2019

AP® CollegeBoard

AP® Physics 1: Algebra-Based

Scoring Guidelines

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.

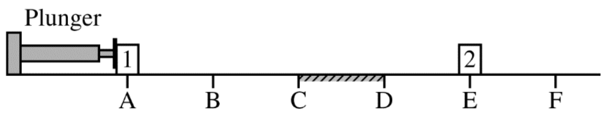
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked 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 1

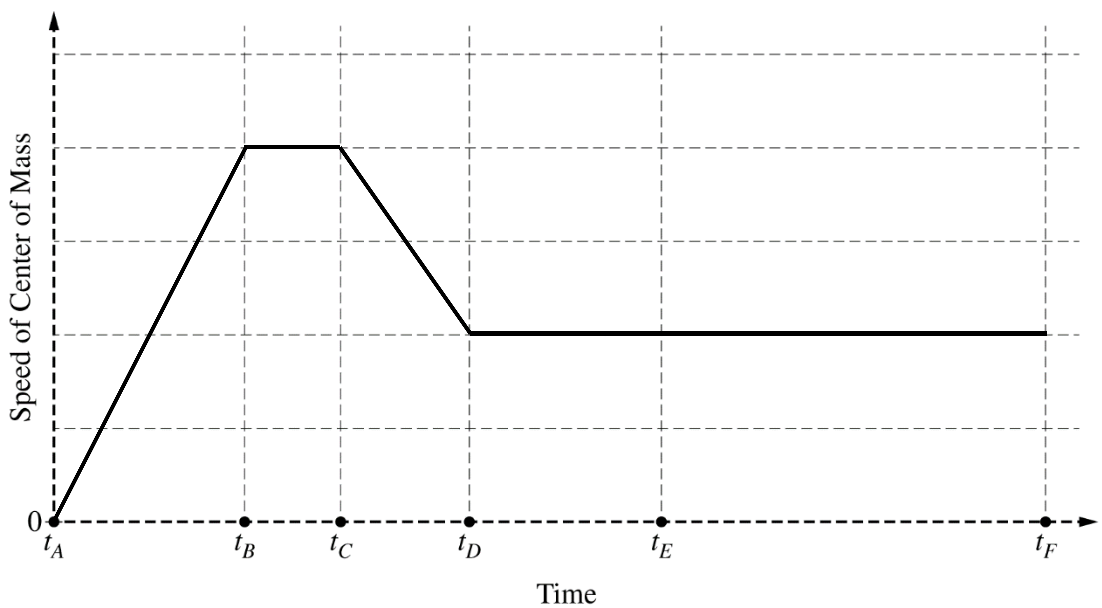
7 points



Identical blocks 1 and 2 are placed on a horizontal surface at points A and E, respectively, as shown. The surface is frictionless except for the region between points C and D, where the surface is rough. Beginning at time t_A, block 1 is pushed with a constant horizontal force from point A to point B by a mechanical plunger. Upon reaching point B, block 1 loses contact with the plunger and continues moving to the right along the horizontal surface toward block 2. Block 1 collides with and sticks to block 2 at point E, after which the two-block system continues moving across the surface, eventually passing point F.

(a) LO 4.A.1.1, SP 1.2, 1.4, 2.3, 6.4; LO 4.A.2.3, SP 1.4, 2.2; LO 4.A.3.2, SP 1.4; LO 5.D.3.1, SP 6.4
5 points

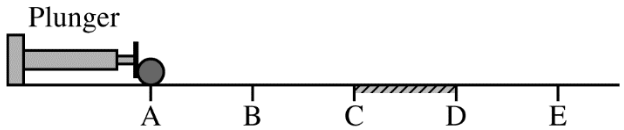
On the axes below, sketch the speed of the center of mass of the two-block system as a function of time, from time t_A until the blocks pass point F at time t_F. The times at which block 1 reaches points A through F are indicated on the time axis.



For a straight line that begins at zero at t_A and increases between t_A and t_B		1 point
For a segment that is horizontal and nonzero between t_B and t_C		1 point
For a segment that decreases linearly between t_C and t_D		1 point
For a segment that is horizontal, nonzero, and constant (but different value than segment from t_B to t_C) from t_D through t_F (with no change at t_E)		1 point
For a curve that is continuous from t_A through t_F, with the possible exception of t_E. Note: If the speed changes at t_E, the fourth point is not earned while this point may still be earned.		1 point
Note: No credit is earned for a horizontal line along the t-axis.		

