Question 4: Qualitative Quantitative Translation (QQT) **8 points**

A	For indicating $a_1 < a_2$	**Point A1**
	For a justification that indicates that the blocks have the same weight or mass	**Point A2**
	For a justification that indicates that the salt water exerts a larger buoyant force than the freshwater exerts (or the freshwater exerts a smaller buoyant force than the saltwater exerts)	**Point A3**
	Example Response *There are identical downward forces (mg) on the block in both liquids. Each submerged block also has an upward buoyant force. Because the buoyant force is proportional to the density of the fluid, the block in salt water has a larger buoyant force exerted on it. Therefore, the block in salt water has a larger net force and so has a larger acceleration.*	
B	For a multistep derivation that includes Newton's second law	**Point B1**
	For indicating ρVg is the buoyant force	**Point B2**
	For a correct expression for the initial upward acceleration a, consistent with the indicated expression for buoyant force **Scoring Note:** A correct, isolated, final expression for a earns points B2 and B3.	**Point B3**
	Example Response $\Sigma F = m_{sys}a_{sys}$ $F_B - mg = ma$ $\rho Vg - mg = ma$ $a = \frac{\rho Vg}{m} - g$	
C	For attempting to address the functional dependence between a and ρ in the equation derived in part B **Scoring Note:** It is not necessary to use the functional dependence correctly to earn this point. The response only needs to use functional dependence language such as proportional, inversely proportional, related, numerator, and denominator, to relate a and ρ.	**Point C1**
	For correctly using functional dependence to evaluate the relationship between a and ρ consistent with the expression derived in part B and the claim made in part A	**Point C2**
	Example Response *The expression for the acceleration a is consistent with part A. In part A, I said the acceleration would be larger in salt water because the density is greater. In my expression, the acceleration increases with increasing density because of the* $\frac{\rho Vg}{m}$ *term.*	

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.

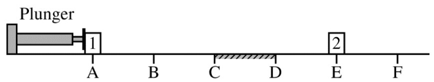
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked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

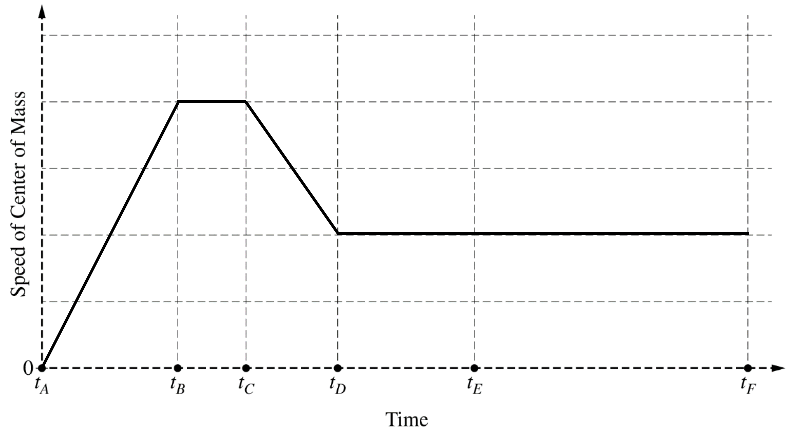
7 points



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

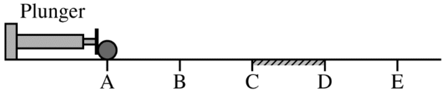
On the axes below, sketch the speed of the center of mass of the two-block system as a function of time, from time t_A until the blocks pass point F at time t_F. The times at which block 1 reaches points A through F are indicated on the time axis.



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 <u>constant</u> 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 <u>Note:</u> 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]

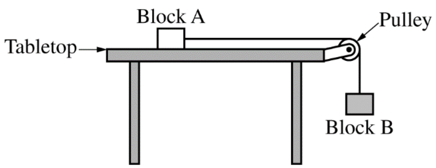
LO 5.D.3.1: The student is able to predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center of mass motion of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

2019 SCORING GUIDELINES

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 <u>greater</u> 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 <u>greater</u> than the mass of block B. Reasoning: See two-point examples above.		

ii.
1 point

Now suppose the mass of block A is much <u>less</u> 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.

2019 SCORING GUIDELINES

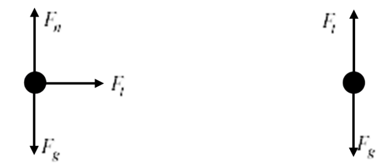
Question 2 (continued)

(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. $a = \dfrac{m_B}{m_A + m_B} g$ (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)

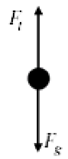
(e) (continued)

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

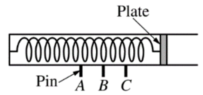


Figure 1. Uncompressed spring

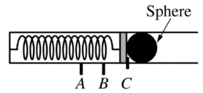


Figure 2. Compressed spring

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 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 $k = m_S v_L^2/d^2$. Compare the *k* values for each spring position. If the values agree within experimental uncertainty, then the hypothesis is confirmed.

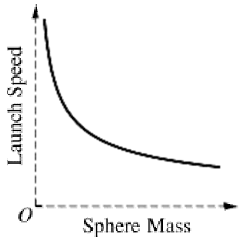
Question 3 (continued)

(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 $\frac{1}{2}kd^2 = mg\Delta y_{\text{avg}}$ (if measuring height from the release (pin) position) $\frac{1}{2}kd^2 = mg\left(\Delta y_{\text{avg}} + d\right)$ (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

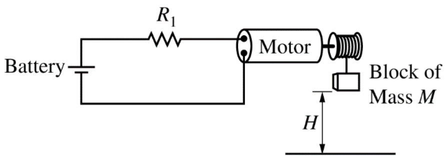
Question 3 (continued)

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 (Note: 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.		

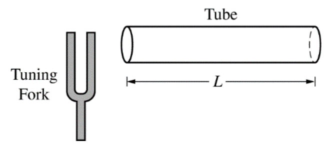
Question 4 (continued)

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 open 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 $340\ \text{m/s}$.

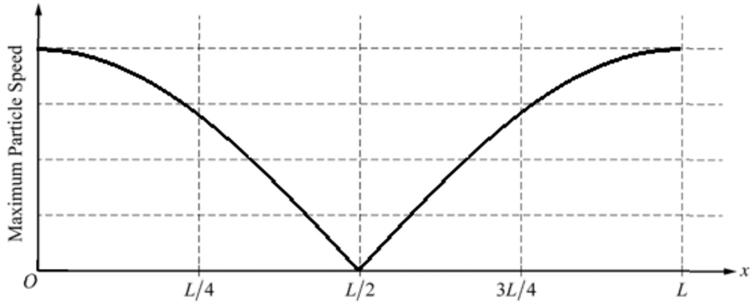
(a) LO 6.D.3.4, SP 1.2; LO 6.D.4.2, SP 2.2
2 points

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

2019 SCORING GUIDELINES

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]

2018

AP CollegeBoard

AP Physics 1: Algebra-Based

Scoring Guidelines

2018 SCORING GUIDELINES

General Notes About 2018 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*.

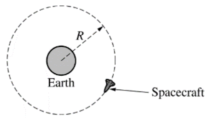
5. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but the use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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.

2018 SCORING GUIDELINES

Question 1

7 points total **Distribution of points**

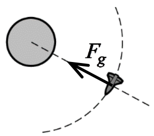


Note: Figure not drawn to scale.

A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E .

(a) LO / SP: 3.A.2.1 / 1.1; 3.B.2.1 / 1.1, 1.4
2 points

In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.



Note: Figure not drawn to scale.

For an arrow directed toward Earth's center		1 point
For a correct label on the arrow representing the gravitational force, where the arrow is pointing toward Earth's center		1 point
Note: A maximum of 1 point may be earned if extraneous forces are present.		

2018 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(b) LO / SP: 2.B.2.1 / 2.2; 3.A.1.1 / 1.5, 2.2; 3.B.1.3 / 1.5, 2.2; 3.B.2.1 / 1.1, 1.4, 2.2, 3.C.1.2 / 2.2
4 points

i. 3 points

Derive an equation for the orbital period T of the spacecraft in terms of m, M_E, R, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

For using (or implying) Newton's second law and equating the centripetal force to the gravitational force: $F_g = ma = \frac{mv^2}{R}$ $\quad \frac{GmM_E}{R^2} = \frac{mv^2}{R}$		1 point
For explicitly or implicitly determining that the speed of the spacecraft is: $v = \frac{2\pi R}{T}$		1 point
For a correct answer algebraically equivalent to: $T = \sqrt{\frac{4\pi^2 R^3}{GM_E}}$		1 point
Note: It is acceptable to leave answer in terms of T^2 $T^2 = \frac{4\pi^2 R^3}{GM_E}$		

ii. 1 point

A second spacecraft of mass $2m$ is placed in a circular orbit with the same radius R. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

Correct answer: "Equal to" Note: For an incorrect answer consistent with part (b)(i), the explanation is still graded for consistency with part (b)(i).		
For a correct explanation that the period of the spacecraft does not depend on the spacecraft mass (or only depends on the mass of Earth and the radius of the orbit) OR an explanation consistent with the answer from (b)(i)		1 point
Note: The explanation must be consistent with the checked answer.		

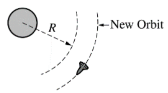
2018 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(c) LO / SP: 2.B.1.1 / 2.2; 3.A.1.1 / 1.5, 2.2; 3.B.1.3 / 1.5, 2.2; 3.B.2.1 / 1.1, 1.4, 2.2; 3.C.1.2 / 2.2
1 point

The first spacecraft is moved into a new circular orbit that has a radius greater than R, as shown in the figure below.



Note: Figure not drawn to scale.

Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

Correct answer: "Less than" Note: If the wrong selection is made, the explanation is not graded.		
For a correct explanation of why speed decreases with increasing orbital radius		1 point
Example: Derivation step in (b)(i) shows that speed decreases with increasing R.		

2018 SCORING GUIDELINES

Question 1 (continued)

Learning Objectives (LO)

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 and 7.2]

LO 2.B.2.1: The student is able to apply $g = GM/r^2$ to calculate the gravitational field due to an object with mass M, where the field is a vector directed toward the center of the object of mass M. [See Science Practice 2.2]

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, and 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.B.1.3: The student is able to re-express 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 and 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, and 2.2]

LO 3.C.1.2: The student is able to use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion (for circular orbital motion only in Physics 1). [See Science Practice 2.2]

2018 SCORING GUIDELINES

Question 2

12 points total — **Distribution of points**

A group of students prepare a large batch of conductive dough (a soft substance that can conduct electricity) and then mold the dough into several cylinders with various cross-sectional areas A and lengths ℓ. Each student applies a potential difference ΔV across the ends of a dough cylinder and determines the resistance R of the cylinder. The results of their experiments are shown in the table below.

Lab Station	$A\ (\text{m}^2)$	ℓ (m)	ΔV (V)	R (Ω)	Example: $RA\ (\Omega\text{•m}^2)$	Example: $\ell/A\ (\text{m}^{-1})$
1	0.00049	0.030	1.02	23.6	0.012	61
2	0.00049	0.050	2.34	31.5	0.015	102
3	0.00053	0.080	3.58	61.2	0.032	151
4	0.00057	0.150	6.21	105.0	0.060	263

(a) LO / SP: 1.E.2.1 / 4.1; 5.B.9.3 / 2.2; 5.C.3.2 / 4.1, 5.1
7 points

The students want to determine the resistivity of the dough cylinders.

i. 2 points

Indicate below which quantities could be graphed to determine a value for the resistivity of the dough cylinders. 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: ________________________

For quantities derived from R, ℓ, and A only		1 point
For choosing two quantities that, graphed together, can be used to determine the resistivity		1 point

2018 SCORING GUIDELINES

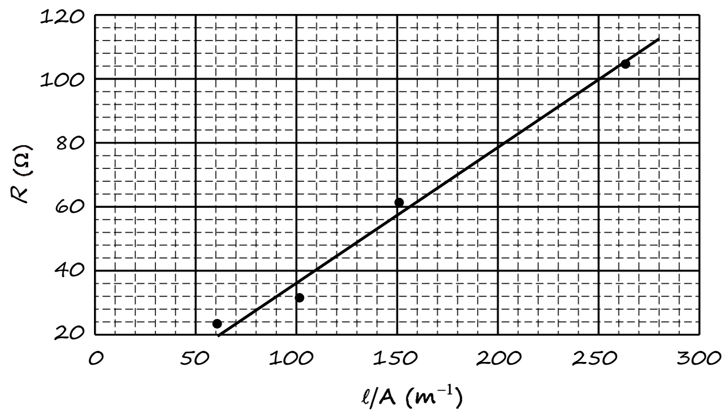
Question 2 (continued)

Distribution of points

(a) (continued)

ii. 3 points

On the grid below, plot the appropriate quantities to determine the resistivity of the dough cylinders. Clearly scale and label all axes, including units as appropriate.



Note: The following points can be earned only if the graphed points correspond to the quantities chosen in (a)(i).		
For a linear scale where the plotted data uses at least half the grid		1 point
For labeling both axes, with units as appropriate		1 point
For data points plotted that represent the appropriate trend based on chosen quantities Note: The appropriate trend depends on the choice of graphed quantities and may be e.g., linear, inversely proportional, etc.		1 point

2018 SCORING GUIDELINES

Question 2 (continued)

Distribution of points

(a) (continued)

iii. 2 points

Use the above graph to estimate a value for the resistivity of the dough cylinders.

For correctly using the slope of the graph to find the resistivity or a statement that a calculator was used to find the appropriate value from the graph		1 point
For a correct value of the resistivity $\rho = 0.42\ \Omega\bullet\text{m}\ (\pm 0.03)$ calculated from graph or data		1 point

(b) LO / SP: 1.E.2.1 / 4.1
1 point

Another group of students perform the experiment described in part (a) but shape the dough into long rectangular shapes instead of cylinders. Will this change affect the value of the resistivity determined by the second group of students?
____ Yes ____ No
Briefly justify your reasoning.

Correct answer: "No" Note: If the wrong selection is made, the explanation is not graded.		
For indicating that resistivity only depends on material, not shape		1 point

(c) LO / SP: 1.E.2.1 / 4.1; 5.B.9.2 / 4.2; 5.B.9.3 / 2.2; 5.C.3.2 / 4.1, 4.2; 5.C.3.3 / 1.4, 2.2
4 points

Describe an experimental procedure to determine whether or not the resistivity of the dough cylinders depends on the temperature of the dough. Give enough detail so that another student could replicate the experiment. As needed, include a diagram of the experimental setup. Assume equipment usually found in a school physics laboratory is available.

For explicitly or implicitly controlling all variables (e.g., length and area) except for temperature		1 point
For a plausible way to change the temperature of the dough		1 point
For indicating that the temperature will be varied		1 point
For a valid and feasible experiment in which resistance, OR voltage and current, are appropriately measured		1 point
Example: Make two dough cylinders of the same length and cross-sectional area. Keep one cylinder at room temperature, and heat the other cylinder on a hot plate to 30°C (measured with a thermometer). Apply the same voltage to each cylinder (measured with a voltmeter), and measure the current through each cylinder with an ammeter.		

2018 SCORING GUIDELINES

Question 2 (continued)

Learning Objectives (LO)

LO 1.E.2.1: The student is able to choose and justify the selection of data needed to determine resistivity for a given material. [See Science Practice 4.1]

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 ($\Delta V = 0$) 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, and 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, and 7.2]

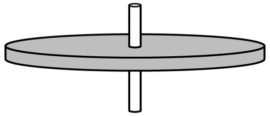
LO 5.C.3.2: The student is able to design an investigation of an electrical circuit with one or more resistors in which evidence of conservation of electric charge can be collected and analyzed. [See Science Practices 4.1, 4.2, and 5.1]

LO 5.C.3.3: The student is able to use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit. [See Science Practices 1.4 and 2.2]

2018 SCORING GUIDELINES

Question 3

12 points total **Distribution of points**



The disk shown above spins about the axle at its center. A student's experiments reveal that, while the disk is spinning, friction between the axle and the disk exerts a constant torque on the disk.

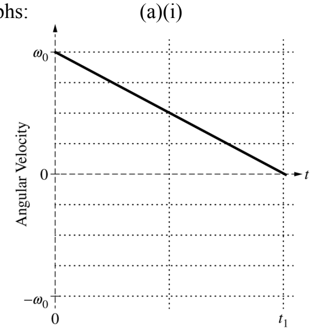
(a) LO / SP: 3.A.1.1 / 1.5, 2.2; 3.F.1.1 / 1.4; 3.F.2.1 / 6.4; 4.D.2.1 / 1.2, 1.4
4 points

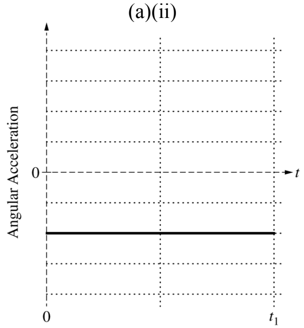
At time $t = 0$ the disk has an initial counterclockwise (positive) angular velocity ω_0. The disk later comes to rest at time $t = t_1$.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.

Example graphs: (a)(i) (a)(ii)





i. 2 points

For a curve that has an angular velocity of $+\omega_0$ at time $t = 0$ and decreases to zero at time $t = t_1$		1 point
For a curve that is a straight line with a negative slope showing the angular velocity approaching zero (can be a positive slope, if the initial angular velocity on the graph is negative)		1 point

2018 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

(a) (continued)
ii. 2 points

For a curve that is negative for the entire time		1 point
For a curve that is a constant nonzero function		1 point

(b) LO / SP: 3.A.1.1 / 1.5, 2.2; 3.F.2.1 / 6.4; 4.D.1.1 / 1.2, 1.4; 4.D.2.1 / 1.2, 1.4; 4.D.3.1 / 2.2
3 points

The magnitude of the frictional torque exerted on the disk is τ_0. Derive an equation for the rotational inertia I of the disk in terms of τ_0, ω_0, t_1, and physical constants, as appropriate.

For using an equation for the rotational version of Newton's second law		1 point
For using an appropriate rotational kinematics equation $\alpha = \Delta\omega/\Delta t$		1 point
For a correct answer in terms of the listed quantities, derived from first principles $I = \dfrac{\tau_0 t_1}{\omega_0}$ <u>Note</u>: This point is still earned if there is a minus sign, e.g., from using $-\tau_0$ or $-\omega_0$.		1 point

Alternate solution using angular momentum and rotational impulse:		
For defining and using angular momentum $L = I\omega$		1 point
For using rotational impulse $\Delta L = \tau\Delta t$		1 point
For a correct answer in terms of the listed quantities, derived from first principles $I = \dfrac{\tau_0 t_1}{\omega_0}$ *<u>Note</u>: This point is still earned if there is a minus sign, e.g., from using* $-\tau_0$ *or* $-\omega_0$.		1 point

2018 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

(c) LO / SP: 3.A.1.1 / 1.5, 2.2; 3.A.3.1 / 6.4, 7.2; 3.F.1.1 / 1.4; 3.F.2.1 / 6.4; 4.D.1.1 / 1.2, 1.4; 4.D.2.1 / 1.2,1.4
4 points

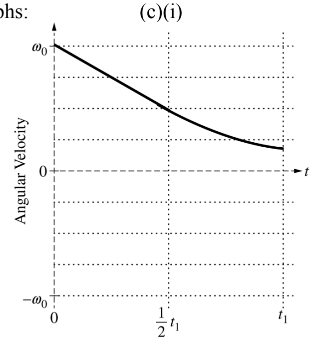
In another experiment, the disk again has an initial positive angular velocity ω_0 at time $t = 0$. At time $t = \frac{1}{2}t_1$, the student starts dripping oil on the contact surface between the axle and the disk to reduce the friction. As time passes, more and more oil reaches that contact surface, reducing the friction even further.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time from $t = 0$ to $t = t_1$, which is the time at which the disk came to rest in part (a).

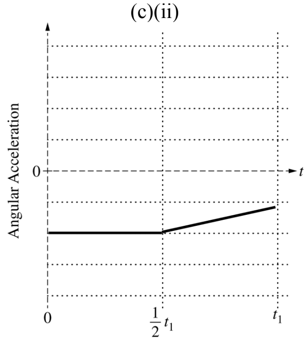
ii. On the grid at right below, sketch the disk's angular acceleration as a function of time from $t = 0$ to $t = t_1$.

Example graphs:

(c)(i)



(c)(ii)



i. 3 points

For curve with a clear change of slope or curvature at $\frac{1}{2}t_1$ and showing a decrease in speed thereafter		1 point
For a curve that indicates slowing at a decreasing rate between times $\frac{1}{2}t_1$ and t_1		1 point
For a curve that does not reach zero at or before time t_1		1 point

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Question 3 (continued)

Distribution of points

(c) (continued)
ii. 1 point

For a curve with decreasing magnitude between times $\frac{1}{2}t_1$ and t_1 Note: The acceleration may reach zero at or before time t_1. If so, it must remain zero for the remaining time.		1 point

(d) LO / SP: 3.F.2.1 / 6.4
1 point

The student is trying to mathematically model the magnitude τ of the torque exerted by the axle on the disk when the oil is present at times $t > \frac{1}{2}t_1$. The student writes down the following two equations, each of which includes a positive constant $(C_1 \text{ or } C_2)$ with appropriate units.

(1) $\tau = C_1\left(t - \frac{1}{2}t_1\right)$ (for $t > \frac{1}{2}t_1$)

(2) $\tau = \dfrac{C_2}{\left(t + \frac{1}{2}t_1\right)}$ (for $t > \frac{1}{2}t_1$)

Which equation better mathematically models this experiment?
____ Equation (1) ____ Equation (2)
Briefly explain why the equation you selected is plausible and why the other equation is not plausible.

Correct answer: "Equation (2)" Note: If the wrong selection is made, the explanation is not graded.		
For stating that Equation (2) is plausible because the frictional torque decreases with increasing time, whereas in Equation (1) torque increases with increasing time		1 point
Examples: Equation (2) because τ decreases. In Equation (1), it doesn't. Equation (2) is plausible because the frictional torque decreases as more oil reaches the contact surface over time. Equation (1) is not plausible because it shows friction increasing as more oil reaches the surface over time.		

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Question 3 (continued)

Learning Objectives (LO)

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, and 2.2]

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 and 7.2]

LO 3.F.1.1: The student is able to use representations of the relationship between force and torque. [See Science Practice 1.4]

LO 3.F.2.1: The student is able to make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis. [See Science Practice 6.4]

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 and 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 and 1.4]

LO 4.D.3.1: The student is able to use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum. [See Science Practice 2.2]

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Question 4

7 points total **Distribution of points**

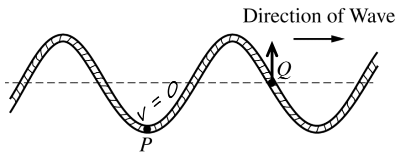
A transverse wave travels to the right along a string.

(a) LO / SP: 3.A.1.1 / 1.5; 6.A.1.2 / 1.2
4 points

Two dots have been painted on the string. In the diagrams below, those dots are labeled *P* and *Q*.

i. 2 points

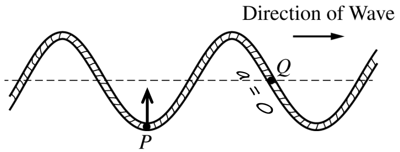
The figure below shows the string at an instant in time. At the instant shown, dot *P* has maximum displacement and dot *Q* has zero displacement from equilibrium. At each of the dots *P* and *Q*, draw an arrow indicating the direction of the instantaneous velocity of that dot. If either dot has zero velocity, write "$v = 0$" next to the dot.



For "$v = 0$" at point *P*		1 point
For an upward arrow at point *Q*		1 point

ii. 2 points

The figure below shows the string at the same instant as shown in part (a)(i). At each of the dots *P* and *Q*, draw an arrow indicating the direction of the instantaneous acceleration of that dot. If either dot has zero acceleration, write "$a = 0$" next to the dot.



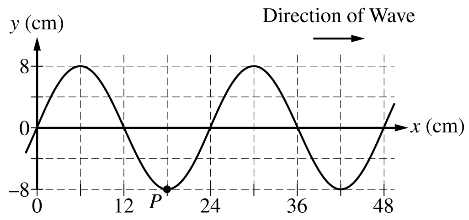
For an upward arrow at point *P*		1 point
For "$a = 0$" at point *Q*		1 point

2018 SCORING GUIDELINES

Question 4 (continued)

Distribution of points

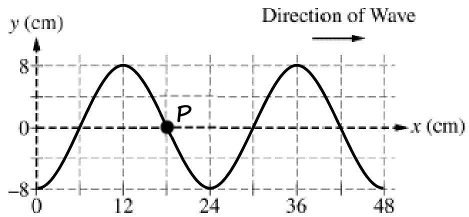
The figure below represents the string at time $t = 0$, the same instant as shown in part (a) when dot P is at its maximum displacement from equilibrium. For simplicity, dot Q is not shown.



(b) LO / SP: 3.A.1.1 / 1.5; 6.A.1.2 / 1.2
2 points

i. 1 point

On the grid below, draw the string at a later time $t = T/4$, where T is the period of the wave.
Note: Do any scratch (practice) work on the grid at the bottom of the page. Only the sketch made on the grid immediately below will be graded.



For a curve shifted to the right by 1/4 of a wavelength (1 gridline) with the same wavelength as the original wave (for example, as indicated by a negative minimum at $x = 0$)		1 point

ii. 1 point
On your drawing above, draw a dot to indicate the position of dot P on the string at time $t = T/4$ and clearly label the dot with the letter P.

For point P on the string and at the dot's original x position, 3/4 of a wavelength (3 grid units) to right of origin		1 point

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Question 4 (continued)

Distribution of points

(c) LO / SP: 6.A.3.1 / 1.4
1 point

Now consider the wave at time $t = T$. Determine the distance traveled (not the displacement) by dot P between times $t = 0$ and $t = T$.

For the correct numerical answer: 32 cm		1 point

Learning Objectives (LO)

LO 3.A.1.1: The student is able to express the motion of an object using narrative, mathematical, and graphical representations. [See Science Practice 1.5]

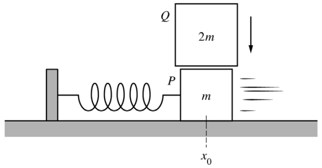
LO 6.A.1.2: The student is able to describe representations of transverse and longitudinal waves. [See Science Practice 1.2]

LO 6.A.3.1: The student is able to use graphical representation of a periodic mechanical wave to determine the amplitude of the wave. [See Science Practice 1.4]

2018 SCORING GUIDELINES

Question 5

7 points total **Distribution of points**



Block *P* of mass m is on a horizontal, frictionless surface and is attached to a spring with spring constant *k*. The block is oscillating with period T_P and amplitude A_P about the spring's equilibrium position x_0. A second block *Q* of mass $2m$ is then dropped from rest and lands on block *P* at the instant it passes through the equilibrium position, as shown above. Block *Q* immediately sticks to the top of block *P*, and the two-block system oscillates with period T_{PQ} and amplitude A_{PQ}.

(a) LO / SP: 3.B.3.1 / 6.4
1 point

Determine the numerical value of the ratio T_{PQ}/T_P.

For a correct answer: $\sqrt{3}$		1 point

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Question 5 (continued)

Distribution of points

(b) LO / SP: 3.B.3.1 / 6.4, 7.2; 3.B.3.4 / 2.2, 6.2; 4.C.1.1 / 1.4, 2.2; 4.C.1.2 / 6.4; 5.B.3.1/ 2.2, 6.4; 5.B.3.3 / 1.4, 2.2; 5.B.4.1 / 6.4, 7.2; 5.B.4.2 / 1.4, 2.1, 2.2; 5.D.2.1 / 6.4, 7.2
6 points

How does the amplitude of oscillation A_{PQ} of the two-block system compare with the original amplitude A_P of block *P* alone?

____ $A_{PQ} < A_P$ ____ $A_{PQ} = A_P$ ____ $A_{PQ} > A_P$

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, explain your reasoning.

Correct answer: $A_{PQ} < A_P$. Note: The response is graded even if an incorrect selection is made.		
For applying conservation of momentum to the collision		1 point
For correctly finding that the post-collision speed has decreased (or, for determining that $v_f = \frac{1}{3}v_i$)		1 point
Note: The first 2 points can be earned for stating that the collision is inelastic		
For stating or implying that the system's kinetic energy has decreased (or, for calculating a lower final kinetic energy)		1 point
For stating or implying kinetic energy of blocks right after collision equals maximum potential energy of spring OR For stating or implying that the maximum potential energy equals the total mechanical energy just after the collision (Simply stating that $E_{tot} = \frac{1}{2}kA^2$ is sufficient.)		1 point
For stating or implying that maximum potential energy is reached when the displacement from equilibrium equals the amplitude of oscillation		1 point
Note: The previous 2 points can be earned in a single sentence in which one or both of the points is implicit.		
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

Alternate solution for first 2 points in part (b):		
A frictional force is exerted on block P by Q, so it slows down. *Note: The third point can be earned if energy loss is stated.*		*2 points*

2018 SCORING GUIDELINES

Question 5 (continued)

Example:

The second block (Q) adds mass without changing the horizontal momentum of the two-block system. In effect, block P (mass m) becomes block PQ (mass $3m$). This reduces the speed at equilibrium from v_{max} to $v_{max}/3$ according to conservation of momentum. To see how this affects amplitude, we must analyze what happens to the maximum kinetic energy (K) of the oscillating mass:

$$K_P = \frac{1}{2}mv_{max}^2 \qquad K_{PQ} = \frac{1}{2}(3m)\left(\frac{v_{max}}{3}\right)^2 = \frac{1}{6}mv_{max}^2 = \frac{1}{3}K_P$$

Because the maximum K is reduced, this means the maximum potential energy in the spring is also reduced (to $1/3$ of its former value). Because amplitude is related to maximum potential energy $\left(U_{max} = \frac{1}{2}kA^2\right)$, the amplitude of block PQ is less than that of block P.

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Question 5 (continued)

Learning Objectives (LO)

LO 3.B.3.1: The student is able to predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. [See Science Practices 6.4, 7.2]

LO 3.B.3.4: The student is able to construct a qualitative and/or a quantitative explanation of oscillatory behavior given evidence of a restoring force. [See Science Practices 2.2, 6.2]

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 4.C.1.2: The student is able to predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system. [See Science Practice 6.4]

LO 5.B.3.1: The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [See Science Practices 2.2, 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.4.1: The student is able to describe and make predictions about the internal energy of systems. [See Science Practices 6.4, 7.2]

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.D.2.1: The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [See Science Practices 6.4, 7.2]

AP® Physics 1
2016 Scoring Guidelines

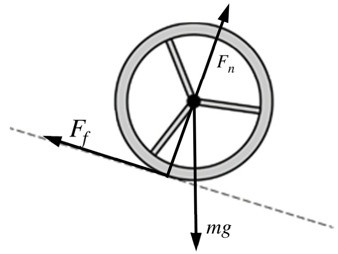
2016 SCORING GUIDELINES

Question 1

7 points total | **Distribution of points**

(a)

i. 2 points



For a labeled arrow representing the gravitational force, starting at the wheel's center and directed downward — 1 point

For labeled arrows representing the friction and normal forces or a single arrow representing the resultant of the friction and normal forces (i.e., the force exerted on the wheel by the surface), with no extraneous forces — 1 point

The friction force should start at the wheel-ramp contact and be directed up and left along the ramp.

The normal force should start at the wheel-ramp contact and be perpendicular to the ramp and toward the wheel's center. It does not have to go exactly through the center but must come reasonably close.

ii. 1 point

Correct answer: The friction force

No points are earned if the wrong force is given.

For correctly explaining that friction is the only force that exerts a torque with respect to the wheel's center of mass — 1 point

This point is also earned for a causal chain of reasoning about forces: e.g., the gravitational force leads to a normal force (and acceleration down the ramp), which leads to a frictional force, which exerts a torque (or changes the angular velocity).

2016 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(b) 2 points

For an expression for the sum of the force components parallel to the ramp that recognizes that there are two forces with components parallel to the ramp — 1 point
The expression need not be correct or consistent with the force diagram in part (a).

$$\sum F_{||} = Mg\sin\theta - F_f$$

For indicating that the frictional force is $(0.4)Mg\sin\theta$ (explicitly or implicitly) and correctly solving for the acceleration in terms of correct variables — 1 point

$$\sum F_{||} = Mg\sin\theta - (0.4)Mg\sin\theta$$

$$a = \frac{\sum F_{||}}{M} = \frac{Mg\sin\theta - 0.4Mg\sin\theta}{M} = \frac{0.6Mg\sin\theta}{M}$$

$$a = 0.6g\sin\theta$$

(c)

i. 1 point

Correct answer: Block
No credit for answer without explanation.
For a correct explanation in terms of forces — 1 point
Example: The wheel experiences a counteracting frictional force, so the block has a greater net force exerted upon it and therefore has greater acceleration.

ii. 1 point

For a correct explanation in terms of energy conservation — 1 point
Example: Both object-Earth systems lose the same amount of potential energy and therefore gain the same amount of kinetic energy. With the ice block — but not the wheel — all the kinetic energy is translational, and none is rotational, so the block is faster.

2016 SCORING GUIDELINES

Question 2

12 points total — **Distribution of points**

Note: For parts (a) and (b), quantities that are proportional to mechanical energy, rather than energy itself, may be calculated, because terms like *g* or the ball's mass do not change during the experiment.

(a) 4 points

Parts i, ii, and iii are scored as a unit.
For an overall plan in which quantities are measured that could be used to compare mechanical energy before and after a collision with a hard surface — 1 point
For a conceptually plausible plan to measure pre- and post-collision positions and/or speeds that could be used to compare pre- and post-collision mechanical energies, without extraneous equipment and/or measurements — 1 point
For having lab equipment and measurement procedures well specified — 1 point
For a procedure that includes trials of different pre-collision speeds, ranging from low speed to high speed (as is needed to test the student's hypothesis) — 1 point

Example 1:
i. The drop height of the ball and the bounce height.
ii. A meterstick to measure the heights and a video camera to record the ball's motion.
iii. Place the meterstick upright against the wall.
Drop the ball from 10 different drop heights, using the video camera to record the bounce heights.

Example 2:
i. The speed of the ball immediately before and immediately after it bounces.
ii. A photogate near the floor, at a height just above the diameter of the ball, to measure the ball's speed.
iii. Drop the ball through the photogate.
Record the speeds measured by the photogate before and after the bounce.
Change the drop height of the ball at least five times, covering a range of heights from "low" to "high."

(b) 4 points

For describing how to plot or otherwise represent the data in a way that could be used to test the hypothesis — 1 point
For describing how to compare the post-collision to pre-collision mechanical energy (or a plausible alternative) to quantify the elasticity of the collision — 1 point
For comparing the low-speed versus high-speed results — 1 point
For addressing the hypothesis with an analysis such as a slope, ratio, or difference — 1 point

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Question 2 (continued)

Distribution of points

(b) (continued)

Example 1:

Make a graph of the bounce height h_f as a function of the drop height h_i. If the data are consistent with the hypothesis, then the data will (1) lie close to the line $h_f = h_i$ for low drop heights, and (2) lie below this line for high drop heights.

Example 2:

Make a graph of $v_f^2 - v_i^2$ as a function of v_i, where v_f and v_i are the ball's speed just after and just before the bounce, respectively. If the data are consistent with the hypothesis, then $v_f^2 - v_i^2$ will (1) be close to zero for low speeds, and (2) be negative for high speeds.

(c)

i. 2 points

For drawing a graph or table that shows that the low-speed collisions are nearly perfectly elastic — 1 point

For drawing a graph or table that shows a violation of a physics principle for higher-speed collisions — 1 point

Example for energy conservation:

A graph of the ratio $\dfrac{\text{Post-collision mechanical energy}}{\text{Pre-collision mechanical energy}}$ as a function of pre-collision speed, in which the graph stays near 1.0 for low initial speeds but becomes greater than 1.0 for high-speed collisions.

ii. 2 points

For a correct description of the aspect of the graph or table that shows a violation of the physical principle indicated — 1 point

For a correct explanation of why the representation shows a violation of the physical principle indicated — 1 point

Example for energy conservation using the graph described above: The value of the energy ratio shows a violation of conservation of energy when it becomes greater than 1.0 because the final energy cannot be greater than the initial energy.

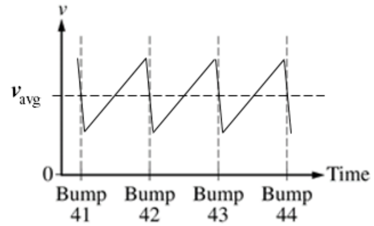
2016 SCORING GUIDELINES

Question 3

12 points total

Distribution of points

(a)



i. 3 points

For having a constant upward slope in each segment between bumps — 1 point

For having the velocity "reset" abruptly at each bump (i.e., as a sawtooth function, not a sinusoidal curve) to a minimum positive value that is the same for each bump — 1 point

For having the same maximum value in each cycle that occurs near the bump times (This point can be earned for a sinusoidal curve with peaks at the bump times.) — 1 point

ii. 1 point

For drawing a v_{avg} line that is horizontal and consistent with the graph drawn, even if that graph is wrong — 1 point

(b) 2 points

Correct answer: Greater than

No points are earned if the correct answer is selected, but the explanation is completely incorrect or there is no explanation.

No points are earned if the wrong answer is selected.

For indicating that there is more time between bumps — 1 point

For connecting that the cart has more time or more distance to accelerate between bumps — 1 point

Example: The maximum speed is greater because the cart has more space (or time) to accelerate (build up speed) between bumps.

Alternate solution in terms of energy — *Alternate points*

For indicating that the potential energy difference increases due to increased height between successive bumps — *1 point*

For relating the increase in potential energy to an increase in kinetic energy — *1 point*

2016 SCORING GUIDELINES

Question 3 (continued)

	Distribution of points
(c) 2 points	
Correct answer: Greater than	
No points are earned if the correct answer is selected, but the explanation is completely incorrect or there is no explanation.	
No points are earned if the wrong answer is selected.	
For indicating that the acceleration is greater	1 point
For indicating that the component of the gravitational force increases	1 point
Alternate solution in terms of energy	*Alternate points*
For indicating that the potential energy difference increases due to increased height between successive bumps	*1 point*
For relating the increase in potential energy to an increase in kinetic energy	*1 point*

(d)

i. 2 points

Correct answer: No

No points are earned if the correct answer is selected, but the explanation is completely incorrect or there is no explanation.

For indicating that v_{avg} is not proportional to M	1 point
For connecting the equation to the data	1 point

Examples:

The y-intercept of the graph is not zero, but the equation indicates that it should be zero.

Doubling the mass from the graph does not double v_{avg}, but the equation indicates that it should double.

If "yes" is selected, one point may be earned for explaining that v_{avg} increases with M or that v_{avg} looks (approximately) proportional to M for a limited portion of the data (e.g., the points at M = 1.0 kg and M = 2.0 kg).

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Question 3 (continued)

	Distribution of points
(d) ii. 2 points	
Correct answer: No	
For indicating that the distance dependency is incorrect	1 point
For indicating that, according to the equation, greater d leads to a smaller v_{avg}, OR for stating or implying the contradiction between this inverse relation and the reasoning of part (b)	1 point
Credit is earned for any answer that is consistent with reasoning in part (b).	

Example: According to the equation, a larger d corresponds to a smaller v_{avg}, because they are inversely proportional. But according to the reasoning of part (b), a bigger distance d between the bumps leads to a larger maximum average speed, showing that the equation is implausible.

If "yes" is selected, one point can be earned for indicating that an increase in the angle increases v_{avg}.

2016 SCORING GUIDELINES

Question 4

7 points total | **Distribution of points**

(a) 3 points

Correct ranking is $(A = D) > (B = C)$.

For indicating that the potential difference is the same across A and D because the current is the same through each (A and D are in series.) — 1 point

For indicating that the potential difference is the same across B and C because B and C are in parallel — 1 point

For indicating that the potential difference is less across B (and/or C) than across A (and/or D) because the current splits or the current is less through B and C — 1 point

Example: The full battery current passes through both A and D, so they have the same current. Because they have the same resistance, $\Delta V_A = \Delta V_D$. B and C are in parallel, so $\Delta V_B = \Delta V_C$. Less than the full current passes through B, and A and B have the same resistance, so ΔV_B is less than ΔV_A .

(b) 2 points

Correct answer: Decrease

No points are earned if the correct answer is selected, but the explanation is completely incorrect, or there is no explanation.

If the wrong answer is selected, up to one point can still be earned.

For indicating that the effective resistance of the circuit increases — 1 point

For a correct explanation of why the current through A decreases based on changes in current or potential difference throughout the circuit — 1 point

Examples:

Because B is replaced with an infinite resistance, the effective resistance of the circuit increases and the battery current decreases. Because the battery current decreases and that current equals the current through A, the current through A decreases.

