2023

AP®

AP® Physics C: Mechanics

Sample Student Responses and Scoring Commentary Set 1

Inside:

Free-Response Question 1

☑ Scoring Guidelines

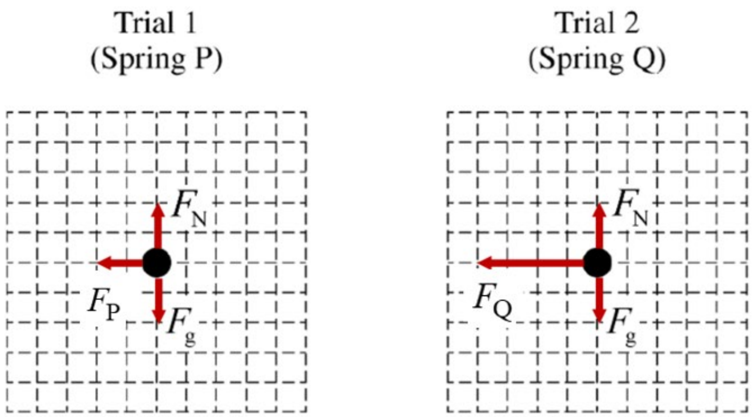
☑ Student Samples

☑ Scoring Commentary

Question 1: Free-Response Question — 15 points

(a)	For correctly drawing and labeling the force of gravity and the normal force on both dots	**1 point**
	For drawing and labeling the spring force to the left on both dots, where the force for Spring Q (Trial 2) is twice as long as the force for Spring P (Trial 1)	**1 point**

Example Solution



Scoring Note: Examples of appropriate labels for the force due to gravity include: F_G, F_g, F_{grav}, W, mg, Mg, "grav force", "F Earth on block", "F on block by Earth", $F_{\text{Earth on block}}$, $F_{\text{E,Block}}$. The labels G and g are not appropriate labels for the force due to gravity. F_n, F_N, N, "normal force", "ground force", or similar labels may be used for the normal force.

Scoring Note: A response that includes extraneous vectors can earn a maximum of 1 point.

	Total for part (a)	**2 points**
(b)(i)	For a statement that the work is equal to the area under the curve	**1 point**
(b)(ii)	For stating the spring compression will be greater than 0.040 m with an attempt at a relevant justification	**1 point**
	For a justification that indicates that the heights are equal when the area between each function and the horizontal axis are equal, which happens after $x = 0.040$ m	**1 point**

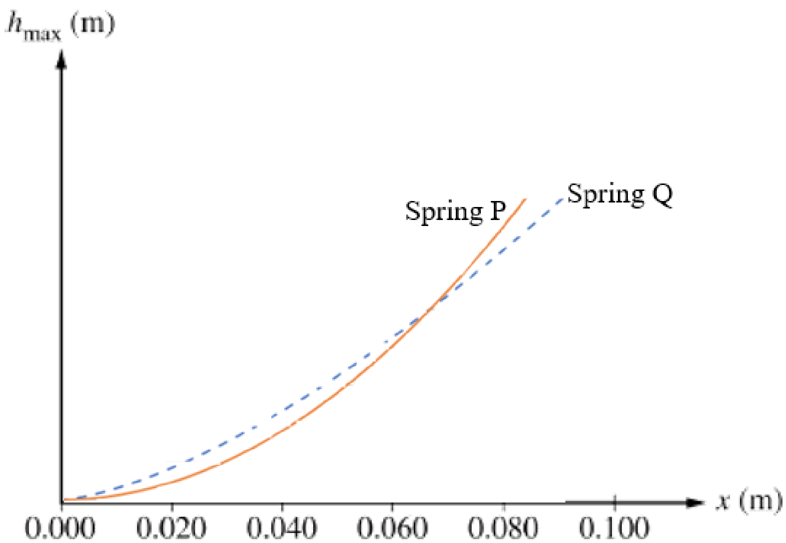
Scoring Note: While a mathematical solution is not required to earn credit for this point, students may reference a mathematical solution.

Example Solution

The work done by each spring is equal to the area under their respective curves. This work is converted to the change in potential energy and therefore relates to the maximum height reached by the block. At $x = 0.040$ m, the area under the curve for Spring Q is greater than that of Spring P. Therefore, it is not until a compression greater than $x = 0.040$ m that the areas under the two curves are equal, have the same work, and convert to the same maximum height.