Question 1 (continued)

(b) LO 4.D.1.1, SP 1.2, 1.4; LO 4.D.2.1, SP 1.2, 1.4; LO 5.E.1.1, SP 6.4, 7.2
2 points



The plunger is returned to its original position, and both blocks are removed. A uniform solid sphere is placed at point A, as shown. The sphere is pushed by the plunger from point A to point B with a constant horizontal force that is directed toward the sphere's center of mass. The sphere loses contact with the plunger at point B and continues moving across the horizontal surface toward point E. In which interval(s), if any, does the sphere's angular momentum about its center of mass change? Check all that apply.

____ A to B ____ B to C ____ C to D ____ D to E _____ None

Briefly explain your reasoning.

Correct Answer: "C to D"		
For reasoning that a change in angular momentum is caused by a net external torque		1 point
For correctly indicating that friction from C to D is the only force producing an external torque over the entire interval from A to E Note: This point is not earned if a statement is made that the angular momentum or angular speed decreases between C and D or that the sphere stops rotating at point D.		1 point
Claim: The sphere's angular momentum about its center of mass changes in the interval C to D. Evidence: There is friction between points C and D. Reasoning: Friction applies a torque in region C to D about the central axis of the cylinder to increase/change its angular momentum.		

Question 1 (continued)

Learning Objectives

LO 4.A.1.1: The student is able to use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semiquantitatively. [See Science Practices 1.2, 1.4, 2.3, 6.4]

LO 4.A.2.3: The student is able to create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system. [See Science Practices 1.4, 2.2]

LO 4.A.3.2: The student is able to use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system. [See Science Practice 1.4]

LO 4.D.1.1: The student is able to describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system. [See Science Practices 1.2, 1.4]

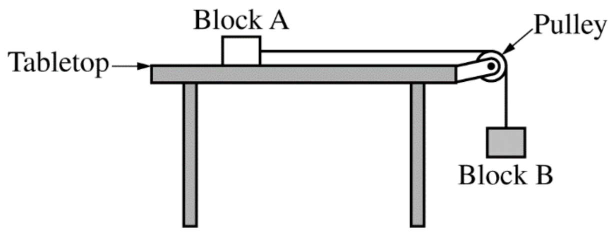
LO 4.D.2.1: The student is able to describe a model of a rotational system and use that model to analyze a situation in which angular momentum changes due to interaction with other objects or systems. [See Science Practices 1.2, 1.4]

LO 5.D.3.1: The student is able to predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center of mass motion of the system and is able to determine that there is no external force). [See Science Practice 6.4]

LO 5.E.1.1: The student is able to make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque. [See Science Practices 6.4, 7.2]

Question 2

12 points



This problem explores how the relative masses of two blocks affect the acceleration of the blocks. Block A, of mass m_A, rests on a horizontal tabletop. There is negligible friction between block A and the tabletop. Block B, of mass m_B, hangs from a light string that runs over a pulley and attaches to block A, as shown above. The pulley has negligible mass and spins with negligible friction about its axle. The blocks are released from rest.

(a) LO 3.A.1.1, SP 1.5; LO 3.B.1.1, SP 6.4, 7.2

i.
2 points

Suppose the mass of block A is much greater than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Briefly explain your reasoning without deriving or using equations.

Examples of correct answers: “Zero”, “small”, “negligible”, “much less than g”, or “<<g”		
For a correct answer and attempt at a consistent justification		1 point
For correct reasoning		1 point
Example earning 1 point: Nearly zero. Because block A is much heavier than block B.		
Examples earning 2 points: “Very small. Because block A has a large inertia, it won’t speed up much.” “Close to zero because block B is so light that it can hardly budge block A.”		
Claim: The acceleration of the blocks is zero/small/negligible/ “<<g”. Evidence: The mass of block A is much greater than the mass of block B. Reasoning: See two-point examples above.		

ii.
1 point

Now suppose the mass of block A is much less than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Briefly explain your reasoning without deriving or using equations.

