2017

AP® CollegeBoard

AP Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

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AP® PHYSICS
2017 SCORING GUIDELINES

General Notes About 2017 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 one 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 and 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 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 3

12 points total | **Distribution of points**

(a) 1 point

Correct answer: "To the right of *C*"
Reasoning cannot earn credit if the incorrect selection is made.

For an explanation that the torque exerted by the disk or the angular momentum of the disk is greater when farther from the pivot — 1 point

Example 1: The disk exerts a greater torque on the rod when it pushes the rod farther from the pivot.
Example 2: The disk has greater angular momentum when it's farther from the pivot. The disk loses almost all its speed during the collision and hence gives the rod almost all its angular momentum. So the rod ends up with more angular momentum when the disk hits it farther from the pivot.

(b) 2 points

Correct answer: "Yes"
If "No" is selected, the explanation may still earn full credit if an incorrect selection was made in part (a).

For a selection consistent with the selection from part (a) — 1 point
For indicating that the equation shows that ω increases with increasing x — 1 point

Example: According to the equation, ω increases with x; a bigger x produces a bigger angular speed. This agrees with my reasoning from part (a), where I said a bigger x creates a bigger angular speed after the collision.

(c) 3 points

For focusing on functional dependence (instead of, for example, considering units/dimensions) — 1 point
For addressing m_{disk}, I, or both — 1 point
For correctly concluding that the equation is wrong because of the dependence on m_{disk}, I, or both — 1 point

Example: If m_{disk} is large, then more angular momentum will be transferred during the collision. But the equation shows the angular speed decreasing with increasing m_{disk}, because it is in the denominator.

Question 3 (continued)

Distribution of points

(d) 4 points

For using an expression of conservation of angular momentum for the disk and rod — 1 point
Note: This point is not awarded for equating angular and linear momentum.

For indicating that the initial angular momentum of the system is equal to $m_{disk} v_0 x$ — 1 point

For a dimensionally correct expression for the post-collision angular momentum that includes $I\omega$ — 1 point

For indicating the correct rotational inertia of the system after the collision: $I + m_{disk} x^2$ — 1 point

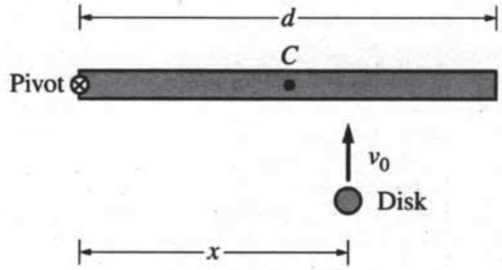
(e) 2 points

Correct answer: "Greater than"

For indicating, either directly or by analogy to the linear case, that the disk's angular momentum with respect to the pivot changes more in the bouncy scenario than in the original scenario OR for using a similar argument in terms of impulse — 1 point
Note: This point is for describing what happens to the disk.

For using conservation of angular momentum or momentum-impulse reasoning to conclude that the rod gains more angular momentum, and hence more angular speed, in the bouncy scenario — 1 point
Note: This point is for describing what happens to the rod.

Example: After the bouncy collision, the disk has angular momentum in the clockwise direction. To keep the system angular momentum constant, the magnitude of the rod's counterclockwise angular momentum must be greater than before.



Top View

3. (12 points, suggested time 25 minutes)

The left end of a rod of length d and rotational inertia I is attached to a frictionless horizontal surface by a frictionless pivot, as shown above. Point C marks the center (midpoint) of the rod. The rod is initially motionless but is free to rotate around the pivot. A student will slide a disk of mass m_{disk} toward the rod with velocity v_0 perpendicular to the rod, and the disk will stick to the rod a distance x from the pivot. The student wants the rod-disk system to end up with as much angular speed as possible.

(a) Suppose the rod is much more massive than the disk. To give the rod as much angular speed as possible, should the student make the disk hit the rod to the left of point C, at point C, or to the right of point C ?

____ To the left of C ____ At C ✓ To the right of C

Briefly explain your reasoning without manipulating equations.

Due to the rod being much more massive than the disk, the collision can be approximated as an impulse delivered to the rod. To maximize angular speed and thus angular momentum, the largest possible angular impulse should be delivered, so the lever arm should be maximized, which happens when the collision point is to the right of C.

(b) On the Internet, a student finds the following equation for the postcollision angular speed ω of the rod in this situation: $\omega = \frac{m_{disk} x v_0}{I}$. Regardless of whether this equation for angular speed is correct, does it agree with your qualitative reasoning in part (a) ? In other words, does this equation for ω have the expected dependence as reasoned in part (a) ?

✓ Yes ____ No

Briefly explain your reasoning without deriving an equation for ω.

In this equation, increasing x, the lever arm, means increasing ω. This agrees with part (a) because the lever arm is longer when the disk hits to the right of C.

GO ON TO THE NEXT PAGE.