(b)(iii)	For drawing smooth concave upward curves for both springs P and Q	**1 point**
	For showing that the curves intersect after $x = 0.05$ m, but before $x = 0.10$ m	**1 point**
	For showing the curve for Spring P below Spring Q before an intersection and the curve for Spring P above Spring Q after this intersection	**1 point**

Example Solution



Total for part (b) **6 points**

(c)(i)	For correctly applying conservation of energy to solve for the velocity of Block A just before it collides with Block B	**1 point**

Example Response

$$m_A gH = \frac{1}{2} m_A v_A^2$$
$$v_A = \sqrt{2gH}$$
$$v_A = \sqrt{2\left(9.8\ \frac{\text{m}}{\text{s}^2}\right)(0.75\ \text{m})}$$
$$\therefore v_A = 3.8\ \text{m/s}$$

For substituting the calculated value for v_A into a correct conservation of linear momentum expression and solving for v_f — **1 point**

Example Response

$$m_A v_A = (m_A + m_B) v_f$$
$$v_f = \frac{m_A v_A}{(m_A + m_B)}$$
$$v_f = \frac{(0.120\ \text{kg})(3.8\ \text{m/s})}{(0.120\ \text{kg} + 0.070\ \text{kg})}$$
$$\therefore v_f = 2.4\ \text{m/s}$$

Example Solution

$$m_A gH = \frac{1}{2} m_A v_A^2$$
$$v_A = \sqrt{2gH}$$
$$v_A = \sqrt{2\left(9.8\ \frac{m}{s^2}\right)(0.75\ m)}$$
$$\therefore v_A = 3.8\ \text{m/s}$$

$$m_A v_A = (m_A + m_B) v_f$$
$$v_f = \frac{m_A v_A}{(m_A + m_B)}$$
$$v_f = \frac{(0.120\ \text{kg})(3.8\ \text{m/s})}{(0.120\ \text{kg} + 0.070\ \text{kg})}$$
$$\therefore v_f = 2.4\ \text{m/s}$$

(c)(ii) For equating kinetic energy of the two-block system and elastic potential energy of the spring **1 point**

Example Response

$$\frac{1}{2}mv^2 = \int F(x)\,dx$$

For correctly integrating to determine the elastic potential energy at the spring's maximum compression **1 point**

Example Response

$$\frac{1}{2}mv^2 = \int_0^{x_{\text{max}}} Cx^{1/2}dx$$

$$\frac{1}{2}mv^2 = \frac{2}{3}Cx_{\text{max}}{}^{3/2}$$

For substituting the value for v_f from part (c)(i) into the integrated equation and solving for x_{max} **1 point**

Example Response

$$x_{\text{max}} = \left(\frac{3}{4}\frac{mv^2}{C}\right)^{2/3}$$

$$x_{\text{max}} = \left(\frac{3}{4}\frac{(0.190\ \text{kg})(2.4\ \text{m/s})^2}{20.0\ \text{N/m}^{1/2}}\right)^{2/3}$$

Example Solution

$$K = U_s$$

$$\frac{1}{2}mv^2 = \int F(x)\,dx$$

$$\frac{1}{2}mv^2 = \int_0^{x_{\text{max}}} Cx^{1/2}dx$$

$$\frac{1}{2}mv^2 = \frac{2}{3}Cx_{\text{max}}{}^{3/2}$$

$$\rightarrow x_{\text{max}} = \left(\frac{1}{2}mv^2\frac{3}{2C}\right)^{2/3}$$

$$x_{\text{max}} = \left(\frac{3}{4}\frac{mv^2}{C}\right)^{2/3}$$

$$x_{\text{max}} = \left(\frac{3}{4}\frac{(0.190\ \text{kg})(2.4\ \text{m/s})^2}{20.0\ \text{N/m}^{1/2}}\right)^{2/3}$$

$$\therefore x_{\text{max}} = 0.12\ \text{m}$$

Total for part (c) 5 points

(d)	For selecting $C > D$ with an attempt at a relevant justification	**1 point**
	For one of the following: • a statement that correctly relates the total energy of the system, the maximum compression distance of the springs, and the spring constant • a statement that correctly relates the force exerted on the blocks by the spring, the maximum compression distance of the springs, and the spring constant	**1 point**

Example Solutions

The energy of the two-block-spring system before the blocks compress the spring is the same in both procedures, so the total potential energy of both springs must be the same when each spring is at its maximum compression. Since Spring Q is compressed less than Spring R, C must be greater than D.

OR

The blocks are traveling at the same speed before colliding with the spring in each procedure. The maximum compression of Spring Q is less than Spring R, so the average force exerted on the blocks by Spring Q to stop the blocks must be greater than that of Spring R. Therefore, C must be greater than D.

Total for part (d) 2 points

Total for question 1 15 points

Question 1

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

PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

Figure 1

1. A block sitting on a horizontal surface is pushed against a spring, Spring P, that is attached to a wall, compressing the spring a distance x, as shown in Figure 1. The block is then released from rest. The block slides along the horizontal surface and up a ramp, reaching a maximum height $h_{max,P}$. Frictional forces between the block and all surfaces are negligible.