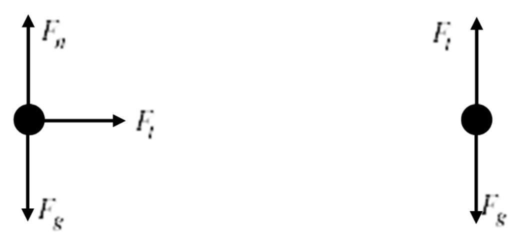
Question 2 (continued)

(a) (continued)
ii. (continued)

Examples of correct answers: g or 9.8 m/s^2 or 10 m/s^2 (or just 9.8 or 10)		
For a correct answer and correct justification		1 point
Examples: Nearly equal to g. Because block B is almost in free fall. 10 m/s^2, because block A has negligible mass and the tension in the string is nearly zero.		
Claim: The acceleration of the blocks is close to g. Evidence: The mass of block A is much <u>less</u> than the mass of block B. There is negligible friction between block A and the tabletop. The pulley has negligible mass and spins with negligible friction about its axle. Reasoning: See examples above.		

(b) LO 3.A.2.1, SP 1.1; LO 3.A.3.1, SP 6.4
3 points

Now suppose neither block's mass is much greater than the other, but that they are not necessarily equal. The dots below represent block A and block B, as indicated by the labels. On each dot, draw and label the forces (not components) exerted on that block after release. Represent each force by a distinct arrow starting on, and pointing away from, the dot.



Block A Block B

For a correct normal force on block A with acceptable label: N, F_N, "normal force," F_{table}, "table force," or any other label indicating the force is "normal" or comes from the table		1 point
For correct gravitational forces with acceptable label on both diagrams: F_g, F_{grav}, W, mg, $m_A g$, "gravity," "grav force," but NOT G or g, and no extraneous forces on either diagram		1 point
For correct tension forces with acceptable label on both diagrams: "tension," "string force," F_T, $F_{tension}$, F_{string}, F_S, T, or some other label indicating that the force comes from the string or from tension. NOT acceptable: $m_B g$, F_{m_B}, "force from block B" or other indications that the force is "created" by block B		1 point

Question 2 (continued)

(c) LO 2.B.1.1, SP 2.2; LO 3.A.1.1, SP 1.5, 2.2; LO 3.B.1.3, SP 1.5, 2.2; LO 3.B.2.1, SP 1.4, 2.2; LO 4.A.2.1, SP 6.4
3 points

Derive an equation for the acceleration of the blocks after release in terms of m_A, m_B, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

For using separate Newton's second law equations for each block		1 point
For combining the equations with correct notation, including correctly using m_A and m_B, indicating that the same tension force acts on both blocks, *and* that they share the same acceleration		1 point
For a correct equation for *a* with supporting work: $a = \dfrac{m_B}{m_A + m_B} g$		1 point

Alternate Solution:

For writing a "whole-system" equation for the total mass that does not contain internal forces. $F_{net} = m_{total} a$		*1 point*
For substituting the net force and system mass with correct quantities $m_B g = (m_A + m_B) a$		*1 point*
Note: Writing the correct whole-system equation is sufficient to earn the first two points.		
For a correct equation for a with supporting work: $a = \dfrac{m_B}{m_A + m_B} g$		*1 point*

(d) LO 3.A.1.1, SP 2.2; LO 3.A.3.1, SP 6.4; LO 3.B.1.3, SP 2.2
1 point

Consider the scenario from part (a)(ii), where the mass of block A is much less than the mass of block B. Does your equation for the acceleration of the blocks from part (c) agree with your reasoning in part (a)(ii)?

____ Yes ____ No

Briefly explain your reasoning by addressing why, according to your equation, the acceleration becomes (or approaches) a certain value when m_A is much less than m_B.

