2019

AP® CollegeBoard

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

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General Notes About 2019 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 3

12 points

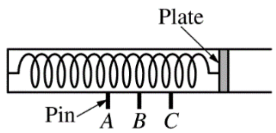


Figure 1. Uncompressed spring

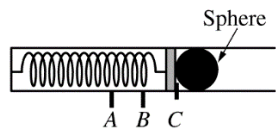


Figure 2. Compressed spring

A projectile launcher consists of a spring with an attached plate, as shown in Figure 1. When the spring is compressed, the plate can be held in place by a pin at any of three positions *A*, *B*, or *C*. For example, Figure 2 shows a steel sphere placed against the plate, which is held in place by a pin at position *C*. The sphere is launched upon release of the pin.

A student hypothesizes that the spring constant of the spring inside the launcher has the same value for different compression distances.

(a) i. and ii.
LO 5.B.5.5, SP 2.2
3 points

The student plans to test the hypothesis by launching the sphere <u>using the launcher</u>.

i. State a basic physics principle or law the student could use in designing an experiment to test the hypothesis.
ii. Using the principle or law stated in part (a)(i), determine an expression for the spring constant in terms of quantities that can be obtained from measurements made with equipment usually found in a school physics laboratory.

For an equation that is consistent with a relevant principle or law as written in (a)(i)		1 point
For a valid equation that contains measurable quantities and includes spring constant		1 point
For a correct and valid algebraic expression for spring constant. The expression must be solved for *k*.		1 point

(b) LO 3.A.1.2, SP 4.2; LO 4.C.1.1, SP 2.2; LO 5.B.3.3, SP 1.4, 2.2; LO 5.B.5.2, SP 4.2
5 points

Design an experimental procedure to test the hypothesis <u>in which the student uses the launcher to launch the sphere</u>. Assume equipment usually found in a school physics laboratory is available.

In the table below, list the quantities and associated symbols that would be measured in your experiment. Also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement

Question 3 (continued)

(b) (continued)

Describe the overall procedure to be used to test the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances, referring to the table. 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 and/or include a simple diagram of the setup.

Measurements and Equipment		
For listing relevant/appropriate equipment that matches all measured quantities in the experimental procedure Note: This point can be earned if the sphere is not launched.		1 point
Procedure		
For describing measurements of quantities sufficient to determine the spring constant Note: This point can be earned if the sphere is not launched.		1 point
For a plausible procedure (i.e., can be done in a typical school physics lab) that involves launching the sphere to determine the spring constant		1 point
For launching the sphere from at least 2 different initial positions		1 point
For attempting to reduce uncertainty (e.g., multiple trials at a pin setting) Note: This point can be earned if the sphere is not launched.		1 point

Example Procedure 1:

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement
Mass of sphere	m_S	Triple beam balance
Spring compression distance	Δx	Ruler
Launch speed of sphere	v_L	Motion sensor

The mass of the sphere is measured with a triple beam balance. The launcher is aimed horizontally on a level surface toward a motion sensor. The spring is compressed to pin position A and the spring compression distance is measured. The mass is launched. The motion sensor measures launch speed. The process is repeated three times at position A. The procedure is repeated with the spring compressed to pin positions B and C.

Example Procedure 2:

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement
Mass of sphere	m_S	Triple beam balance
Spring compression distance	d	Ruler
Horizontal displacement of sphere	Δx	Meterstick
Vertical displacement of sphere	Δy	Meterstick

The launcher is aimed horizontally at a height above the ground so that the sphere will follow a projectile path and land on the floor. The spring is compressed to pin position A and the sphere is launched. Measure the mass of the sphere, the initial spring compression, and the vertical and horizontal displacements of the sphere from release to landing position. Repeat three times at pin position A. The procedure is repeated with the spring compressed to pin positions B and C.

Question 3 (continued)

(b) (continued)

Example Procedure 3:

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement
Mass of sphere	m_S	Triple beam balance
Spring compression distance	d	Ruler
Maximum vertical displacement of sphere	Δy	Meterstick

Aim the launcher vertically. Compress the spring to pin position A. Launch the sphere vertically. Measure the mass of the sphere, the initial spring compression, and vertical displacement of the sphere above the release position. Repeat three times at pin position A. Repeat the procedure with the spring compressed to pin positions B and C.

(c) LO 3.A.1.3, SP 5.1; LO 4.C.1.1, SP 2.2; LO 5.A.2.1, SP 6.4; LO 5.B.3.3, SP 1.4, 2.2
2 points

Describe how the experimental data could be analyzed to confirm or disconfirm the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances.