Question 1

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

A student compares $h_{max,P}$ for Spring P with the maximum height $h_{max,Q}$ achieved with a different spring, Spring Q. Each spring exerts a force of magnitude F on the block that varies as a function of the distance x that the spring is compressed, as shown in Figure 2. For Spring P, $F_P(x) = kx$, where $k = 100.0\ \text{N/m}$, and for Spring Q, $F_Q(x) = Cx^{1/2}$, where $C = 20.0\ \text{N/m}^{1/2}$.

$\frac{1}{2}k\Delta x^2$

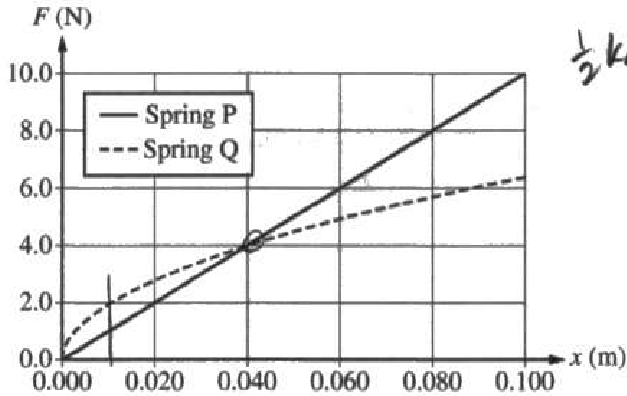
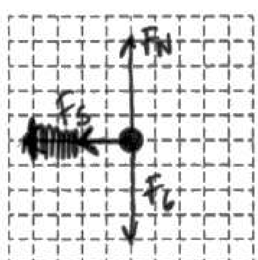


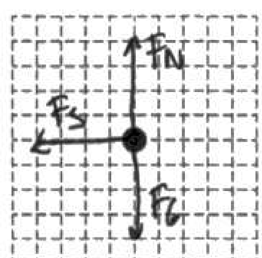
Figure 2

(a) For the experiment, the block is pushed against one of the springs, compressing the spring a distance $x = 0.010\ \text{m}$. The block is then released from rest. In Trial 1, Spring P is used, and in Trial 2, Spring Q is used. On the following dots, representing the block in Trials 1 and 2, draw and label the forces (not components) that are exerted on the block at the instant the block is released. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. The lengths of the horizontal vectors should represent the relative magnitude of the horizontal forces and the lengths of the vertical vectors should represent the relative magnitude of the vertical forces.

Trial 1
(Spring P)



Trial 2
(Spring Q)



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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

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

(b)

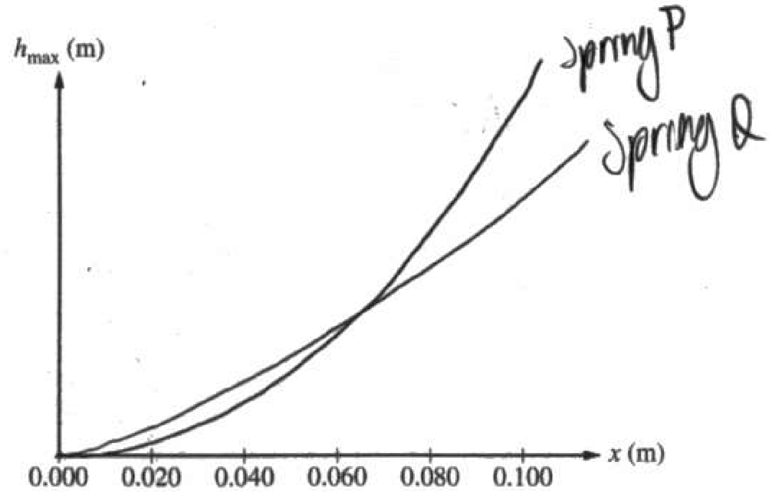
i. What feature(s) of the graph in Figure 2 could be used to estimate the work done on the block by each spring as each spring is compressed?

Because $W = \int \vec{F} \cdot d\vec{r}$, we can use the area under the curve up to the compression for each spring to estimate the work done on the block

ii. There is one compression distance x_0 for which the maximum height h_{max} reached by the block is the same regardless of which spring, Spring P or Spring Q, is used. Predict whether the value of x_0 is greater than, less than, or equal to 0.040 m. Use the graph in Figure 2 to justify your answer.

The compression distance that provides the same h_{max} regardless of spring will be greater than 0.04m, because the work done by spring Q is greater than spring P up to 0.04m and decreases beyond 0.04m, so the work will be equal beyond 0.04m.

iii. On the axes provided, for both Spring P and Spring Q, sketch a graph of the maximum height h_{max} reached by the block as a function of the distance each spring is compressed for values of x ranging from 0 to 0.100 m. Clearly label the curve for Spring P and Spring Q.



