Unit 6 Progress Check: FRQ

1. This question is a long free-response question. Show your work for each part of the question.

In a physics lab, a group of students are provided with a sphere of unknown mass, a roll of string, a ring stand, and measuring devices that are commonly found in a physics lab. The students must graphically determine the acceleration due to gravity near Earth's surface by putting the sphere into simple harmonic motion.

(a) State a basic physics principle, law, or equation that the students could use to graphically determine the acceleration due to gravity near Earth's surface by putting the sphere into simple harmonic motion.

(b) Design an experimental procedure the students could use to graphically determine the acceleration due to gravity near Earth's surface by putting the sphere into simple harmonic motion.

In the table below, list the quantities and associated symbols that would be measured in the experiment and 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

Describe the overall procedure to be used, referring to the table. Include any steps necessary to reduce experimental uncertainty. Provide enough detail so that another student could replicate the experiment. As needed, use the symbols listed in the table and include a circuit diagram of the setup.

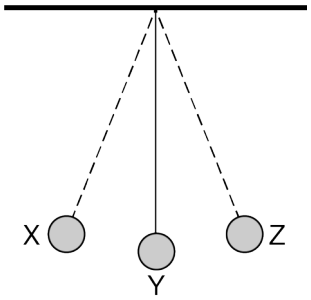
(c) The students must graph the data that they have collected so that they can determine the acceleration due to gravity near Earth's surface.

i. Indicate below which quantities could be graphed on the horizontal axis or the vertical axis to determine the acceleration due to gravity near Earth's surface by using a best fit line. You may use the remaining columns in the table above, as needed, to record any quantities (including units) that are not already in the table.

Vertical axis:_____ Horizontal axis: _____

ii. The students determine that the slope of the line is m. Derive an equation that can be used to determine the acceleration due to gravity near Earth's surface by using the slope of the graph that is described by the quantities plotted from part (c)i. Express your answer in terms of the slope m and any other fundamental constants.

Unit 6 Progress Check: FRQ



In a second experiment, the students attach a sphere to a string such that it undergoes simple harmonic motion between points X, Y, and Z, as shown in the figure. Points X and Z are at the sphere's maximum displacement from its equilibrium position, and point Y is at the sphere's equilibrium position. As the sphere swings along its arc, a student cuts the string at point Z.

(d) Predict the motion of the sphere after the string is cut in terms of the sphere's displacement, initial speed, and acceleration.

Part (a)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

Student response accurately includes the following criteria.

- ☐ 1 point is earned for stating that the equation for the period of a simple pendulum should be used.

Example Response:

$T_p = 2\pi\sqrt{\frac{\square}{g}}$

Part (b)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5	6 ✓

Student response accurately includes fives of the following criteria.

- ☐ 1 point is earned for listing relevant/appropriate equipment that matches the measured quantities from the

Unit 6 Progress Check: FRQ

table.

- [ ] 1 point is earned for stating an appropriate procedure to measure the length of the string.
- [ ] 1 point is earned for stating an appropriate procedure to measure the period of oscillation of the sphere.
- [ ] 1 point is earned for stating that the length of the string should be changed when a new set of data must be collected.
- [ ] 1 point is earned for stating that multiple trials should be conducted for each length of string tested to reduce experimental uncertainty.
- [ ] 1 point is earned for stating that the sphere should only be released from a small angle (less than or equal to 15° as measured from the equilibrium position of the sphere and the position from which it is released) to reduce experimental uncertainty.

Example Response:

1. Secure one end of the string to the ring stand (or a stationary physical location) and secure the other end of the string to the sphere. Let the sphere hang at rest.

2. Measure the length of the string with a meterstick.

3. Using a protractor, raise the sphere (while keeping the string taut) to a location where the angle between the sphere's new location and its hanging rest position is at or less than 15°

4. Release the sphere from rest.

5. Use a stopwatch to record the amount of time that it takes the sphere to make 10 complete oscillations.

6. Perform this trial multiple times.

7. Change the length of the string and repeat steps 1-6 for at least four different lengths of string.

Part (c)i

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

Student response accurately includes one of the following criteria.

- [ ] 1 point is earned for point for choosing two quantities that, when graphed together, can be used to determine the acceleration due to gravity near Earth's surface.

Example Response:

T_p vs. $\sqrt{\diamondsuit}$

T_p vs. $2\pi\sqrt{\diamondsuit}$

Unit 6 Progress Check: FRQ

$\frac{T_p}{2\pi}$ vs. $\sqrt{\diamondsuit}$

T_p^2 vs. $\diamondsuit$

T_p^2 vs. $4\pi^2\diamondsuit$

$\frac{T_p^2}{4\pi^2}$ vs. $\diamondsuit$

Part (c)ii

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

Student response accurately includes two of the following criteria.