For comparing the measurements of the spring constant (or a suitable proxy) at all three possible compression distances (A, B, C)		1 point
For considering uncertainties in confirming the hypothesis (e.g., "If numbers match within experimental uncertainty," or "If the numbers are about the same") <u>Note:</u> This point is not earned for saying "if the numbers are the same" or similar phrasing that does not address experimental uncertainty.		1 point

Example Analysis 1:
For each pin position, take the average $v_{\text{L-avg}}$ of the launch speeds measured at that position. Calculate the spring constant k using the energy conservation relation $\frac{1}{2}k(\Delta x)^2 = \frac{1}{2}m_S v_{\text{L-avg}}^2$ or $k = m_S v_{\text{L-avg}}^2 / (\Delta x)^2$. Then compare the k values for each spring position. If the values agree within experimental uncertainty, then the hypothesis is confirmed.

Example Analysis 2:
For each pin position, take the averages Δx_{avg} and Δy_{avg} of the horizontal and vertical sphere displacements. Calculate the time interval Δt using the kinematics equation $\Delta y_{\text{avg}} = \frac{1}{2}g(\Delta t)^2$, and then calculate the launch speed $v_L = \Delta x_{\text{avg}} / \Delta t$. Calculate the spring constant using the relation $k = m_S v_L^2 / d^2$. Compare the k values for each spring position. If the values agree within experimental uncertainty, then the hypothesis is confirmed.

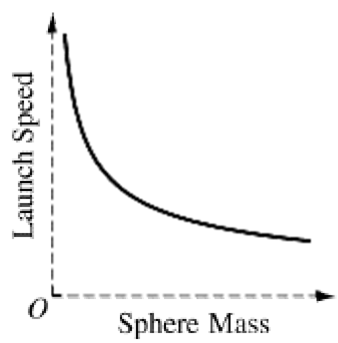
Question 3 (continued)

(c) (continued)

Example Analysis 3: For each pin position, take the average Δy_{avg} of the maximum vertical sphere displacement. Use conservation of energy to calculate a value for the spring constant k from the equation $\frac{1}{2}kd^2 = mg\Delta y_{avg}$ (if measuring height from the release (pin) position) $\frac{1}{2}kd^2 = mg\left(\Delta y_{avg} + d\right)$ (if measuring height from the spring's uncompressed position) Compare the k values for each spring position. If the values agree within experimental uncertainty, then the hypothesis is confirmed.

(d) LO 3.B.1.1, SP 6.4; LO 5.B.4.2, SP 1.4, 2.2
2 points

Another student uses the launcher to consecutively launch several spheres that have the same diameter but different masses, one after another. Each sphere is launched from position A. Consider each sphere's launch speed, which is the speed of the sphere at the instant it loses contact with the plate. On the axes below, sketch a graph of launch speed as a function of sphere mass.



For a curve where launch speed always decreases with increasing sphere mass		1 point
For a curve that is entirely concave up AND has the launch speed always decreasing with increasing sphere mass		1 point

Question 3 (continued)

Learning Objectives

LO 3.A.1.2: The student is able to design an experimental investigation of the motion of an object. [See Science Practice 4.2]

LO 3.A.1.3: The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical, and graphical representations. [See Science Practice 5.1]

LO 3.B.1.1: The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension. [See Science Practices 6.4, 7.2]

LO 4.C.1.1: The student is able to calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy. [See Science Practices 1.4, 2.1, 2.2]

LO 5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [See Science Practices 6.4, 7.2]

LO 5.B.3.3: The student is able to apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. [See Science Practices 1.4, 2.2]

LO 5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [See Science Practices 1.4, 2.1, 2.2]

LO 5.B.5.2: The student is able to design an experiment and analyze graphical data in which interpretations of the area under a force-distance curve are needed to determine the work done on or by the object or system. [See Science Practices 4.2, 5.1]

LO 5.B.5.5: The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. [See Science Practices 2.2, 6.4]

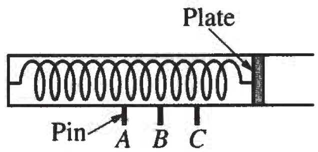


Figure 1. Uncompressed spring

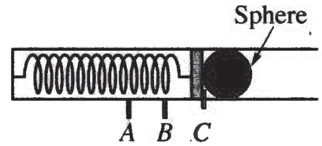


Figure 2. Compressed spring

3. (12 points, suggested time 25 minutes)

A projectile launcher consists of a spring with an attached plate, as shown in Figure 1. When the spring is compressed, the plate can be held in place by a pin at any of three positions *A*, *B*, or *C*. For example, Figure 2 shows a steel sphere placed against the plate, which is held in place by a pin at position *C*. The sphere is launched upon release of the pin.