Question 1

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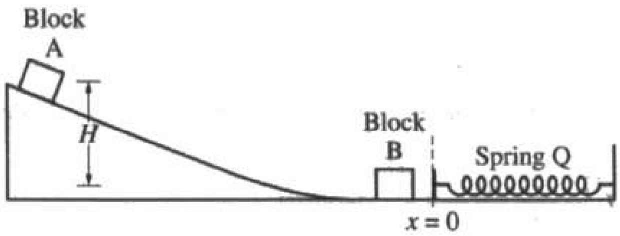

Figure 3

(c) Spring Q is attached to the wall and is at equilibrium, as shown in Figure 3. Block A has a mass of 0.120 kg and Block B has a mass of 0.070 kg. Block A is held at rest at the top of the ramp and Block B is at rest on the horizontal surface. The student releases Block A, and it moves down the ramp and collides with Block B. The change in vertical height of Block A is $H = 0.75$ m. After the collision, the blocks stick together and move to the right, compressing the spring. Frictional forces between the blocks and all surfaces are negligible.

i. Calculate the velocity of the two-block system immediately after the collision between Blocks A and B.

$U_a = KE_{f_a}$

$m_a g H = \frac{1}{2} m_a v_a^2$

$v_a^2 = 2gH$

$v_a = \sqrt{2gH}$

$p_{a_i} + p_{b_i} = p_{ca+b)f}$

$m_a v_a + m_b v_b^{\to 0} = (m_a + m_b) v_f$

$v_f = \frac{m_a \sqrt{2gH}}{m_a + m_b} = \frac{0.12kg\sqrt{2(9.8)(0.75)}}{0.12kg + 0.07kg}$

$v_f = 2.422 m/s$

ii. Calculate the maximum compression of the spring.

$KE_i = U_s$

$\frac{1}{2}(m_a + m_b) v_f^2 = \int_0^x 20 x^{1/2} dx$

$\left[\frac{40}{3} x^{3/2}\right]_0^x = \frac{40}{3} x^{3/2} = \frac{1}{2}(m_a + m_b) v_f^2$

$x = \left[\frac{3}{80}(m_a + m_b) v_f^2\right]^{2/3}$

$x = 0.12 m$

Question 1

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

(d) Spring Q where $F_Q(x) = Cx^{1/2}$ is replaced by a different nonlinear spring, Spring R, and the procedure described in part (c) is repeated. For Spring R, $F_R(x) = Dx^{1/2}$. The maximum compression of Spring R is greater than the maximum compression of Spring Q. Which of the following correctly compares the constants C and D ?

_________ $C < D$ ____X____ $C > D$ _________ $C = D$

Briefly justify your answer.

Since spring R compressed more, it is clear that the D constant is smaller, since to reach the same amount of work done on the blocks, the lesser force of spring R must be applied over a longer distance.

Question 1

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

PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

3 Questions

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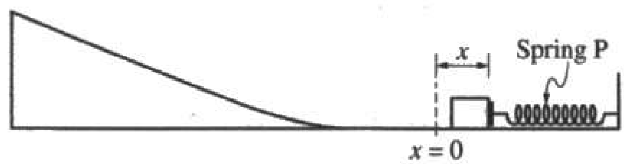

Figure 1

1. A block sitting on a horizontal surface is pushed against a spring, Spring P, that is attached to a wall, compressing the spring a distance x, as shown in Figure 1. The block is then released from rest. The block slides along the horizontal surface and up a ramp, reaching a maximum height $h_{max,P}$. Frictional forces between the block and all surfaces are negligible.

GO ON TO THE NEXT PAGE.

Question 1

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A student compares $h_{max,P}$ for Spring P with the maximum height $h_{max,Q}$ achieved with a different spring, Spring Q. Each spring exerts a force of magnitude F on the block that varies as a function of the distance x that the spring is compressed, as shown in Figure 2. For Spring P, $F_P(x) = kx$, where $k = 100.0$ N/m, and for Spring Q, $F_Q(x) = Cx^{1/2}$, where $C = 20.0$ N/m$^{1/2}$.

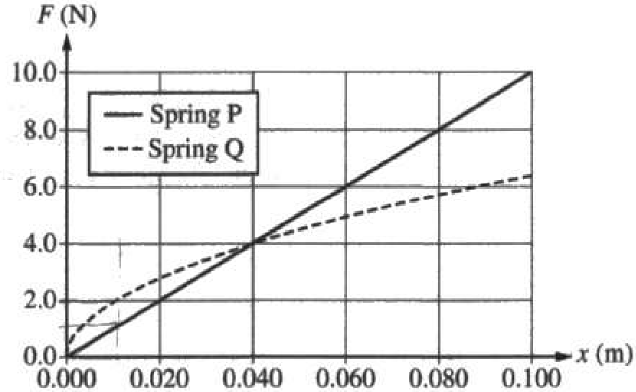
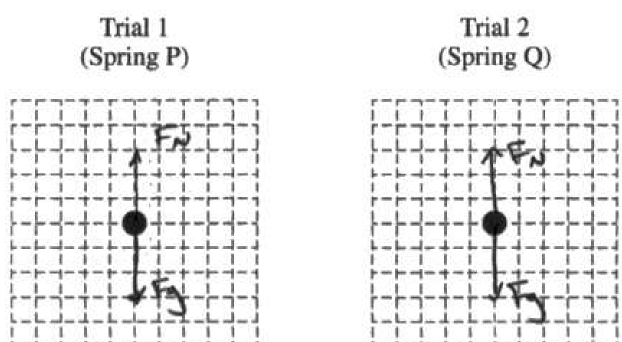