Correct answer: "Yes"		
Note: "No" is acceptable if the equation is inconsistent with the answer in (a)(ii).		
For valid reasoning that addresses the result in part (c) and the reasoning in part (a)(ii)		1 point

Question 2 (continued)

(d) (continued)

Claims: Yes, the equation for the acceleration of the blocks from part (c) agrees with the reasoning in part (a)(ii). or No, the equation for the acceleration of the blocks from part (c) does not agree with the reasoning in part (a)(ii). Evidence: The mass of block A is much less than the mass of block B. $a = \frac{m_B}{m_A + m_B} g$ (derived as part (c) answer) Reasoning for "Yes" claim: When m_A is much less than m_B, it can be neglected in the equation derived in part (c), giving an acceleration close to g as stated in (a)(ii). Reasoning for "No" claim, if the answer in part (a)(ii) is wrong: When m_A is much less than m_B, it can be neglected in the equation derived in part (c), giving an acceleration close to g. This disagrees with the value of ___ stated in (a)(ii). Reasoning for "No" claim, if the answer in part (c) is wrong: When m_A is much less than m_B, it can be neglected in the equation derived in part (c), giving an acceleration of ___. This disagrees with the value of g stated in (a)(ii).		

(e) LO 3.A.1.1, SP 2.2; LO 3.B.1.1, SP 6.4,7.2; LO 3.B.1.3, SP 2.2
2 points

While the blocks are accelerating, the tension in the vertical portion of the string is T_1. Next, the pulley of negligible mass is replaced with a second pulley whose mass is not negligible. When the blocks are accelerating in this scenario, the tension in the vertical portion of the string is T_2. How do the two tensions compare to each other?

____ $T_2 > T_1$ ____ $T_2 = T_1$ ____ $T_2 < T_1$

Briefly explain your reasoning.

Correct answer: $T_2 > T_1$. Note: A maximum of 1 point can be earned if an incorrect selection is made.		
For reasoning that the acceleration of both blocks is smaller		1 point
For doing any one of the following, consistent with the answer selection and Newton's second law for block B • Concluding that a smaller acceleration implies that T_2 is greater than T_1 • Concluding that an unchanged acceleration implies that T_2 is the same as T_1 • Concluding that a larger acceleration implies that T_2 is less than T_1		1 point

Question 2 (continued)

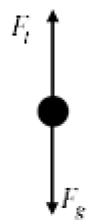
(e) (continued)

Claim: $T_2 > T_1$

Evidence:

The pulleys spin with negligible friction about the axle.
The original pulley has negligible mass.
The second pulley's mass is not negligible.

$$\vec{a} = \frac{\sum \vec{F}}{m}$$



Block B

Reasoning:

The rotational inertia of the second pulley results in a smaller acceleration for the blocks. Block B must have a smaller net force to have a smaller acceleration, so the rope tension must be larger than before (closer in magnitude to the gravitational force on block B).

Learning Objectives

LO 2.B.1.1: The student is able to apply F = mg to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems. [See Science Practices 2.2, 7.2]
LO 3.A.1.1: The student is able to express the motion of an object using narrative, mathematical, and graphical representations. [See Science Practices 1.5, 2.1, 2.2]
LO 3.A.2.1: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [See Science Practice 1.1]
LO 3.A.3.1: The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [See Science Practices 6.4, 7.2]
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 3.B.1.3: The student is able to reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [See Science Practices 1.5, 2.2]
LO 3.B.2.1: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, 2.2]
LO 4.A.2.1: The student is able to make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [See Science Practice 6.4]

Question 3

12 points

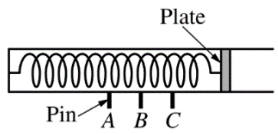


Figure 1. Uncompressed spring

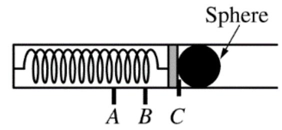


Figure 2. Compressed spring

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") 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.

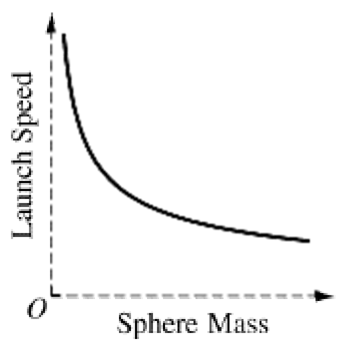
Question 3 (continued)

(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

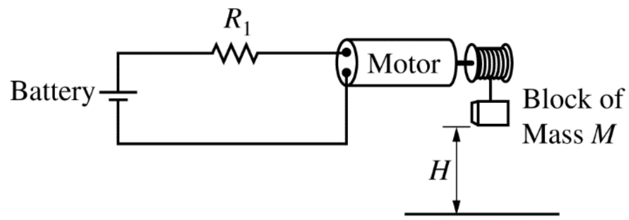
Question 3 (continued)

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]

Question 4

7 points



A motor is a device that when connected to a battery converts electrical energy into mechanical energy. The motor shown above is used to lift a block of mass M at constant speed from the ground to a height H above the ground in a time interval Δt. The motor has constant resistance and is connected in series with a resistor of resistance R_1 and a battery.