A student hypothesizes that the spring constant of the spring inside the launcher has the same value for different compression distances.

(a) The student plans to test the hypothesis by launching the sphere <u>using the launcher</u>.

i. State a basic physics principle or law the student could use in designing an experiment to test the hypothesis.

Conservation of Energy

ii. Using the principle or law stated in part (a)(i), determine an expression for the spring constant in terms of quantities that can be obtained from measurements made with equipment usually found in a school physics laboratory.

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

$k = \frac{2mgh}{x}$

(b) Design an experimental procedure to test the hypothesis <u>in which the student uses the launcher to launch the sphere</u>. Assume equipment usually found in a school physics laboratory is available.

In the table below, list the quantities and associated symbols that would be measured in your experiment. Also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

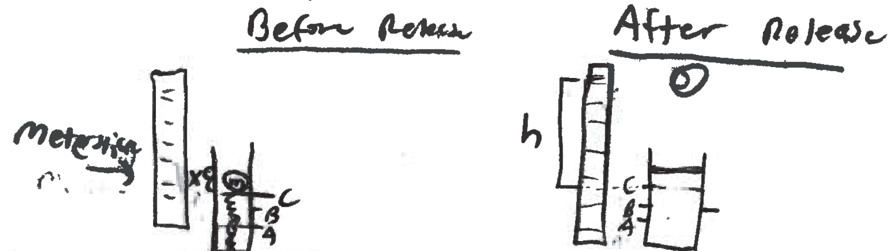
Quantity to be Measured	Symbol for Quantity	Equipment for Measurement
Compression of spring	x	ruler
Mass of Sphere	m	triple-beam-scale
max height of Sphere	h	meterstick

GO ON TO THE NEXT PAGE.

(b) Continued

Describe the overall procedure to be used to test the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances, referring to the table. 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 and/or include a simple diagram of the setup.

1. First, use the ruler to measure the compression distance for the spring at each position (A, B, C) - this will be x. Also, measure the mass of the sphere, this will be m.
2. Next, compress the spring to a chosen position, place the pin, and load the sphere
3. Release the pin, and measure the maximum distance (h) that the ball travelled above its release point.
4. Repeat the experiment (starting at step 2) multiple times at each position, and repeat it at each of the three positions.



(c) Describe how the experimental data could be analyzed to confirm or disconfirm the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances.

First, the experiment should be repeated multiple times at each position to limit experimental uncertainty. At each distance calculate the spring constant with the expression $k = \frac{2mgh}{x^2}$, with the average height at that position as h, the measured mass of the sphere as m, and the measured compression distance at that position as x. If k is very close at each of the positions, then the hypothesis is confirmed, otherwise, it is disconfirmed.

Question 3 continues on the next page.

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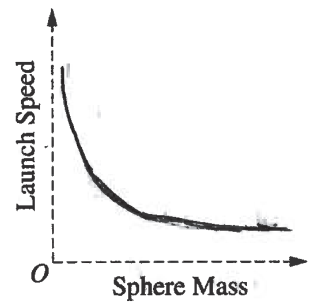
(d) Another student uses the launcher to consecutively launch several spheres that have the same diameter but different masses, one after another. Each sphere is launched from position A. Consider each sphere's launch speed, which is the speed of the sphere at the instant it loses contact with the plate. On the axes below, sketch a graph of launch speed as a function of sphere mass.



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

$kx^2 = mv^2$

$v^2 = \frac{kx^2}{m}$

$v = \sqrt{\frac{kx^2}{m}}$ kx^2 constant

v

$v \propto \frac{1}{\sqrt{m}}$

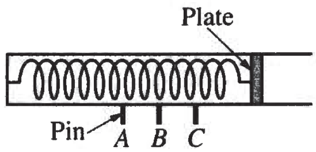


Figure 1. Uncompressed spring

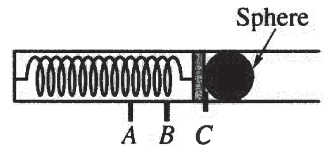


Figure 2. Compressed spring

3. (12 points, suggested time 25 minutes)

A projectile launcher consists of a spring with an attached plate, as shown in Figure 1. When the spring is compressed, the plate can be held in place by a pin at any of three positions *A*, *B*, or *C*. For example, Figure 2 shows a steel sphere placed against the plate, which is held in place by a pin at position *C*. The sphere is launched upon release of the pin.

A student hypothesizes that the spring constant of the spring inside the launcher has the same value for different compression distances.