Figure 2

(a) For the experiment, the block is pushed against one of the springs, compressing the spring a distance $x = 0.010$ m. The block is then released from rest. In Trial 1, Spring P is used, and in Trial 2, Spring Q is used. On the following dots, representing the block in Trials 1 and 2, draw and label the forces (not components) that are exerted on the block at the instant the block is released. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. The lengths of the horizontal vectors should represent the relative magnitude of the horizontal forces and the lengths of the vertical vectors should represent the relative magnitude of the vertical forces.



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Question 1

Continue your response to QUESTION 1 on this page.

(b)

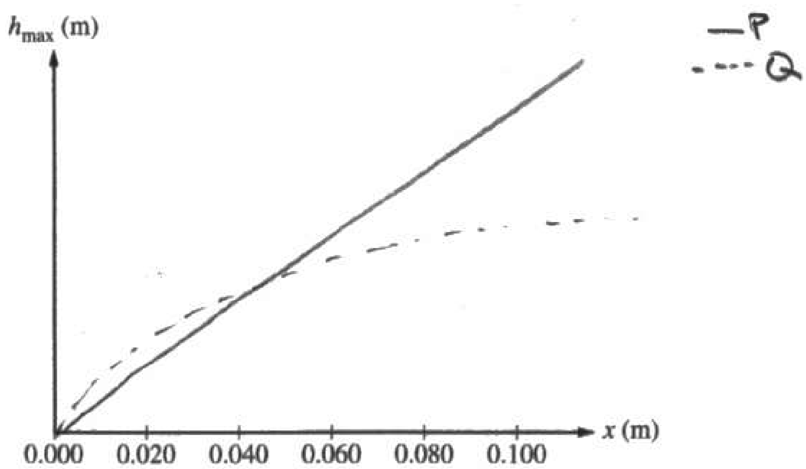
i. What feature(s) of the graph in Figure 2 could be used to estimate the work done on the block by each spring as each spring is compressed?

The area under the curve of a force by distance graph is equal to the work, as $W = \int F \cdot dr$. So, to find the work done by the spring on a block, take the area under the curve for that specific spring and for that specific Δx.

ii. There is one compression distance x_0 for which the maximum height h_{max} reached by the block is the same regardless of which spring, Spring P or Spring Q, is used. Predict whether the value of x_0 is greater than, less than, or equal to 0.040 m. Use the graph in Figure 2 to justify your answer.

The maximum height that the block can reach is proportional to the ΔKE for the block as it stands with 0 velocity and its velocity as the spring releases it determines the height of the block. So, the work done by the spring is equal to the change in kinetic energy, and for both blocks to reach the same height, they must have the same ΔKE or the same work by spring, or area under the graph curve. As Spring Qs graph has more area under the graph from 0 to 0.04, the value of x_0 is greater.

iii. On the axes provided, for both Spring P and Spring Q, sketch a graph of the maximum height h_{max} reached by the block as a function of the distance each spring is compressed for values of x ranging from 0 to 0.100 m. Clearly label the curve for Spring P and Spring Q.



Question 1

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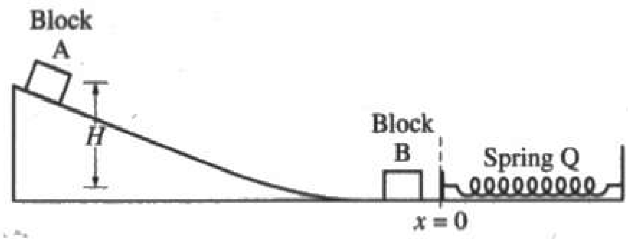

Figure 3

(c) Spring Q is attached to the wall and is at equilibrium, as shown in Figure 3. Block A has a mass of 0.120 kg and Block B has a mass of 0.070 kg. Block A is held at rest at the top of the ramp and Block B is at rest on the horizontal surface. The student releases Block A, and it moves down the ramp and collides with Block B. The change in vertical height of Block A is $H = 0.75$ m. After the collision, the blocks stick together and move to the right, compressing the spring. Frictional forces between the blocks and all surfaces are negligible.

i. Calculate the velocity of the two-block system immediately after the collision between Blocks A and B.

$mgh = \frac{1}{2}mv^2$ (written: mgh = fatal²)

$mg(0.75) = \frac{1}{2}mv^2$

$v = 3.83$

$mv_i = (m+m)v_f$

$(0.120)(3.83) = (0.120 + 0.07)(v_f)$

$2.4215 \approx$ **2.42 m/s**

ii. Calculate the maximum compression of the spring.

$\frac{1}{2}mv^2 - \frac{1}{2}mv^2 = W = \int F \cdot dr$

$\frac{(2.42)^2(0.12+0.07)}{2} = 0.557$

$\int F \cdot dr = \int c\sqrt{x} = c\int x^{1/2} = 2c\frac{x^{3/2}}{3}$

$\frac{2c\,x^{3/2}}{3} = 0.557$

$x = 0.12$ m

Question 1

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

(d) Spring Q where $F_Q(x) = Cx^{1/2}$ is replaced by a different nonlinear spring, Spring R, and the procedure described in part (c) is repeated. For Spring R, $F_R(x) = Dx^{1/2}$. The maximum compression of Spring R is greater than the maximum compression of Spring Q. Which of the following correctly compares the constants C and D ?

✓ $C < D$ ____ $C > D$ ____ $C = D$

Briefly justify your answer.

Final compression = $\frac{2(C \text{ or } D)x^{3/2}}{3}$

As the value C or D has a direct relationship with compression, if the compression increases, so does the coefficient. C<D as compression ↑.

GO ON TO THE NEXT PAGE.

Question 1

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

PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

3 Questions

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Figure 1

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GO ON TO THE NEXT PAGE.

$\frac{y_1 - y_2}{x_1 - x_2}$

Question 1

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

A student compares $h_{max,P}$ for Spring P with the maximum height $h_{max,Q}$ achieved with a different spring, Spring Q. Each spring exerts a force of magnitude F on the block that varies as a function of the distance x that the spring is compressed, as shown in Figure 2. For Spring P, $F_P(x) = kx$, where $k = 100.0\ \text{N/m}$, and for Spring Q, $F_Q(x) = Cx^{1/2}$, where $C = 20.0\ \text{N/m}^{1/2}$.

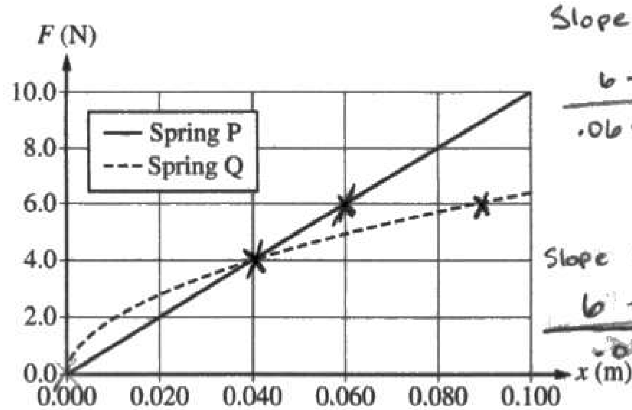


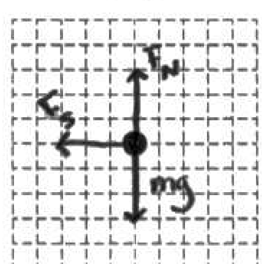
Figure 2

Slope Spring P = $\frac{6 - 4}{.06 - .04} = 100$

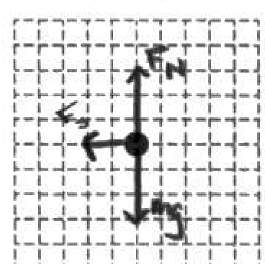
Slope Spring Q = $\frac{6 - 4}{.09 - .04} = 40$

(a) For the experiment, the block is pushed against one of the springs, compressing the spring a distance $x = 0.010\ \text{m}$. The block is then released from rest. In Trial 1, Spring P is used, and in Trial 2, Spring Q is used. On the following dots, representing the block in Trials 1 and 2, draw and label the forces (not components) that are exerted on the block at the instant the block is released. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. The lengths of the horizontal vectors should represent the relative magnitude of the horizontal forces and the lengths of the vertical vectors should represent the relative magnitude of the vertical forces.

Trial 1
(Spring P)



Trial 2
(Spring Q)



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Question 1

Continue your response to QUESTION 1 on this page.

(b)

i. What feature(s) of the graph in Figure 2 could be used to estimate the work done on the block by each spring as each spring is compressed?