- ☐ 1 point is earned for correctly relating the slope of the graph to an expression of the constants from the appropriate equation.
  Example Response:
  Note: *m* represents the slope of the graph.
  $T_p = 2\pi\sqrt{\frac{\diamondsuit}{g}}$
  ${T_p}^2 = 4\pi^2\frac{\diamondsuit}{g}$
  ${T_p}^2 = \frac{4\pi^2}{g}\diamondsuit$
  $m = \frac{4\pi^2}{g}$
- ☐ 1 point is earned for correctly solving for the acceleration due to gravity near Earth's surface.
  Example Response:
  $m = \frac{4\pi^2}{g}$
  $mg = 4\pi^2$
  $g = \frac{4\pi^2}{m}$

Part (d)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

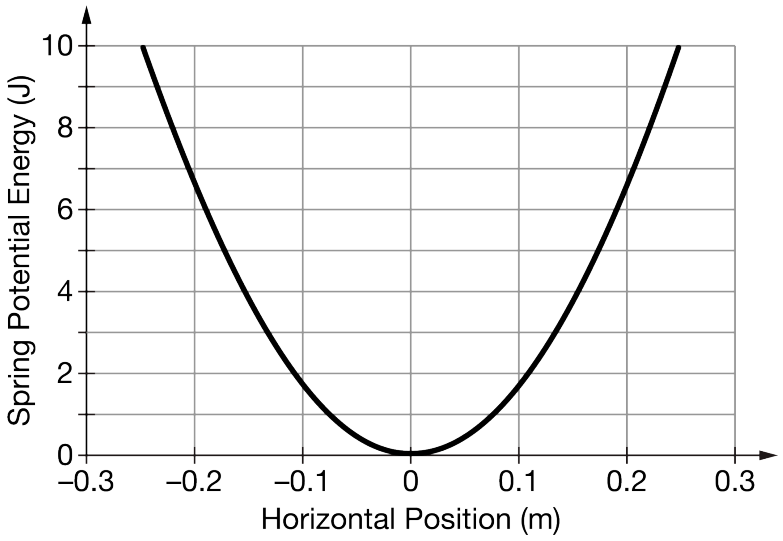
Student response accurately includes all of the following criteria.

Unit 6 Progress Check: FRQ

- [ ] 1 point is earned for point stating that the displacement of the sphere will be vertically downward.
- [ ] 1 point is earned for stating that the sphere has an initial speed of zero but accelerates at g.

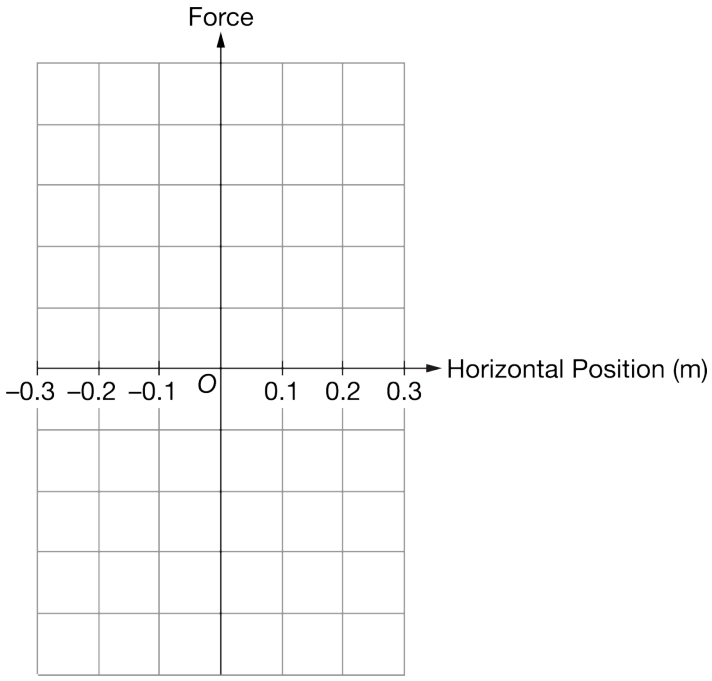
Unit 6 Progress Check: FRQ

2. This question is a short free-response question. Show your work for each part of the question.



A block of mass $0.4\,\text{kg}$ on a horizontal surface is attached to a horizontal spring of negligible mass. The other end of the spring is attached to a wall, and there is negligible friction between the block and the horizontal surface. The center of mass of the block is stretched a horizontal distance $x = 0.25$ beyond its equilibrium position and released from rest such that the block-spring system undergoes simple harmonic motion. A graph of the spring potential energy of the block-spring system as a function of the horizontal position of the center of mass of the block is shown. The positive direction is considered to be to the right.

(a) On the grid below, sketch a graph of the force exerted by the spring on the block as a function of the block's horizontal position.

