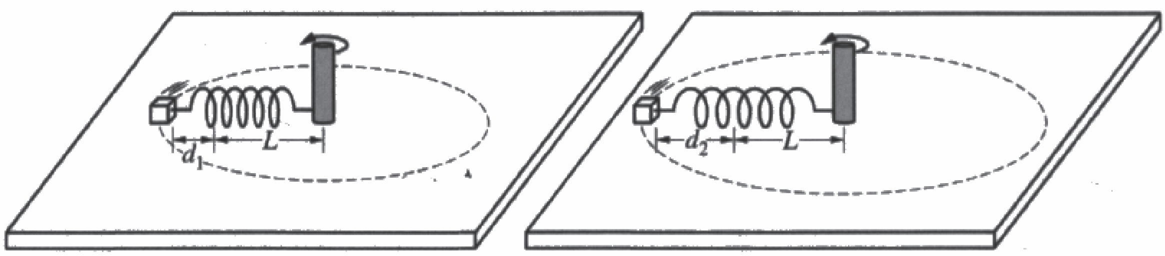


Figure 1 Figure 2

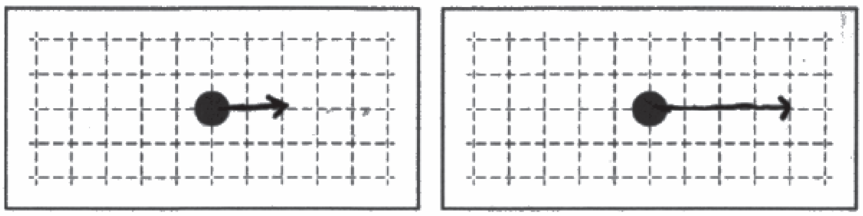
(a) At time $t = t_1$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_1 and the spring is stretched a distance d_1 from the spring's unstretched length, as shown in Figure 1. At time $t = t_2$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_2 and the spring is stretched a distance d_2 from the spring's unstretched length, where $d_2 > d_1$, as shown in Figure 2.

GO ON TO THE NEXT PAGE.

Question 3

Continue your response to QUESTION 3 on this page.

i. On the following dots, which represent the block at the locations shown in Figure 1 and Figure 2, draw the force that is exerted on the block by the spring at times $t = t_1$ and $t = t_2$. The spring force must be represented by a distinct arrow starting on, and pointing away from, the dot.
Note: Draw the relative lengths of the vectors to reflect the relative magnitudes of the forces exerted by the spring at both times.



$t = t_1$ $t = t_2$

ii. Referencing d_1 and d_2, describe your reasoning for drawing the arrows the length that you did in part (a)(i).

$d_2 > d_1$, so the spring at t_2 is stretched further and applies a greater force compared to t_1. The further stretched spring at t_2 applies a greater force on the block, so the force on the block by the spring is greater and has a higher magnitude.

iii. Is the tangential speed v_1 of the block at time $t = t_1$ greater than, less than, or equal to the tangential speed v_2 of the block at time $t = t_2$?

____ $v_1 > v_2$ __✓__ $v_1 < v_2$ ____ $v_1 = v_2$

Justify your answer without using equations.

When the tangential velocity of the block is greater, the centripetal acceleration and force also will be greater. The greater force the spring applies to the block, the further it stretches, such as at t_2

GO ON TO THE NEXT PAGE.

Question 3

Continue your response to **QUESTION 3** on this page.

(b) Consider a scenario where the block travels in a circular path where the spring is stretched a distance d from its unstretched length L.

i. Determine an expression for the magnitude of the net force F_{net} exerted on the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.

$|F| = K|X|$

$F_{net} = K_0 d$

ii. Derive an equation for the tangential speed v of the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.

$F_{net} = ma$

$a_c = \frac{v^2}{r}$

$r = L + d$

$F_{net} = K_0 d$

$F_{net} = m_0 a_c$

$K_0 d = \frac{m v^2}{L+d}$

$\sqrt{\frac{(L+d)(K_0 d)}{m_0}} = v$

(c) Does your equation for the tangential speed v of the block from part (b)(ii) agree with your reasoning from part (a) ?

✓ Yes ____ No

Explain your reasoning.

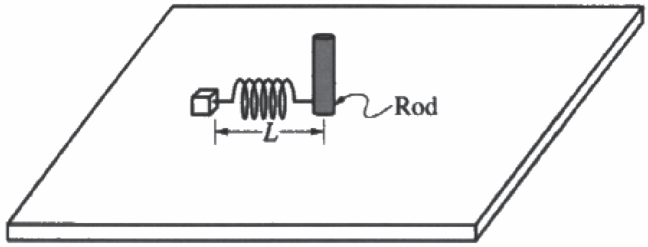
If L, K_0, and m_0 are held constant,

so $\sqrt{\frac{(L+d)(K_0 d)}{m_0}} = V$,

If V increases, so does d, and vice versa

Question 3

Begin your response to **QUESTION 3** on this page.