Slope : Slope Spring P = 100
Slope Spring Q = 40

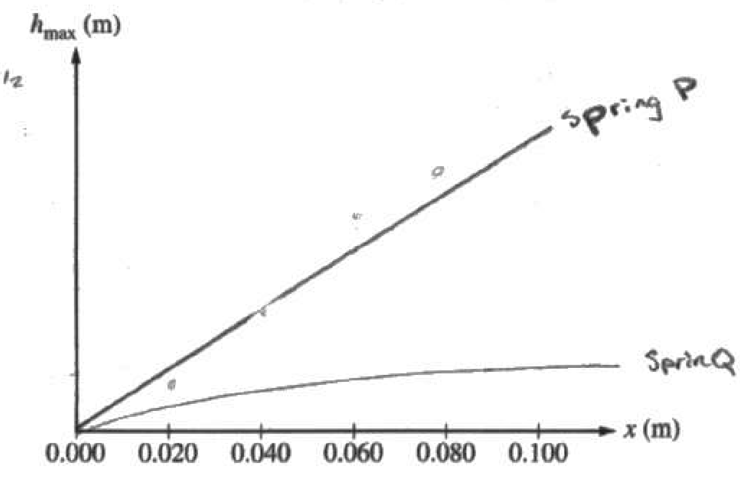
ii. There is one compression distance x_0 for which the maximum height h_{max} reached by the block is the same regardless of which spring, Spring P or Spring Q, is used. Predict whether the value of x_0 is greater than, less than, or equal to 0.040 m. Use the graph in Figure 2 to justify your answer.

Equal to, graph shows for both springs when 4N are applied x is .04m!

iii. On the axes provided, for both Spring P and Spring Q, sketch a graph of the maximum height h_{max} reached by the block as a function of the distance each spring is compressed for values of x ranging from 0 to 0.100 m. Clearly label the curve for Spring P and Spring Q.

P = kx = 100(

$Q = Cx^{1/2} = 20(\ )^{1/2}$



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Question 1

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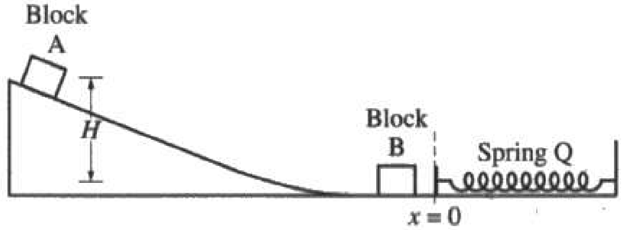

Figure 3

(c) Spring Q is attached to the wall and is at equilibrium, as shown in Figure 3. Block A has a mass of 0.120 kg and Block B has a mass of 0.070 kg. Block A is held at rest at the top of the ramp and Block B is at rest on the horizontal surface. The student releases Block A, and it moves down the ramp and collides with Block B. The change in vertical height of Block A is $H = 0.75$ m. After the collision, the blocks stick together and move to the right, compressing the spring. Frictional forces between the blocks and all surfaces are negligible.

i. Calculate the velocity of the two-block system immediately after the collision between Blocks A and B.

$PE = KE + U_s$

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

$-\frac{1}{2}kx^2$

$2 \cdot mgh - \frac{1}{2}kx^2 = \frac{1}{2}mv^2 \cdot 2$

$\frac{2(mgh - \frac{1}{2}kx^2) = mv^2}{m}$

$\sqrt{\frac{2(mgh - \frac{1}{2}kx^2)}{m}} = v$

$\sqrt{2((.12+.07)(9.8)(.75)}$

$= \sqrt{\frac{2((.12+.07)(9.8)(.75) - \frac{1}{2}(20)(}{(.12+.07)}}$

ii. Calculate the maximum compression of the spring.

$PE_{top} + KE_{bot} = U_s$

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

$\sqrt{\frac{2(mgh + \frac{1}{2}mv^2)}{k}} = x$

Question 1

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

(d) Spring Q where $F_Q(x) = Cx^{1/2}$ is replaced by a different nonlinear spring, Spring R, and the procedure described in part (c) is repeated. For Spring R, $F_R(x) = Dx^{1/2}$. The maximum compression of Spring R is greater than the maximum compression of Spring Q. Which of the following correctly compares the constants C and D ?

______ $C < D$ __X__ $C > D$ __X__ $C = D$

Briefly justify your answer.

D has a ~~bigger~~ spring constant making it easier to compress.

GO ON TO THE NEXT PAGE.

Question 1

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

Overview

The responses were expected to demonstrate understanding of:

- Linear vs. nonlinear elastic forces using functions and F vs. x graphs.
- Work done on an object by both linear and nonlinear springs.
- Conservation of mechanical energy in various situations.
- Conservation of linear momentum.
- The use of calculus to determine the elastic potential energy for a nonlinear spring at maximum compression.

