Question 3: Experimental Design and Analysis (LAB) — 10 points

A

For describing a procedure that includes **both** of the following: **Point A1**

- Attaching the block to the meterstick
- Measuring the force exerted on the left end of the meterstick while the block is attached

For a procedure that indicates a reasonable method of reducing experimental uncertainty **Point A2**

Examples of acceptable responses may include the following:

- Repeating the force measurement for one location of the block
- Collecting force measurements for multiple locations of the block

Example Response

Attach the block of unknown mass m_0 through one of the small holes in the meterstick. Measure the distance from the stand to the block. Record the force reading from the spring scale when the meterstick is horizontal. Repeat data collection by attaching the block to the meterstick through a different small hole in the meterstick. Repeat the measurements by attaching the block at each of the small hole locations numerous times.

B For indicating appropriate quantities that can be plotted so that m_0 can be determined **Point B1**

Scoring Notes:

- Any response that correctly identifies the functional dependence between force and distance earns this point, regardless of any coefficients that contain numbers or physical/fundamental constants, or which axis is chosen to graph each of those quantities.
- This point may be earned independently of the response in part A.

For describing how the slope is related to the unknown mass m_0 **Point B2**

Examples of acceptable responses may include the following:

Graph	Analysis
Force as a function of the distance from the stand to the block	The slope is equal to m_0 times g divided by the distance from the stand to the spring scale. OR m_0 is equal to the slope times the distance from the stand to the spring scale divided by g.
Force as a function of the ratio of the distance from the stand to the block to the distance from the stand to the spring scale	The slope is equal to m_0 times g. OR m_0 is equal to the slope divided by g.
Force as a function of g times the distance from the stand to the block	The slope is equal to m_0 divided by the distance from the stand to the spring scale. OR m_0 is equal to the slope times the distance from the stand to the spring scale.
Force as a function of g times the ratio of the distance from the stand to the block to the distance from the stand to the spring scale	The slope is equal to m_0. OR m_0 is equal to the slope.
Force times the distance from the stand to the spring scale as a function of the distance from the stand to the block	The slope is equal to m_0 times g. OR m_0 is equal to the slope divided by g.
Force times the distance from the stand to the spring scale as a function of g times the distance from the stand to the block	The slope is equal to m_0. OR m_0 is equal to the slope.

Example Response

A graph of the force as a function of the distance from the stand to the block could be used to determine the unknown mass. The slope of the graph times the distance from the stand to the spring scale divided by g will result in the value of the unknown mass m_0.

C **(i)** For listing a quantity that could be plotted on the vertical axis to produce a linear graph whose slope can be used to determine the mass of the meterstick[1] **Point C1**

Examples of acceptable responses may include the following:

- F_T
- $\frac{F_T}{g}$
- $\frac{6}{5}\frac{F_T}{g}$
- $\frac{6}{5}F_T$

Scoring Note: Any response that correctly identifies the functional dependence between tension and angle earns this point, regardless of any coefficients that contain numbers or physical/fundamental constants.

Example Response

Vertical axis: F_T

(ii) For labeling the vertical axis (including units) with a linear scale **Point C2**

For correctly plotting data points consistent with **one** of the following: **Point C3**

- The quantities indicated in part C (i)
- The quantities indicated on the axes
- The quantities indicated in Table 2

(iii) For drawing an appropriate best-fit line that approximates the trend of the plotted data **Point C4**

Scoring Note: If the graph produced is nonlinear, then a line or curve that approximates the trend of that data can earn this point.

Example Response

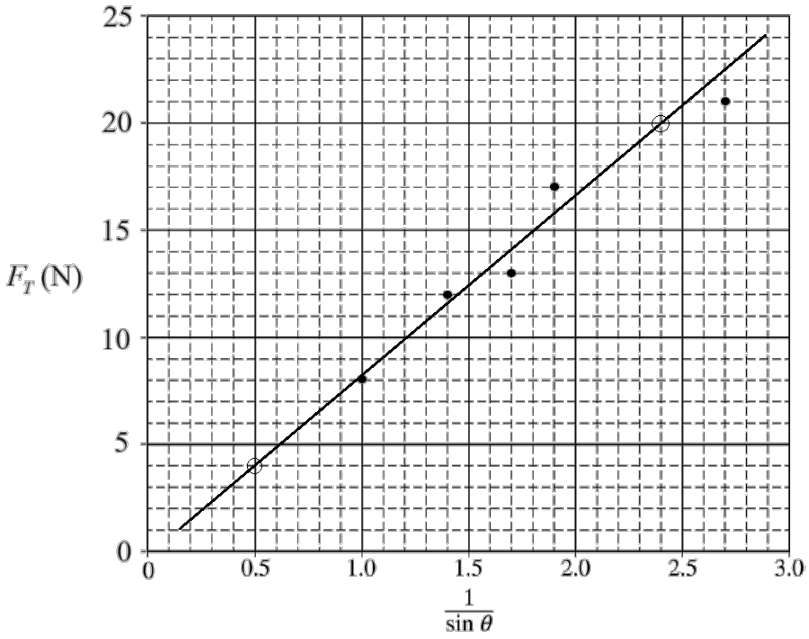


Figure 3

D For correctly relating the slope of the best-fit line to the value of M **Point D1**