When B is removed, the effective resistance of that piece of the circuit increases because there is no longer a parallel combination there. Because the resistance is greater, the potential difference across that piece is a greater percent of the total. So the potential difference across A decreases and thus the current through it decreases.

2016 SCORING GUIDELINES

Question 4 (continued)

Distribution of points

(c) 2 points

Correct answer: Increase

No points are earned if the correct answer is selected, but the explanation is completely incorrect, or there is no explanation.

If the wrong answer is selected, up to one point can still be earned.

For indicating that all the current from the battery passes through C; the current no longer splits — 1 point

For making either a current argument or potential difference argument for the increase (i.e., an argument for why an increase in current through C more than compensates for the decrease in the full current or explaining that, by the loop rule, the potential difference across C must increase in order for the potential difference around the circuit loop to remain zero) — 1 point

2016 SCORING GUIDELINES

Question 5

7 points total | **Distribution of points**

(a) 2 points

For indicating that there is more rope or weight below one point than the other — 1 point

For indicating (explicitly or implicitly) that the tension at any point counteracts or supports the weight below that point — 1 point

Examples:

The rope at P supports more weight than the rope at Q so the tension must be higher at P.

The section of rope below P has an upward force from the rope above it and a downward gravitational force. The same goes for Q. Because the gravitational force is greater on the longer section (the section below P), the upward force — the tension — must be greater at P.

(b) 5 points

For indicating that the wavelength is longer near the top of the rope (or shorter near the bottom) — 1 point

For indicating (explicitly or implicitly) that the frequency is the same throughout the rope — 1 point

For using $v = \lambda f$ to conclude that wave speed is greater near the top of the rope (or less near the bottom), based on the difference in wavelength — 1 point

For indicating (explicitly or implicitly) that, as stated in part (a), tension is greater near the top of the rope (or less near the bottom) — 1 point

For a response that has sufficient paragraph structure, as described in the published requirements for the paragraph-length response — 1 point

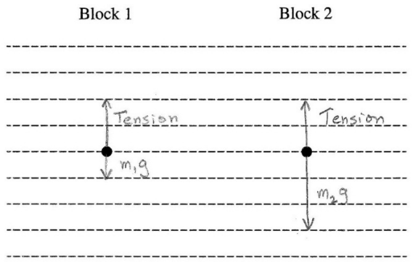
AP® Physics 1
2015 Scoring Guidelines

2015 SCORING GUIDELINES

Question 1

7 points total — **Distribution of points**

(a) 2 points



For drawing two vectors starting on the dots that point upward, have the same length and are labeled as the tension force	1 point
For drawing two vectors starting on the dots that point downward, where the vector for block 1 is smaller than the vector for block 2 and both are labeled as the gravitational force	1 point

One earned point is deducted for drawing any extraneous vectors.
One earned point is deducted for vector lengths that do not allow the system to accelerate in the proper direction.

(b) 3 points

For writing an equation for Newton's second law for block 1	1 point
$m_1 a = T - m_1 g$	
For writing an equation for Newton's second law for block 2	1 point
$m_2 a = m_2 g - T$	
For eliminating T to obtain an equation that can be solved for the acceleration	1 point

$T = m_1 a + m_1 g$

$m_2 a = m_2 g - m_1 a - m_1 g$

$(m_2 + m_1)a = (m_2 - m_1)g$

$a = (m_2 - m_1)g/(m_2 + m_1)$

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Question 1 (continued)

Distribution of points

(b) (continued)

Alternate solution — *Alternate points*

The system of two blocks must move as a unit, so the acceleration of the system is the acceleration of block 2.

For writing an equation showing that the net force acting on the system is the difference in masses times the acceleration of gravity — *1 point*

$F_{net} = (m_2 - m_1)g$

For writing an equation that relates the net force to the sum of the masses and the acceleration of the system — *1 point*

$F_{net} = (m_2 + m_1)a$

For writing an equation that can be solved for the acceleration in terms of the variables used in the summation of forces equations — *1 point*

$(m_2 + m_1)a = (m_2 - m_1)g$

$a = (m_2 - m_1)g/(m_2 + m_1)$

(c) 2 points

The acceleration of the new system, and thus of block 2, is smaller.

For indicating that the mass of the system is larger — 1 point

For a clear indication that the tension on block 2 is greater — 1 point

Alternate solution — *Alternate points*

For indicating that the mass of the system is larger — *1 point*

For indicating that the net force exerted on the system stays the same — *1 point*

Notes:

No points are earned for a correct prediction without a reasonable attempt at an explanation.

No points are earned for an incorrect prediction, regardless of the explanation.

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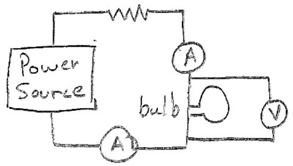
Question 2

12 points total

Distribution of points

(a) 5 points



For drawing a circuit in which the power source, resistor, and bulb are wired in series — 1 point

For connecting at least one ammeter in series with the bulb — 1 point

For connecting the voltmeter across the bulb in parallel — 1 point

For describing measurements that can plausibly be used to answer question 1 — 1 point

Example: Measure the current entering and leaving the bulb with ammeters connected in series on either side of the bulb.

For describing measurements that can plausibly be used to answer question 2 — 1 point

Example: Measure the potential difference across the bulb with a voltmeter connected in parallel with the bulb.

The response does not need to mention multiple measurements.

(b)

(i) 1 point

For describing an analytical method of using the data, and explaining how that analytical method can be used to answer question 1 — 1 point

Example: If the current is the same on both sides of the bulb, then the number of electrons per second entering and leaving the bulb is the same.

(ii) 1 point

For describing an analytical method of using the data, and explaining how that analytical approach can be used to answer question 2 — 1 point

Example: If the potential difference across the bulb is not zero, then electrons that leave the bulb have different electric potential energy than electrons that enter it.

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Question 2 (continued)

Distribution of points

(c)

(i) 1 point

For any of the following: — 1 point

Describing any changes to the circuit needed to have a setup that can plausibly be used to determine whether the bulb's resistance is constant as a function of current.

Describing changes to a circuit that are not needed but do not impair the ability to determine whether the bulb's resistance is constant as a function of current.

Correctly indicating that no changes are needed.

Example based on circuit diagram in part (a): Remove one of the ammeters.

(ii) 1 point

For describing any additional measurements needed to determine whether current varies linearly as a function of voltage, or indicating that none are needed if the appropriate multiple measurements are mentioned in part (a) or (c)(i) — 1 point

Example: Measure the current through the bulb and the potential difference across the bulb for multiple settings of the power source.

(d) 3 points

For describing an analytical method in which data are represented or manipulated in some way that can plausibly be used to determine whether current varies linearly as a function of potential difference — 1 point

Examples:

Graphing measurements of current as a function of potential difference

Calculating the ratio of current to potential difference for multiple settings of the power source

For identifying that linearity is the relevant feature for determining whether the bulb is ohmic — 1 point

Examples:

Evaluating whether a plot of current as a function of voltage is linear

Evaluating whether the ratio of current to potential difference is constant

For describing a strategy for evaluating whether the conclusion of linearity is valid for a given data set taking into account the meter uncertainties — 1 point

Examples:

Drawing error boxes that represent the uncertainties of the meters around each point and evaluating whether a straight line can be drawn that goes through all the error boxes.