(a) The student plans to test the hypothesis by launching the sphere using the launcher.

i. State a basic physics principle or law the student could use in designing an experiment to test the hypothesis. The spring constant can be determined by measuring the time (cycle) it takes for the ball to travel a fixed distance at different compression levels of spring.

ii. Using the principle or law stated in part (a)(i), determine an expression for the spring constant in terms of quantities that can be obtained from measurements made with equipment usually found in a school physics laboratory. $T_s = \left(2\pi\sqrt{\frac{m}{k}}\right)^2$

$U_s = \frac{1}{2}kx^2$ $(k)\ T_s^2 = 4\pi^2\left(\frac{m}{k}\right)(k)$

$$k = \frac{4\pi^2 m}{T_s^2}$$

(b) Design an experimental procedure to test the hypothesis in which the student uses the launcher to launch the sphere. Assume equipment usually found in a school physics laboratory is available.

In the table below, list the quantities and associated symbols that would be measured in your experiment. Also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement
mass of ball	m	balance
length ball travels	d	ruler (cm or m)
ball's speed	v	stopwatch
compression distance	x	ruler

GO ON TO THE NEXT PAGE.

(b) Continued

Describe the overall procedure to be used to test the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances, referring to the table. 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 and/or include a simple diagram of the setup. Measure the mass of ball with the balance. Measure how far the spring is from it's resting position with ruler. Place 1 pin in that place & release at the same time the stop watch is started so the ball moves. Stop the stop watch once ball reaches a meter. Repeat with other compression distances and find velocity. Divide the compression distance by the corresponding velocity and determine if each quotient is the same. If they are the same, then the sring constant is the same no matter the compression distance

(c) Describe how the experimental data could be analyzed to confirm or disconfirm the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances.

The velocity from each trial can be divided by the compression distance. If these values are similar with each trial, the hypothesis can be confirmed that the spring constant inside the launcher has the same value for different compression distances.

Question 3 continues on the next page.

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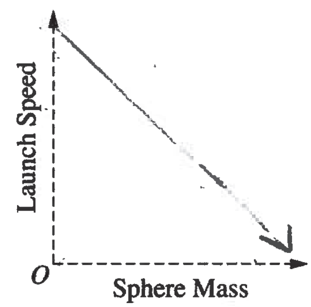
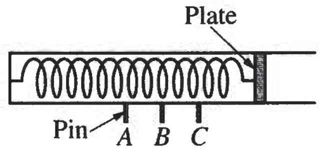
(d) Another student uses the launcher to consecutively launch several spheres that have the same diameter but different masses, one after another. Each sphere is launched from position A. Consider each sphere's launch speed, which is the speed of the sphere at the instant it loses contact with the plate. On the axes below, sketch a graph of launch speed as a function of sphere mass.





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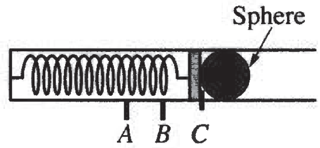

Figure 2. Compressed spring

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A student hypothesizes that the spring constant of the spring inside the launcher has the same value for different compression distances.

(a) The student plans to test the hypothesis by launching the sphere <u>using the launcher</u>.

i. State a basic physics principle or law the student could use in designing an experiment to test the hypothesis.

The Spring formula

ii. Using the principle or law stated in part (a)(i), determine an expression for the spring constant in terms of quantities that can be obtained from measurements made with equipment usually found in a school physics laboratory.

The Spring constant can be found with a meterstick and Stopwatch in school physics laboratory

(b) Design an experimental procedure to test the hypothesis <u>in which the student uses the launcher to launch the sphere</u>. Assume equipment usually found in a school physics laboratory is available.

In the table below, list the quantities and associated symbols that would be measured in your experiment. Also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement
Length	m	Ruler/meterstick
Mass of Sphere	Kg	Triple beam balance
Time	S	Stopwatch

(b) Continued

Describe the overall procedure to be used to test the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances, referring to the table. 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 and/or include a simple diagram of the setup.

First, get the lengths of all the compression point from the start of the tube. Second, test all the compression points. Third, Solve for the Spring constant. Last, compare all of the value to see if the Student was incorrect.

(c) Describe how the experimental data could be analyzed to confirm or disconfirm the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances.

The experimental data can be analyzed by comparing the Spring constant of the different compressioned distances.

Question 3 continues on the next page.