Sample: 1A
Score: 15

Part (a) earned 2 points. The first point was earned for correctly drawing and labeling the gravitational force and the normal force on both dots. The second point was earned for correctly drawing and labeling the spring force vectors to the left on both dots, where the force vector drawn for Spring Q is double the length of the force vector drawn for Spring P. Part (b) earned 6 points. The first point was earned for correctly stating that the work done is equal to the area under the curve: "we can use the area under the curve up to the compression for each spring to estimate the work done on the block." The second point was earned for correctly stating that the spring compression will be greater than 0.040 m. The third point was earned for indicating that the heights are equal when the areas under the curves are equal, which happens after $x = 0.04$ m. The fourth point was earned for drawing a graph that has a smooth, concave upward curve for both springs, P and Q. The fifth point was earned for drawing a graph that shows that the curves intersect after $x = 0.05$ m but before $x = 0.100$ m. The sixth point was earned for correctly showing the curve for Spring P below the curve for Spring Q before the intersection and above the curve for Spring Q after the intersection. Part (c) earned 5 points. The first point was earned for correctly applying conservation of energy to solve for the velocity of Block A just before it collides with Block B. The second point was earned for correctly substituting the value of the velocity determined using energy conservation into a correct statement of conservation of momentum to solve for the final velocity of the two-block system. The third point was earned for equating the kinetic energy of the two-block system and the elastic potential energy of the spring. The fourth point was earned for correctly integrating the force to determine the elastic potential energy at the spring's maximum compression. The fifth point was earned for substituting the value for v_f calculated in part (c)(i) into an integrated equation that solves for x_{max}. Part (d) earned 2 points. The first point was earned for selecting C > D and attempting a relevant justification. The second point was earned for including an appropriate and relevant justification.

Question 1 (continued)

Sample: 1B
Score: 10

Part (a) earned 1 point for correctly drawing and labeling the gravitational force and the normal force on both dots. The second point was not earned because the response does not draw a spring force to the left on either dot. Part (b) earned 4 points. The first point was earned for correctly stating that the work done is equal to the area under the curve. The second point was earned for correctly stating that the spring compression will be greater than 0.040 m. The third point was earned for indicating that the heights are equal when the areas under the curves are equal, which happens after $x = 0.04\text{ m}$. The fourth point was not earned because the graph in the response draws a linear curve for Spring P and a concave downward curve for Spring Q. The fifth point was not earned because the graph in the response shows that the curves intersect before $x = 0.05\text{ m}$. The sixth point was earned for correctly showing the curve for Spring P below the curve for Spring Q before the intersection and above the curve for Spring Q after the intersection. Part (c) earned 5 points. The first point was earned for correctly applying conservation of energy to solve for the velocity of Block A just before it collides with Block B. The second point was earned for correctly substituting the value of the velocity determined using energy conservation into a correct statement of conservation of momentum to solve for the final velocity of the two-block system. The third point was earned for equating the kinetic energy of the two-block system and the elastic potential energy of the spring. The fourth point was earned for correctly integrating the force to determine the elastic potential energy at the spring's maximum compression. The fifth point was earned for substituting the value for v_f calculated in part (c)(i) into an integrated equation that solves for x_{max}. Part (d) earned no points. The first point was not earned because the response selects $C < D$. The second point was not earned because the response includes an incorrect justification that indicates the constant is directly proportional to the compression.

Question 1 (continued)

Sample: 1C
Score: 2

Part (a) earned 1 point for correctly drawing and labeling the gravitational force and the normal force on both dots. The second point was not earned because, although the response correctly draws and labels the spring force vectors to the left on both dots, the force vector drawn for Spring Q is not double the length of the vector drawn for Spring P. Part (b) earned no points. The first point was not earned because the response does not state that the work done is equal to the area under the curve. The second point was not earned because the response states that the spring compression will be equal to 0.040 m. The third point was not earned because the response indicates that the heights are equal when the forces are equal, which happens at $x = 0.04$ m. The fourth point was not earned because the graph in the response shows a linear curve for Spring P and a concave downward curve for Spring Q. The fifth point was not earned because the graph in the response shows that the curves do not intersect. The sixth point was not earned because the graph in the response shows that the curves do not intersect. Part (c) earned no points. The first point was not earned because, although the response includes an application of conservation of energy to solve for the velocity of Block A just before it collides with Block B, the response includes an elastic potential energy term. The second point was not earned because the response does not substitute the value of the velocity determined using energy conservation into a correct statement of conservation of momentum to solve for the final velocity of the two-block system. The third point was not earned because the response does not equate the kinetic energy of the two-block system and the elastic potential energy of the spring; the response includes a gravitational potential energy term. The fourth point was not earned because the response does not integrate the force to determine the elastic potential energy at the spring's maximum compression. The fifth point was not earned because response does not substitute the value for v_f calculated in part (c)(i) into an integrated equation. Part (d) earned 1 point for selecting C > D and attempting a relevant justification. The second point was not earned because the response includes a justification that does not include an energy or force equivalence statement.