(c) Another student deriving an equation for the postcollision angular speed ω of the rod makes a mistake and comes up with $\omega = \frac{Ixv_0}{m_{disk}d^4}$. Without deriving the correct equation, how can you tell that this equation is not plausible—in other words, that it does not make physical sense? Briefly explain your reasoning.

In this equation, increasing Mdisk would decrease ω, all else remaining constant.
This is impossible because a larger disk delivers a larger impulse to the rod due to it having more momentum to begin with, thus increasing ω.

For parts (d) and (e), do NOT assume that the rod is much more massive than the disk.

(d) Immediately before colliding with the rod, the disk's rotational inertia about the pivot is $m_{disk}x^2$ and its angular momentum with respect to the pivot is $m_{disk}v_0x$. Derive an equation for the postcollision angular speed ω of the rod. Express your answer in terms of d, m_{disk}, I, x, v_0, and physical constants, as appropriate.

by conservation of angular momentum:

$$M_{disk}V_0x = (I + M_{disk}x^2)\omega$$

$$\omega = \frac{M_{disk}V_0x}{I + M_{disk}x^2}$$

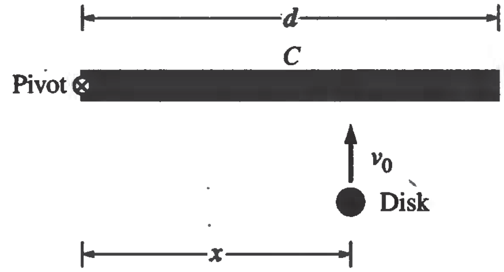
(e) Consider the collision for which your equation in part (d) was derived, except now suppose the disk bounces backward off the rod instead of sticking to the rod. Is the postcollision angular speed of the rod when the disk bounces off it greater than, less than, or equal to the postcollision angular speed of the rod when the disk sticks to it?

✓ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

By conservation of angular momentum, total angular momentum is constant before and after collision. When the disk sticks, the disk's final angular momentum is positive while it's negative if it bounces back. Thus for the sum of the disk and rod's angular momentum to be equal, the angular momentum and thus the angular speed of the rod must be greater if the disk bounces back.

P1 Q3 B1



Top View

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(a) Suppose the rod is much more massive than the disk. To give the rod as much angular speed as possible, should the student make the disk hit the rod to the left of point C, at point C, or to the right of point C ?

____ To the left of C ____ At C √ To the right of C

Briefly explain your reasoning without manipulating equations.

The farther away C is from the pivot, because torque is greater due to the longer lever arm.

(b) On the Internet, a student finds the following equation for the postcollision angular speed ω of the rod in this situation: $\omega = \frac{m_{disk} x v_0}{I}$. Regardless of whether this equation for angular speed is correct, does it agree with your qualitative reasoning in part (a) ? In other words, does this equation for ω have the expected dependence as reasoned in part (a) ?

√ Yes ____ No

Briefly explain your reasoning without deriving an equation for ω.

Yes, because x increases as the disk moves to the right of C, so the angular speed then increases.

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(c) Another student deriving an equation for the postcollision angular speed ω of the rod makes a mistake and comes up with $\omega = \frac{Ixv_0}{m_{disk}d^4}$. Without deriving the correct equation, how can you tell that this equation is not plausible—in other words, that it does not make physical sense? Briefly explain your reasoning.

I, or Rotational inertia has the unit kgm², x has unit m, v has unit m/s², mdisk has unit kg, d⁴ has unit m⁴. If all variables are plugged in for, the final unit would be $\frac{1}{s^2}$, which is not a possible unit for angular speed.

For parts (d) and (e), do NOT assume that the rod is much more massive than the disk.

(d) Immediately before colliding with the rod, the disk's rotational inertia about the pivot is $m_{disk}x^2$ and its angular momentum with respect to the pivot is $m_{disk}v_0x$. Derive an equation for the postcollision angular speed ω of the rod. Express your answer in terms of d, m_{disk}, I, x, v_0, and physical constants, as appropriate.

conservation of angular momentum

$L_{disk_0} = L_{disk+rod}$

$m_{disk} v_0 x = (I + m_{disk} x^2) \cdot \omega$

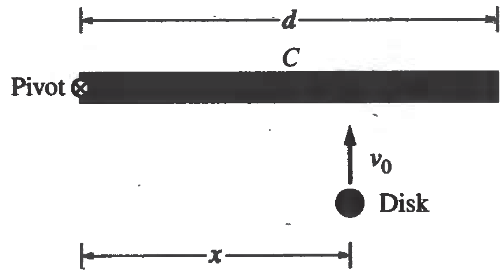
$$\omega = \frac{m_{disk} v_0 x}{I + m_{disk} x^2}$$

(e) Consider the collision for which your equation in part (d) was derived, except now suppose the disk bounces backward off the rod instead of sticking to the rod. Is the postcollision angular speed of the rod when the disk bounces off it greater than, less than, or equal to the postcollision angular speed of the rod when the disk sticks to it?

__L__ Greater than   __✓__ Less than   ____ Equal to

Briefly explain your reasoning.