Mechanical power, the rate at which mechanical work is done on the block, increases if the potential difference (voltage drop) between the two terminals of the motor increases.

(a) LO 5.B.5.5, SP 2.2
2 points

Determine an expression for the mechanical power in terms of M, H, Δt, and physical constants, as appropriate.

For an expression that implies reasoning in terms of energy (as opposed to e.g., kinematics)		1 point
Example: MgH		
For a correct expression for the power generated by the motor lifting the block at constant speed		1 point
$MgH/\Delta t$		

(b) LO 5.B.9.2, SP 4.2, 6.4, 7.2; LO 5.B.9.3, SP 6.4, 7.2
5 points

Without M or H being changed, the time interval Δt can be decreased by adding one resistor of resistance R_2, where $R_2 > R_1$, to the circuit shown above. How should the resistor of resistance R_2 be added to the circuit to decrease Δt ?

___ In parallel with the battery   ___ In parallel with R_1 ___ In parallel with the motor   ___ In series with the battery, R_1, and the motor

In a clear, coherent, paragraph-length response that may also contain figures and/or equations, justify why your selection would decrease Δt.

Correct answer: "In parallel with R_1"		
Note: If the wrong selection is made, the justification may still earn credit.		

Question 4 (continued)

(b) (continued)

For a justification that correctly asserts that power must increase for Δt to decrease, or correctly asserting that the faster the rate of energy transfer means that works gets done in a smaller time interval		1 point
For a correct assertion that current increases as resistance of the circuit decreases *Alternate Method: Potential difference across the parallel resistors will decrease if their resistance decreases.*		1 point
For making the connection that there is an increase in current specifically in the motor because it is the same as the total current in the circuit *Alternate Method: There is an increase in potential difference specifically across the motor because the potential difference across the parallel resistors decreases (Kirchhoff's loop rule).*		1 point
For a justification that indicates that connecting R_2 in parallel with R_1 will decrease the equivalent resistance of the circuit		1 point
For a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response		1 point

Example Paragraph Response 1: The work required to lift the block is MgH, so the rate at which the motor must do work to lift the block in the given time is $W/\Delta t = MgH/\Delta t$. The rate at which the motor does work increases with the potential difference across the motor (<u>Note:</u> This information is given in the question, so no points allotted in rubric for this statement.) To decrease the time, the motor must increase the rate at which the work is done, which requires a larger potential difference across the motor (or a larger current through the motor because $\Delta V = IR$). To increase the potential difference across the motor, the potential difference across R_1 must decrease, by Kirchhoff's loop rule (for a loop containing the battery, the motor and R_1). When R_2 is placed in parallel with R_1 the equivalent resistance of the combination decreases and the potential difference across that section decreases.		
Example Paragraph Response 2: Resistor R_2 should be connected in parallel with R_1. This will result in a smaller equivalent resistance in series with the battery and motor, so the current in the circuit (and through the motor) will be larger. The larger motor current results in the motor having a higher mechanical power. Because this power $MgH/\Delta t$ is larger and MgH is constant, the time interval Δt will be smaller.		

Question 4 (continued)

Learning Objectives

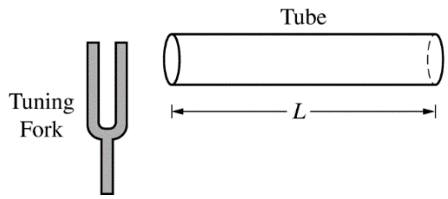
LO 5.B.5.5: The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. [See Science Practices 2.2, 6.4]

LO 5.B.9.2: The student is able to apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\Sigma \Delta V = 0$) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches. [See Science Practices 4.2, 6.4, 7.2]

LO 5.B.9.3: The student is able to apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch. [See Science Practices 2.2, 6.4, 7.2]

Question 5

7 points



A tuning fork vibrating at 512 Hz is held near one end of a tube of length L that is <u>open</u> at both ends, as shown above. The column of air in the tube resonates at its fundamental frequency. The speed of sound in air is $340\ \text{m/s}$.