3. (12 points, suggested time 25 minutes)

A small block of mass m_0 is attached to the end of a spring of spring constant k_0 that is attached to a rod on a horizontal table. The rod is attached to a motor so that the rod can rotate at various speeds about its axis. When the rod is not rotating, the block is at rest and the spring is at its unstretched length L, as shown. All frictional forces are negligible.

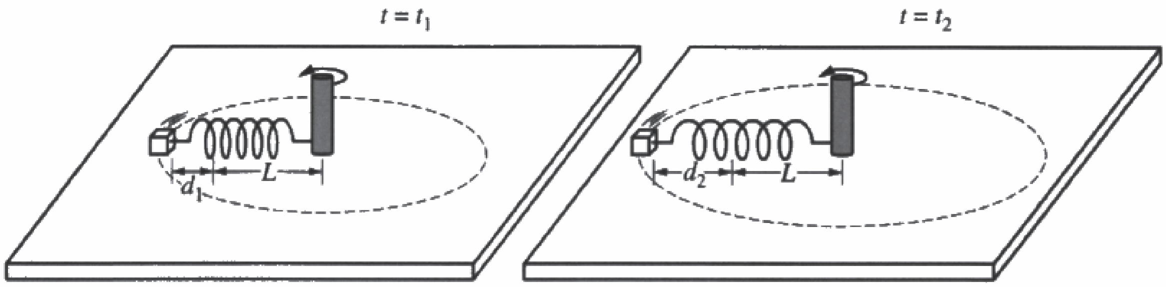


Figure 1 Figure 2

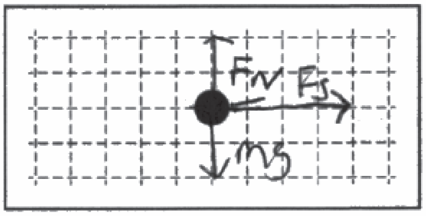
(a) At time $t = t_1$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_1 and the spring is stretched a distance d_1 from the spring's unstretched length, as shown in Figure 1. At time $t = t_2$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_2 and the spring is stretched a distance d_2 from the spring's unstretched length, where $d_2 > d_1$, as shown in Figure 2.

GO ON TO THE NEXT PAGE.

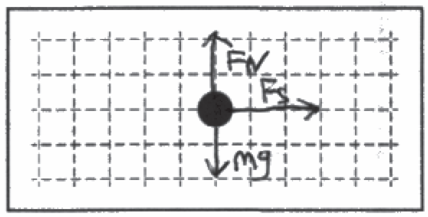
Question 3

Continue your response to QUESTION 3 on this page.

i. On the following dots, which represent the block at the locations shown in Figure 1 and Figure 2, draw the force that is exerted on the block by the spring at times $t = t_1$ and $t = t_2$. The spring force must be represented by a distinct arrow starting on, and pointing away from, the dot.
Note: Draw the relative lengths of the vectors to reflect the relative magnitudes of the forces exerted by the spring at both times.



$t = t_1$



$t = t_2$

ii. Referencing d_1 and d_2, describe your reasoning for drawing the arrows the length that you did in part (a)(i).

As the distance grows between the block and ~~t~~ the spring force will get ~~w~~weaker and ~~w~~weaker since it is further away from the center

iii. Is the tangential speed v_1 of the block at time $t = t_1$ greater than, less than, or equal to the tangential speed v_2 of the block at time $t = t_2$?

____ $v_1 > v_2$ ✓ $v_1 < v_2$ ~~✓~~ $v_1 = v_2$

Justify your answer without using equations.

Tangential speed ~~is~~ is affected by the distance from the center. the lower the distance the higher the tangential speed

GO ON TO THE NEXT PAGE.

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

Question 3

Continue your response to QUESTION 3 on this page.

(b) Consider a scenario where the block travels in a circular path where the spring is stretched a distance d from its unstretched length L.

i. Determine an expression for the magnitude of the net force F_{net} exerted on the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.

$\Sigma F = ma$ $\quad F_{net} = m_0 \frac{v^2}{r}$ $\quad F_{net} = m_0 \frac{(k_0 \cdot F_N)^2}{L+d}$

$F_{net} = m_0 \frac{(k_0 \cdot F_N)^2}{L+d}$

ii. Derive an equation for the tangential speed v of the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.

~~$v^2 k$~~

$v = k_0 \cdot F_N$

$k_0 \cdot F_N = \frac{F_{net} \cdot (L+d)}{m_0}$

(c) Does your equation for the tangential speed v of the block from part (b)(ii) agree with your reasoning from part (a)?

✓ Yes ____ No

Explain your reasoning.