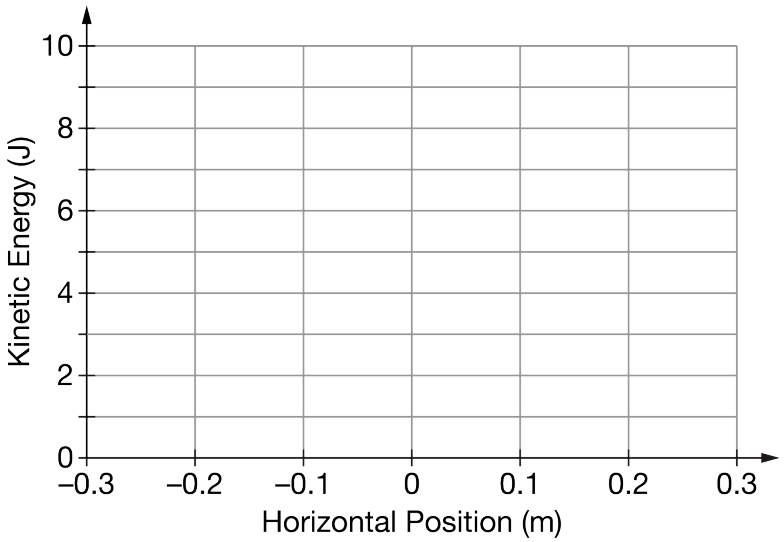


Unit 6 Progress Check: FRQ

(b) Calculate the period of oscillation for the block-spring system.

A new block of mass $1.0\,\text{kg}$ is attached to the spring. The center of mass of the block is stretched a horizontal distance $x = 0.25\,\text{m}$ beyond its equilibrium position and released from rest such that the block-spring system undergoes simple harmonic motion.

(c) The grid below represents the kinetic energy of this new block-spring system as a function of the horizontal position of the center of mass of the block. Sketch the curve for the kinetic energy of the block-spring system as a function of the horizontal position of the center of mass of the block.



Part (a)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

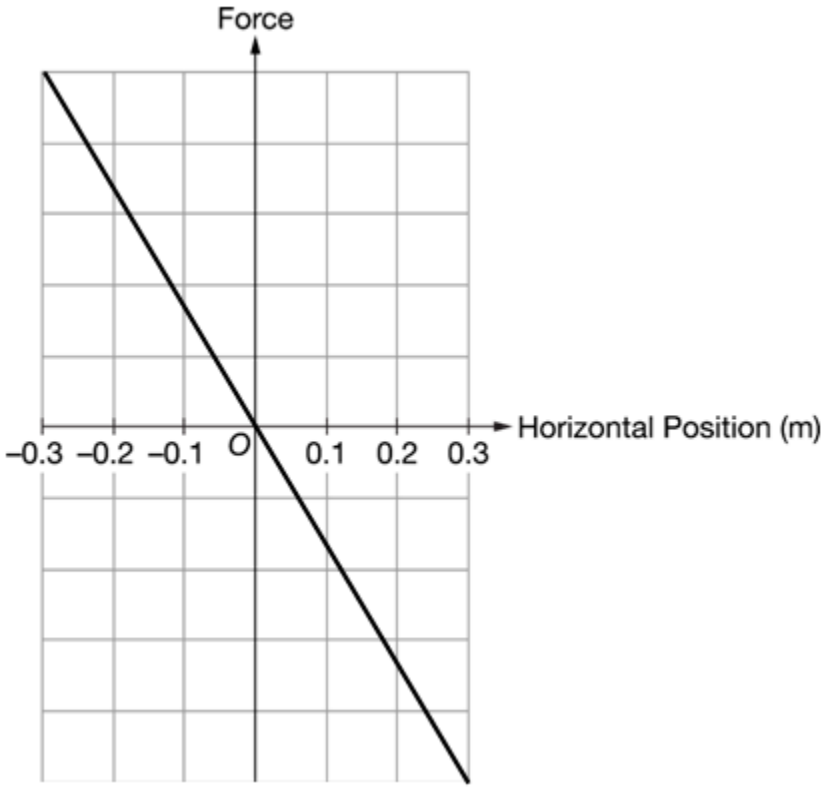
0	1	2 ✓

Student response accurately includes both of the following criteria.

- ☐ 1 point is earned for a straight line passing through the origin.
- ☐ 1 point is earned for a curve or line with a slope that is negative at all points.

Example Response:

Unit 6 Progress Check: FRQ



Part (b)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

Student response accurately includes all of the following criteria.

- ☐ 1 point is earned for relating the horizontal distance stretched of the spring to the spring potential energy stored in the spring.
- ☐ 1 point is earned for a correct expression for the spring constant of the spring.

  Example Response:

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

  $\frac{2U_s}{x^2} = k$

  $k = \frac{2(10\,\text{J})}{(0.25\,\text{m})^2}$

  $k = 320\,\text{N/m}$
- ☐ 1 point is earned for the correct period of oscillation for the block-spring system.

  Note: The test taker can still earn this point if the value of the spring constant is consistent with what was determined or assumed in the previous point.

  Example Response:

Unit 6 Progress Check: FRQ

$$T_s = 2\pi\sqrt{\frac{m}{k}}$$
$$T_s = 2\pi\sqrt{\frac{0.4\,\text{kg}}{320\,\text{N/m}}}$$
$$T_s \approx 0.22\,\text{s}$$

Part (c)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

Two (2) Points

Student response accurately includes all of the following criteria.

- ☐ 1 point is earned for minimum values at $x = -0.25\,\text{m}$ and $x = 0.25\,\text{m}$ and for a maximum value at $x = 0\,\text{m}$ with a value of $10\,\text{J}$.
- ☐ 1 point is earned for the correct shape of the curve (concave down parabola).

Example Response:

