2019

AP® CollegeBoard

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

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AP® PHYSICS
2019 SCORING GUIDELINES

General Notes About 2019 AP Physics Scoring Guidelines

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

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

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

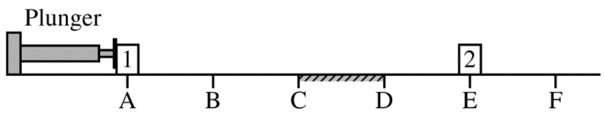
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked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

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

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

Question 1

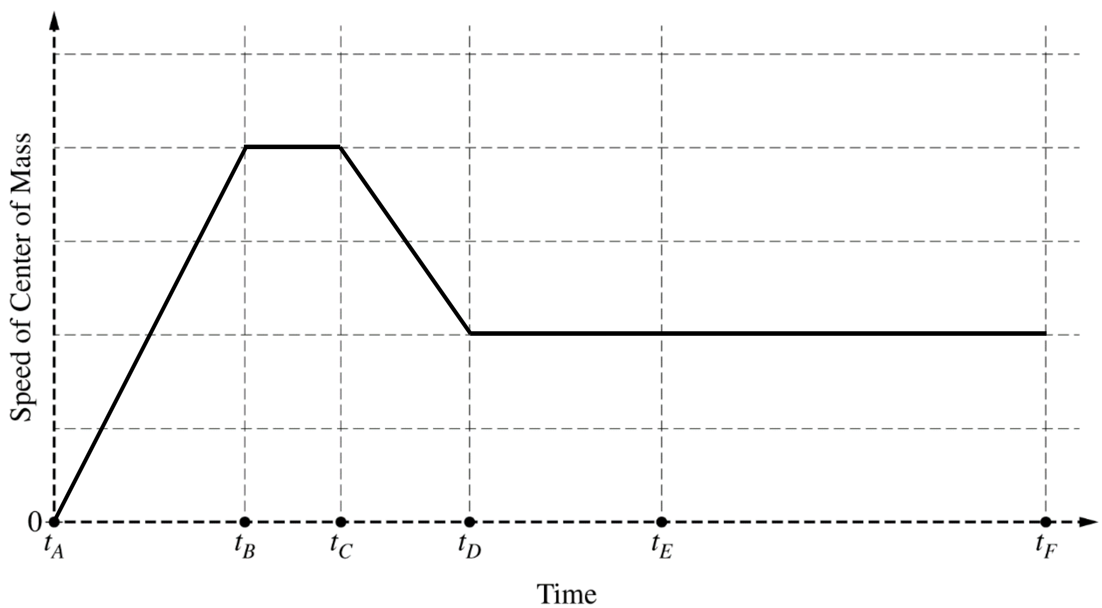
7 points



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

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

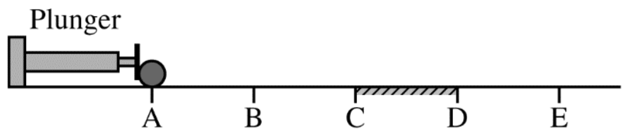
On the axes below, sketch the speed of the center of mass of the two-block system as a function of time, from time t_A until the blocks pass point F at time t_F. The times at which block 1 reaches points A through F are indicated on the time axis.



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

Question 1 (continued)

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



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

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

Briefly explain your reasoning.

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

Question 1 (continued)

Learning Objectives

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

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

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

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

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

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

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

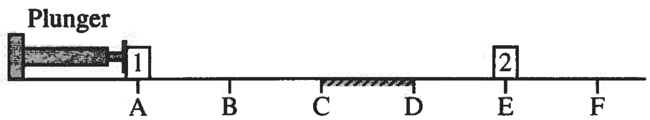
PHYSICS 1

Section II

Time—1 hour and 30 minutes

5 Questions

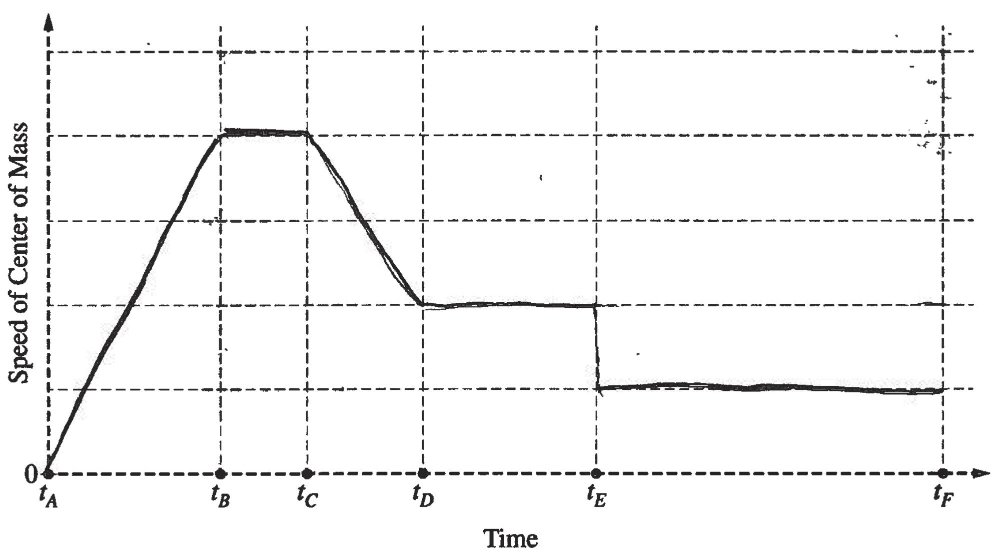
Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



1. (7 points, suggested time 13 minutes)

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) 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.



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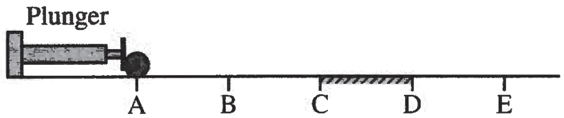

(b) The plunger is returned to its original position, and both blocks are removed. A uniform solid sphere is placed at point A, as shown. The sphere is pushed by the plunger from point A to point B with a constant horizontal force that is directed toward the sphere's center of mass. The sphere loses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

____ A to B ____ B to C ✓____ C to D ____ D to E ______ None

Briefly explain your reasoning.

A change in angular momentum means that the sphere has a torque being applied to it over a period of time. ($L = \tau\Delta t$). A torque is not applied from A to B because the force is directed towards the center of mass. Since the surface is frictionless at B to C and D to E, there is no force that is applied to the sphere, and therefore no torque. A torque is only applied during the interval from C to D, since the surface is rough, which means that friction exists. The force of friction applies a torque to the sphere causing the angular momentum to change at C to D.

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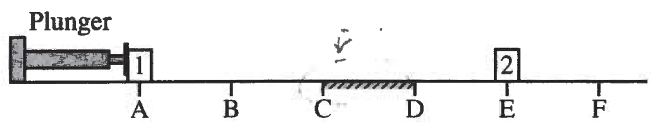

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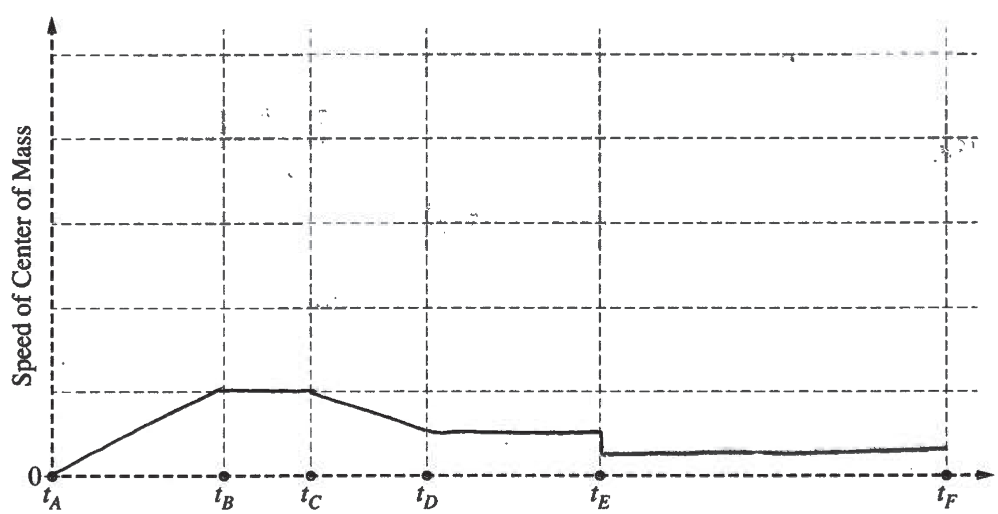

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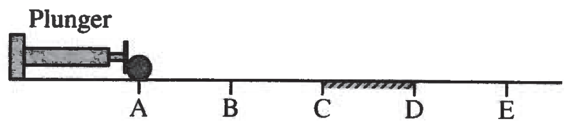

(b) The plunger is returned to its original position, and both blocks are removed. A uniform solid sphere is placed at point A, as shown. The sphere is pushed by the plunger from point A to point B with a constant horizontal force that is directed toward the sphere's center of mass. The sphere loses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

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

Briefly explain your reasoning. $L = I\omega$ or Ft

Angular momentum is conserved in the absence of an external force. From A to B, the constant force of the plunger results in a change in momentum. From B to C and D to E, there is no external force. From C to D, a rough surface means there is a frictional force exerted on the sphere, reducing angular momentum, and finally from D to E, momentum is conserved.

PHYSICS 1
Section II
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5 Questions

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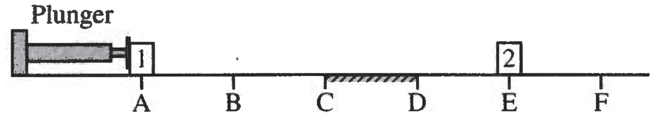

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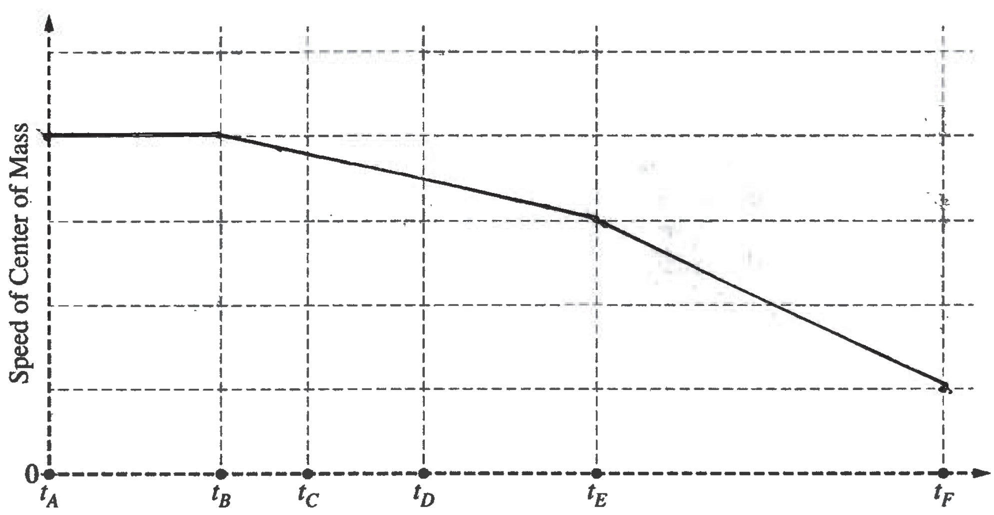

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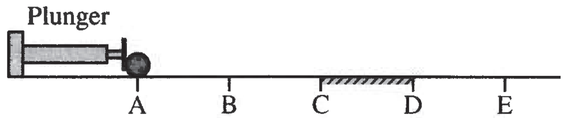

(b) The plunger is returned to its original position, and both blocks are removed. A uniform solid sphere is placed at point A, as shown. The sphere is pushed by the plunger from point A to point B with a constant horizontal force that is directed toward the sphere's center of mass. The sphere loses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

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

Briefly explain your reasoning.

The sphere's angular momentum changes from A to B because an external force caused by the plunger is moving the sphere to the right. The sphere's angular momentum changes from C to D because there is a friction force in the opposite direction of the sphere's direction.

Question 1

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

Overview

This question assessed students' understanding of the center of mass of a two-object system and the rotational motion of sliding or rolling objects. Students had to:

- Indicate that the velocity of an object on a horizontal surface with negligible friction remains constant.
- Show that the center of mass velocity remains unchanged in a collision.
- Recognize that a constant force leads to a linear change in velocity with time, as occurs both while the sphere is pushed by the plunger and while it slides across a frictional surface.
- Demonstrate skills presenting data in a graph.
- Reason that a net torque leads to a change in angular momentum. Specifically, a tangential force at the surface, such as friction, produces a torque that leads to an increase in angular momentum in this problem, while a force directed toward the center of the sphere, such as the force imposed by the plunger, gravity, or the normal force, does not produce a torque.

Sample: 1A
Score: 6

In part (a) 4 of the 5 points were earned for a graph that increases linearly from zero between t_A and t_B, remains horizontal from t_B to t_C, decreases linearly from t_C to t_D, and is continuous from t_A to t_F (with the exception of the discontinuity at t_E). One point was not earned because the graph changes at t_E (rather than remaining horizontal between t_D to t_F). In part (b) the full 2 points were earned for reasoning that a torque is required to change the angular momentum and that friction acting on the surface of the sphere between points C and D is the only torque in the interval A to E.

Sample: 1B
Score: 4

In part (a) 4 of the 5 points were earned for a graph that increases linearly from zero between t_A and t_B, remains horizontal from t_B to t_C, decreases linearly from t_C to t_D, and is continuous from t_A to t_F (with the exception of the discontinuity at t_E). One point was not earned because the graph changes at t_E (rather than remaining horizontal between t_D to t_F). In part (b) no points were earned because the response does not indicate that a net torque acting on the sphere produces a change in angular momentum and does not indicate that only the force of friction between C and D leads to a change in angular momentum.

Sample: 1C
Score: 2

In part (a) 2 of the 5 points were earned for a graph that decreases linearly from t_C to t_D and is continuous from t_A to t_F. Three points were not earned because the graph is horizontal from t_A to t_B (rather than increasing linearly from zero), decreases from t_B to t_C (rather than remaining horizontal), and decreases between t_D to t_F (rather than remaining horizontal). In part (b) no points were earned because the response does not indicate that a net torque acting on the sphere produces a change in angular momentum and states that the angular momentum changes from A to B (and not that only the force of friction between C and D leads to a change in angular momentum).