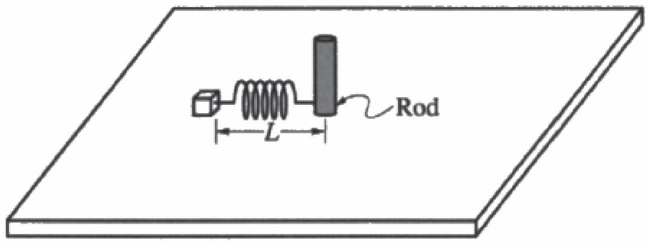
As L+D is in the numerator it means that an increase in the distance would actually increase the tangential speed of the block.

GO ON TO THE NEXT PAGE.

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

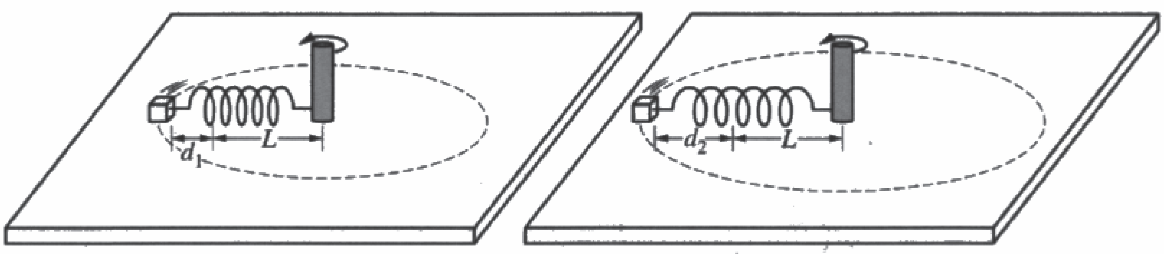
Question 3

Begin your response to QUESTION 3 on this page.



3. (12 points, suggested time 25 minutes)

A small block of mass m_0 is attached to the end of a spring of spring constant k_0 that is attached to a rod on a horizontal table. The rod is attached to a motor so that the rod can rotate at various speeds about its axis. When the rod is not rotating, the block is at rest and the spring is at its unstretched length L, as shown. All frictional forces are negligible.



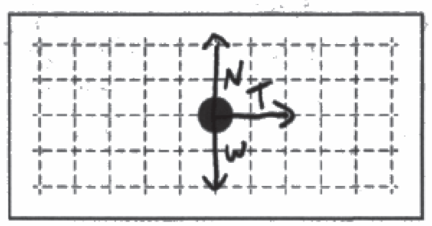
(a) At time $t = t_1$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_1 and the spring is stretched a distance d_1 from the spring's unstretched length, as shown in Figure 1. At time $t = t_2$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_2 and the spring is stretched a distance d_2 from the spring's unstretched length, where $d_2 > d_1$, as shown in Figure 2.

GO ON TO THE NEXT PAGE.

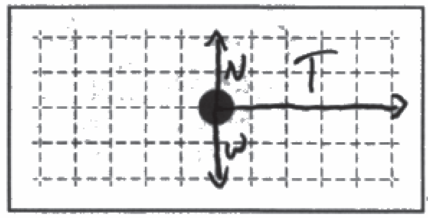
Question 3

Continue your response to **QUESTION 3** on this page.

i. On the following dots, which represent the block at the locations shown in Figure 1 and Figure 2, draw the force that is exerted on the block by the spring at times $t = t_1$ and $t = t_2$. The spring force must be represented by a distinct arrow starting on, and pointing away from, the dot.
Note: Draw the relative lengths of the vectors to reflect the relative magnitudes of the forces exerted by the spring at both times.



$t = t_1$



$t = t_2$

ii. Referencing d_1 and d_2, describe your reasoning for drawing the arrows the length that you did in part (a)(i).

I drew the arrow for tension at $t=t_1$ smaller than $t=t_2$ because d_1 is smaller at $t=t_1$ meaning tension does not have to pull as hard as it does when the block is d_2.

iii. Is the tangential speed v_1 of the block at time $t = t_1$ greater than, less than, or equal to the tangential speed v_2 of the block at time $t = t_2$?

____ $v_1 > v_2$ _X_ $v_1 < v_2$ ____ $v_1 = v_2$

Justify your answer without using equations.

The rod is spinning the block faster at t_2 meaning that it has a greater velocity.

Question 3

Continue your response to QUESTION 3 on this page.

(b) Consider a scenario where the block travels in a circular path where the spring is stretched a distance d from its unstretched length L.

i. Determine an expression for the magnitude of the net force F_{net} exerted on the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.

$\tau_{net} = I\alpha$ $f(L+d) = I\alpha$

$f(L+d) = I \frac{1}{2}kd^2$

$f(L+d) = \frac{m_0}{L+d} \cdot \frac{1}{2}kd^2$

$F_{net} = m_0 \cdot \frac{1}{2}kd^2$

ii. Derive an equation for the tangential speed v of the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.