Momentum is still conserved, and the momentum postcollision equals the disk, but it has more rotational inertia, so the angular speed must be lower.



Top View

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(a) Suppose the rod is much more massive than the disk. To give the rod as much angular speed as possible, should the student make the disk hit the rod to the left of point C, at point C, or to the right of point C ?

____ To the left of C ____ At C _✓_ To the right of C

Briefly explain your reasoning without manipulating equations.

In order to give the rod the greatest amount of angular speed possible, you need to have the greatest amount of distance between the pivot point and the point at which the disk hits the rod. Based off of this, the student should make the disk hit the rod to the right of C.

(b) On the Internet, a student finds the following equation for the postcollision angular speed ω of the rod in this situation: $\omega = \frac{m_{disk} x v_0}{I}$. Regardless of whether this equation for angular speed is correct, does it agree with your qualitative reasoning in part (a) ? In other words, does this equation for ω have the expected dependence as reasoned in part (a) ?

_✓_ Yes ____ No

Briefly explain your reasoning without deriving an equation for ω.

Yes the equation would support my reasoning for part (a) because according to the equation, the greater the distance from the pivot that the disk hits the rod, the greater the angular speed.

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(c) Another student deriving an equation for the postcollision angular speed ω of the rod makes a mistake and comes up with $\omega = \dfrac{Ixv_0}{m_{disk}d^4}$. Without deriving the correct equation, how can you tell that this equation is not plausible—in other words, that it does not make physical sense? Briefly explain your reasoning.

This equation is not plausible because the student's equation has the length of the rod in the denominator and also to the power of 4. Physically, the greater the distance of the rod, the greater the angular speed and based off of this equation, if the distance of the rod is multiplied to the 4th power the angular speed would be very low.

For parts (d) and (e), do NOT assume that the rod is much more massive than the disk.

(d) Immediately before colliding with the rod, the disk's rotational inertia about the pivot is $m_{disk}x^2$ and its angular momentum with respect to the pivot is $m_{disk}v_0x$. Derive an equation for the postcollision angular speed ω of the rod. Express your answer in terms of d, m_{disk}, I, x, v_0 and physical constants, as appropriate.

$$\omega = \frac{L}{I} = \frac{m_{disk}v_0x}{I}$$

(e) Consider the collision for which your equation in part (d) was derived, except now suppose the disk bounces backward off the rod instead of sticking to the rod. Is the postcollision angular speed of the rod when the disk bounces off it greater than, less than, or equal to the postcollision angular speed of the rod when the disk sticks to it?

____ Greater than ✓ Less than ____ Equal to

Briefly explain your reasoning.

The mass of the disk would have allowed for a greater angular speed, and so without it, the angular speed will decrease

AP® PHYSICS 1
2017 SCORING COMMENTARY

Question 3

Overview

This question assessed learning objectives 3.F.1.2, 3.F.2.1, 3.F.3.1, 4.D.2.1, 4.D.3.1, 5.E.1.1, and 5.E.1.2. The responses to this question were expected to demonstrate the following:

- Understanding how to connect principles of physics (torque, angular momentum, and impulse) to observed behavior of a physical system.
- The ability to derive a relationship using conservation of angular momentum.
- Understanding how functional relationships in an unfamiliar equation connect to physical reasoning.

Sample: P1 Q3 A
Score: 12

Part (a) earned full credit for stating that the angular impulse increases with an increasing lever arm. Part (b) earned full credit for a selection consistent with the student's answer in part (a) and for correctly discussing the relationship between ω and x. Part (c) earned full credit for discussing the functional dependence between m_{disk} and ω, correctly identifying m_{disk} as the important value, and for concluding that the equation is wrong because of the dependence on m_{disk}. In part (d) full credit was earned for starting with the conservation of angular momentum and for stating the initial and final angular momentum and the total final rotational inertia correctly. Part (e) earned full credit for stating that the change in angular momentum for the disk was greater because it changed direction, and the change in angular momentum of the rod was also greater.

Sample: P1 Q3 B
Score: 7

Part (a) earned full credit for stating that the torque increases with increasing distance from the pivot. Part (b) earned full credit for a selection consistent with the student's answer in part (a) and for correctly discussing the relationship between ω and x. Part (c) earned no credit because it addresses units and not functional dependences. Part (d) earned full credit for starting with the conservation of angular momentum and stating the initial and final angular momentum, and the total final rotational inertia, correctly. No credit was earned in part (e) because the incorrect choice is selected, and the response does not address the change in momentum of the rod or disk.

Sample: P1 Q3 C
Score: 3

No credit was earned in part (a) because the explanation does not address torque or angular momentum. Part (b) earned full credit. Part (c) earned 1 point for addressing functional dependence but does not address I or m_{disk}. No credit was earned in part (d) because there is no expression of conservation of momentum, no indication or expression of initial or final angular momentum of the system, and no expression for the post-collision rotational inertia of the system. Part (e) earned no credit because the selection and explanation are incorrect.