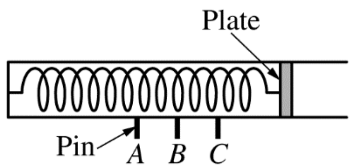


Figure 1. Uncompressed spring

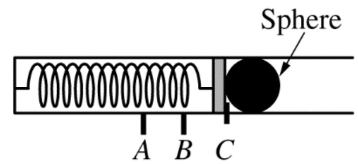


Figure 2. Compressed spring

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.

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.

(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

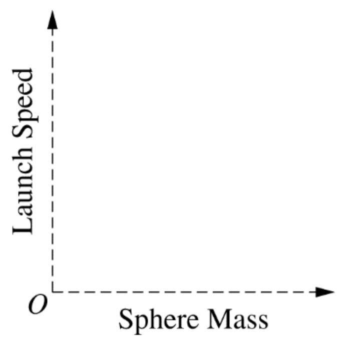
GO ON TO THE NEXT PAGE.

(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.

(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.

(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

12 points

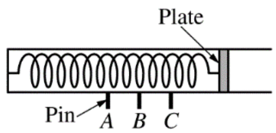


Figure 1. Uncompressed spring

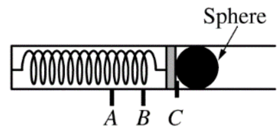


Figure 2. Compressed spring

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 using the launcher.

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 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

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") Note: 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 $k = m_S v_{\text{L}}^2 / d^2$. Compare the k values for each spring position. If the values agree within experimental uncertainty, then the hypothesis is confirmed.

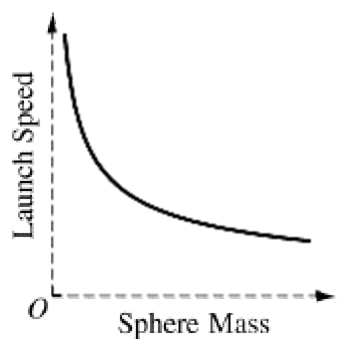
Question 3 (continued)

(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]