???

$R = L+d$

$T = \frac{1}{2}kd^2$

$V_T = \omega \cdot R$

$V_T = \omega \cdot L+d$

(c) Does your equation for the tangential speed v of the block from part (b)(ii) agree with your reasoning from part (a) ?

____ Yes ____ No

Explain your reasoning.

GO ON TO THE NEXT PAGE.

Question 3

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

Overview

The responses were expected to demonstrate the ability to:

- Identify a net force in a given scenario.
- Compare relative magnitudes of the net force in two different scenarios.
- Relate force and spring length through functional dependence.
- Relate force and tangential velocity in a circular motion through functional dependence.
- Compare tangential velocities in two scenarios based on centripetal force/acceleration.
- Derive an expression for tangential velocity beginning with Newton's second law equation.
- Identify the net force as a centripetal force.
- Identify the functional dependence between stretch length of a rotating spring and tangential velocity.
- Determine consistency between reasoning based on a conceptual argument and a derived equation.

Sample: 3A
Score: 12

Part (a)(i) earned 2 points. One point was earned for indicating two arrows drawn to the right. The second point was earned for indicating the length of the arrow at t_2 as longer than the arrow at t_1. Part (a)(ii) earned 1 point for stating, "the spring at t_2 is stretched further and applies a greater force compared to t_1." The length is related to the spring force. Part (a)(iii) earned 3 points. One point was earned for checking the correct selection, $v_1 < v_2$, with an attempt to justify the selection. The second point was earned for identifying the force as the spring force by stating, "[t]he greater force the spring applies to the block" and indicating the net force as the centripetal force. The third point was earned for stating, "When the tangential velocity of the block is greater, the centripetal acceleration and force will also be greater." Part (b)(i) earned 1 point for correctly identifying the net force expression with the correct variables substituted. Part (b)(ii) earned 3 points. One point was earned for attempting to use Newton's second law. The second point was earned for correctly substituting $L + d$ for the radius, and the third point was earned for giving the correct equation. Part (c) earned 2 points. One point was earned for indicating a functional dependence between velocity and distance by stating, "If v increases, so does d, and vice versa." The second point was earned for correctly relating the equation from part (b) to the reasoning in part (a).

Question 3 (continued)

Sample: 3B
Score: 7

Part (a)(i) earned 1 point for indicating two arrows drawn to the right. Extraneous arrows are labeled and correct. The second point was not earned because the response does not indicate the length of the arrow at t_2 is longer than the arrow at t_1. Part (a)(ii) earned 1 point for stating, "As the distance grows between the block and L the spring force will get weaker and weaker." The length is related to the spring force. This is consistent with the arrows drawn in part (a)(i). Part (a)(iii) earned 1 point for checking the correct selection, $v_1 < v_2$, with an attempt to justify the selection. The second point was not earned because the response does not identify the spring force as the net force. The third point was not earned because the response does not show a relationship between the spring force and the velocity. Part (b)(i) earned no points because the response does not give a correct expression for the net force. Part (b)(ii) earned 2 points. One point was earned for attempting to use Newton's second law. The second point was earned for correctly substituting $\frac{v^2}{r}$ for the centripetal acceleration, and the third point was not earned because the response did not give the correct equation. Part (c) earned 2 points. One point was earned for attempting to express a functional dependence between velocity and distance by stating, "an increase in the distance would actually increase the tangential speed of the block." The second point was earned for correctly relating the equation in part (b) to support the reasoning in part (a). The response states, "As $L + d$ is in the numerator it means that an increase in the distance would actually increase the tangential speed."

Sample: 3C
Score: 5

Part (a)(i) earned 2 points. One point was earned for indicating two arrows pointing to the right, and the other point was earned for indicating the arrow for t_1 is shorter than the arrow for t_2. Extraneous forces are labeled and correct. Part (a)(ii) earned 1 point for stating, "I drew the arrow for tension at $t = t_1$ smaller than $t = t_2$ because d_1 is smaller." The force (tension) is related to the stretch. Part (a)(iii) earned 1 point for checking the correct selection, $v_1 < v_2$, and attempting a relevant justification. The second point was not earned because the response does not identify the spring force as the net force. The third point was not earned because the response does not show a relationship between the spring force and the velocity. Part (b)(i) earned no points because the response does not give a correct expression for the net force. Part (b)(ii) earned 1 point for correctly substituting $(L + d)$ for the radius. The second point was not earned because the response does not start with Newton's second law, and the third point was not earned because the response does not give the correct equation. Part (c) earned no points. The first point was not earned because the response does not attempt to show a functional dependence between velocity and stretch length. The second point was not earned because the response does not attempt to relate the equation in part (b) to support the reasoning in part (a).