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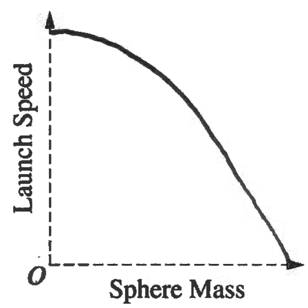
(d) Another student uses the launcher to consecutively launch several spheres that have the same diameter but different masses, one after another. Each sphere is launched from position A. Consider each sphere's launch speed, which is the speed of the sphere at the instant it loses contact with the plate. On the axes below, sketch a graph of launch speed as a function of sphere mass.



Question 3

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

Overview

This question asked students to design an experimental investigation of a spring-mass system using a launcher. Students were to determine if the spring constant of a spring changes with compression distance. The responses to this question were expected to:

- Connect a physics principle to a mathematical expression for spring constant in terms of measurable values. The intent was for students to demonstrate an understanding of the concept of conservation of energy as applied to a spring-mass system — that the potential energy stored in the compressed spring-mass system would be converted to the kinetic energy of the launched sphere, and that this could be expressed mathematically to determine the spring constant.
- Show that they could design an experiment that would measure relevant values to be used in their calculations for the spring-mass system. This involved predicting what would happen upon launching the sphere, having a good comprehension of what quantities are measurable in a lab setting, and knowing what equipment would be used to make those measurements. This also required students to minimize uncertainty in their experimental design.
- Describe how the data could be used to confirm the hypothesis. Students were required to know to compare values at multiple compression distances; this includes recognizing that there would be unavoidable experimental uncertainty, and students should, therefore, not expect their calculated values to be exactly equal.

Sample: 3A
Score: 11

Part (a) earned 2 of 3 points. The equation written agrees with the physics principle (conservation of energy) and is initially written with measurable values, but it is solved incorrectly for k because the x in the denominator should be squared. Part (b) earned all 5 points. The measurements and equipment table in part (b) earned 1 point because all of the quantities are measured with valid tools. The procedure in part (b) earned all 4 points. The procedure could plausibly be used to calculate the spring constant. It lists all measurements that are needed to find the spring constant by vertically launching the sphere. The procedure doesn't need to indicate how differences in launch position would affect height. The launch is done from multiple initial spring compressions, and it is done multiple times at each location. Part (c) earned 2 points. The response indicates that the spring constant will be found at all three starting positions A, B, and C (referenced earlier, in step 4 of the part (b) procedure) and that the values can have some variance due to uncertainty ("[i]f k is very close at each of the positions"). Part (d) earned both points for a correctly drawn graph.

Sample: 3B
Score: 7

Part (a) earned 2 of 3 points. There is not a valid physics principle written in part (i) for the equation to agree with. An equation in part (ii) that contains k is written with measurable values and is correctly solved for k. Even though this equation is not used in the procedure later, these parts are graded independently. Part (b) earned 3 of 5 points. The point for the table of measurements and equipment was not earned because it incorrectly indicates that speed would be measured with a stopwatch. The procedure earned 3 of 4 points. Two of the points were earned because the procedure describes measured quantities that could be used to determine the spring constant and because it is plausible because the procedure describes an experiment where the exit velocity is calculated with a specific distance and time measurement after a horizontal launch.

Question 3 (continued)

Another point was earned because the launch is done from multiple initial spring compressions. One point was not earned because the procedure is not repeated multiple times at each location. Part (c) earned 1 of 2 points. In parts (b) and (c), the points A, B, and C are not referenced — it is unclear if the statement in (b) to repeat the procedure “with other compression distances” refers to all three pin positions, so while it earned a point in (b) for launching the sphere from at least two positions, it did not earn the point in (c) for comparing measurements at all three positions. However, the analysis does recognize that there could be variation in the answers (“If these values are similar”) due to experimental uncertainty, and 1 point was earned. Part (d) earned 1 of 2 points for indicating that launch speed decreases with increasing sphere mass, but it did not earn 1 point because the graph is not concave up.

Sample: 3C
Score: 3

Part (a) earned none of the 3 points. There is no physics principle written in part (i) and no equation written in part (ii). Part (b) earned 1 of 5 points. The measurements and equipment table earned the point because all of the quantities are measured with valid tools. The procedure in part (b) earned none of the 4 points. There is no procedure indicated that involves launching the sphere. There are not sufficient measurements listed. While the procedure is performed at different compression distances, it does not involve launching the sphere and so did not earn the point “for *launching the sphere* from at least 2 different initial positions.” The procedure is not repeated multiple times at each position. Part (c) earned 1 of 2 points because it does indicate that it will compare spring constants found using all pin locations (as referenced in the part (b) procedure, “test all the compression points”). One point was not earned because there is no recognition that the answers could have variation due to uncertainty. Part (d) earned 1 of 2 points for indicating that launch speed decreases with increasing sphere mass, but it did not earn 1 point because the graph is not concave up.