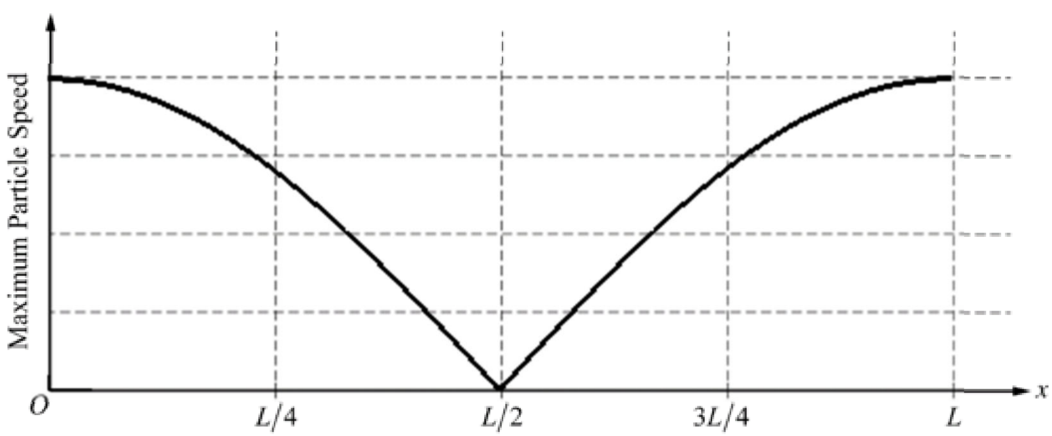
(a) LO 6.D.3.4, SP 1.2; LO 6.D.4.2, SP 2.2
2 points

Calculate the length L of the tube.

For using $\lambda = v/f$		1 point
$\lambda = (340\ \text{m/s})/(512\ \text{Hz}) = 0.66\ \text{m}$		
For a length that is half of the calculated wavelength, with units		1 point
$L = \lambda/2 = 0.33\ \text{m}$		

(b) LO 6.A.1.2, SP 1.2; LO 6.D.3.2, SP 6.4; LO 6.D.3.4, SP 1.2; LO 6.D.4.2, SP 2.2
3 points

The column of air in the tube is still resonating at its fundamental frequency. On the axes below, sketch a graph of the maximum speed of air molecules as they oscillate in the tube, as a function of position x, from $x = 0$ (left end of tube) to $x = L$ (right end of tube). (Ignore random thermal motion of the air molecules.)



For a curve with a node (zero) at $L/2$		1 point
For a curve with maxima at 0, L, and no other points		1 point
For a nonhorizontal curve that is symmetric around $L/2$ and nonnegative everywhere		1 point

Question 5 (continued)

(c) LO 6.D.3.4, SP 1.2; LO 6.D.4.2, SP 2.2)
2 points

The right end of the tube is now capped shut, and the tube is placed in a chamber that is filled with another gas in which the speed of sound is $1005\ \text{m/s}$. Calculate the new fundamental frequency of the tube.

Correct answer: 757 Hz		
For an indication that the fundamental wavelength is $4L$		1 point
For substituting the new sound speed in $v = \lambda f$		1 point

Learning Objectives

LO 6.A.1.2: The student is able to describe representations of transverse and longitudinal waves. [See Science Practice 1.2]
LO 6.D.3.2: The student is able to predict properties of standing waves that result from the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. [See Science Practice 6.4]
LO 6.D.3.4: The student is able to describe representations and models of situations in which standing waves result from the addition of incident and reflected waves confined to a region. [See Science Practice 1.2]
LO 6.D.4.2: The student is able to calculate wavelengths and frequencies (if given wave speed) of standing waves based on boundary conditions and length of region within which the wave is confined, and calculate numerical values of wavelengths and frequencies. Examples should include musical instruments. [See Science Practice 2.2]