Indicating that small differences in the ratios could be due to uncertainty in the meters and would not discount the conclusion that the bulb is ohmic

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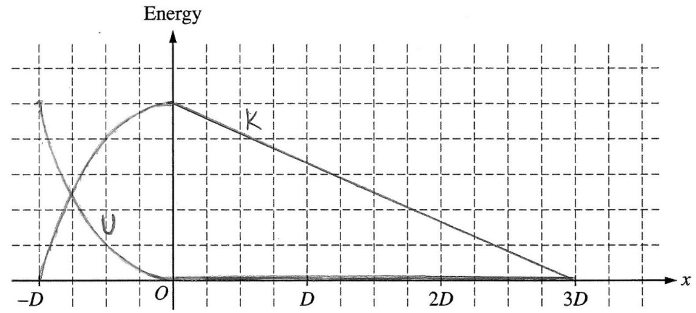
Question 3

12 points total **Distribution of points**

(a) 4 points



For sketching either energy curve with a reasonably correct shape between $x = -D$ and $x = 0$, with zero and maximum values at the correct locations — 1 point

For sketching two curves from $x = -D$ to $x = 0$ with shapes and values such that the total energy is constant (even if the curves are incorrect) — 1 point

For sketching potential energy equal to zero from $x = 0$ to $x = 3D$ — 1 point

For sketching kinetic energy as a linear function from its maximum value at $x = 0$ to zero at $x = 3D$ — 1 point

(b)

(i) 1 point

For identifying that the student is correct that the block will have more energy when it leaves the spring — 1 point

(ii) 1 point

For identifying that the student is incorrect about the new final position of the block because the spring's energy does not scale linearly with its compression — 1 point

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Question 3 (continued)

Distribution of points

(c) 3 points

For indicating that the final energy in the spring (which becomes the mechanical energy of the block as it reaches the rough track) is four times the original energy in the spring	1 point
For indicating that the frictional force remains the same	1 point
For equating the initial energy in the spring to an expression that shows that the energy dissipated by friction is proportional to the distance the block slides down the rough track	1 point

Example:

$U_1 = \frac{1}{2}kD^2$ and $U_2 = \frac{1}{2}k(2D)^2$ so $U_2 = 4U_1$

$W_1 = \mu mg(3D)$ and $W_2 = \mu mg\Delta x_2$

$W_1 = U_1$ and $W_2 = U_2 = 4U_1 = 4W_1$

$\mu mg\Delta x_2 = 4(\mu mg(3D))$

$\Delta x_2 = 4(3D) = 12D$

(d) 3 points

For indicating that the student's correct reasoning that the block has more energy in the second situation is expressed by the calculations comparing the initial energy in the spring	1 point
For indicating that the student's correct reasoning that the block will slide farther is expressed by an equation that indicates that the work done by friction to stop the block in the second situation is some factor greater than the work done in the first situation	1 point
For indicating that the student's incorrect reasoning that energy scales linearly with the spring's compression is corrected by the expression for the initial energy of the spring	1 point

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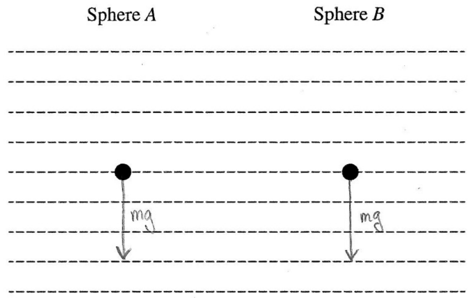
Question 4

7 points total

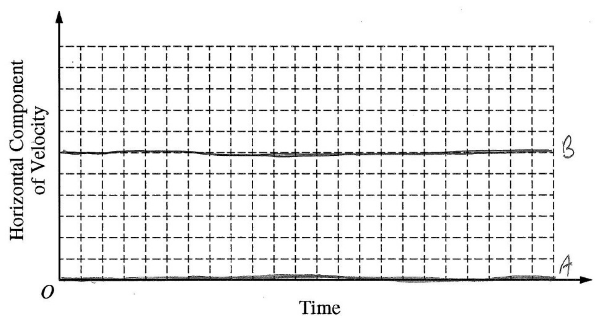
Distribution of points

(a) 1 point



For sketching only one force pointing straight down from each sphere and indicating that this force represents the force of gravity	1 point

(b) 1 point



For sketching a horizontal line at zero velocity for sphere A, and sketching a horizontal line at some non-zero velocity for sphere B	1 point

(c) 5 points

For indicating that the difference in horizontal motion does not affect the vertical motion of the spheres	1 point
For indicating that both spheres start with the same vertical velocity	1 point
For indicating that both spheres have the same vertical acceleration	1 point
For indicating that falling the same height would take the same time	1 point
For no incorrect or irrelevant statements	1 point

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Question 5

7 points total | **Distribution of points**

(a) 3 points

For reasoning that since the strings all have the same length, and since the wavelength of the fundamental depends on the length, all four waves have the same wavelength (e.g., $\lambda_1 = 2L$) — 1 point

For reasoning that since the wavelengths are all the same, different frequencies correspond to different velocities of the waves on the strings — 1 point

For reasoning that all the string tensions are the same due to the same mass M of each block, and therefore the linear mass densities must be different for different velocities since $v = \sqrt{F_T/(m/L)}$ (or since the vertical component of the tension will result in different vertical accelerations for strings with different masses) — 1 point

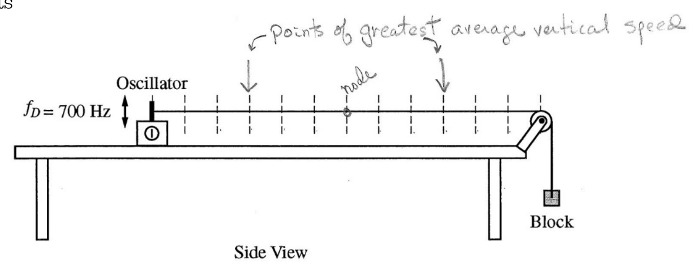
Note: Responses may refer to the physical differences between the strings in a variety of ways, e.g., different linear mass density, different total mass, different thicknesses of the same material

(b) 2 points

For combining $v = f\lambda$ with $v = \sqrt{F_T/(m/L)}$ (or referring to such an equation written in part (a)) — 1 point

For indicating how the equation leads to the conclusion that frequency would not be proportional to the inverse of the linear mass density — 1 point

(c) 2 points



For any indication of the second harmonic on the string, or a wave drawn such that $\lambda_2 = L$. — 1 point

For points which are at the antinodes of the second harmonic, or at the antinodes of any standing wave drawn on the string — 1 point

Notes:

Full credit is earned for having two points that are located one fourth the length of the string and three fourths the length of the string from the oscillator.

One earned point is deducted for each incorrect point marked on the figure