Examples of acceptable responses may include the following:

Graph	Analysis
F_T vs. $\frac{1}{\sin\theta}$	$\text{slope} = \frac{5}{6}Mg$ OR $M = \frac{6}{5}\frac{\text{slope}}{g}$
$\frac{F_T}{g}$ vs. $\frac{1}{\sin\theta}$	$\text{slope} = \frac{5}{6}M$ OR $M = \frac{6}{5}\text{slope}$
$\frac{6}{5}\frac{F_T}{g}$ vs. $\frac{1}{\sin\theta}$	$\text{slope} = M$ OR $M = \text{slope}$
$\frac{6}{5}F_T$ vs. $\frac{1}{\sin\theta}$	$\text{slope} = Mg$ OR $M = \frac{\text{slope}}{g}$

For a value of M within a range of $0.90\ \text{kg}$ to $1.15\ \text{kg}$ **Point D2**

Example Response

$F_T = \frac{5Mg}{6\sin\theta}$

$F_T = \frac{5}{6}Mg\frac{1}{\sin\theta}$

$\text{slope} = \frac{5}{6}Mg$

$M = \frac{6(\text{slope})}{5g}$

$\text{slope} = \frac{20\ \text{N} - 4\ \text{N}}{2.4 - 0.5}$

$\text{slope} = 8.4\ \text{N}$

$M = \frac{(6)(8.4\ \text{N})}{(5)\left(9.8\ \frac{\text{N}}{\text{kg}}\right)}$

$M = 1.0\ \text{kg}$

Question 3: Qualitative/Quantitative Translation — 12 points

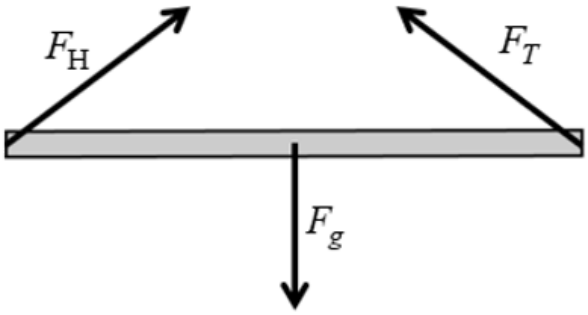
(a)

For drawing the gravitational force at the center of the beam that is directed downward — **1 point**

For drawing the tension force at the right end of the beam that is directed upward and leftward — **1 point**

For a diagram with three force vectors that represent a system in equilibrium — **1 point**

Example Response



Scoring Note: Examples of appropriate labels for the gravitational force include F_G, F_g, F_{grav}, W, mg, Mg, "grav force," F Earth on beam," "F on beam by Earth," $F_{\text{Earth on Beam}}$, $F_{\text{E,Beam}}$, or $F_{\text{Beam,E}}$. The labels G or g are not appropriate labels for the gravitational force.

Scoring Note: Examples of appropriate labels for the normal force include F_n, F_N, N, "normal force," or "wall force."

Scoring Note: Examples of appropriate labels for the tension force include F_{string}, F_{s}, F_T, F_{Tension}, "string force," or "tension force."

Total for part (a) — **3 points**

(b)

For selecting "$F_{\text{T2}} > F_{\text{T1}}$" with an attempt at a relevant justification — **1 point**

For a justification that includes **one** of the following: — **1 point**

- For relating the vertical component of the tension in the string to the weight of the bar
- For relating the force needed to exert the same torque to the angle of the string

Example Response

In order for the beam to remain horizontal and at equilibrium, the torque exerted by the string must remain the same for all angles. When the angle decreases, the perpendicular component of the tension remains the same. Therefore, the tension in the string is greater for a smaller angle.

Total for part (b) — **2 points**

(c) For a multi-step derivation that begins with Newton's second law for rotation, $\Sigma\tau = I\alpha$ or $\Sigma\tau = 0$ **1 point**

For indicating **one** of the following: **1 point**

- The net torque is zero
- The net force is zero

For indicating **one** of the following: **1 point**

- The magnitude of the torque from the string is $(F_T \sin\theta)L$
- The magnitude of the torque from the weight of the beam is $Mg\frac{L}{2}$
- The correct answer, $F_T = \frac{Mg}{2\sin\theta}$

Example Response

$\Sigma\tau = I\alpha$

$\tau_{\text{gravity}} + \tau_{\text{string}} = 0$

$\left(F_g\right)\frac{L}{2}\left(\sin 90^\circ\right) - F_T(L)\sin\theta = 0$

$Mg\frac{L}{2} = (F_T \sin\theta)L$

$F_T = \frac{Mg}{2\sin\theta}$

Total for part (c) 3 points

(d) For an attempt to use functional dependance to relate the derivation in part (c) to the reasoning used in part (b) **1 point**

Scoring Note: The functional dependance does not need to be used correctly to earn this point.

For an explanation that correctly relates the derivation in part (c) to the reasoning used in part (b) **1 point**

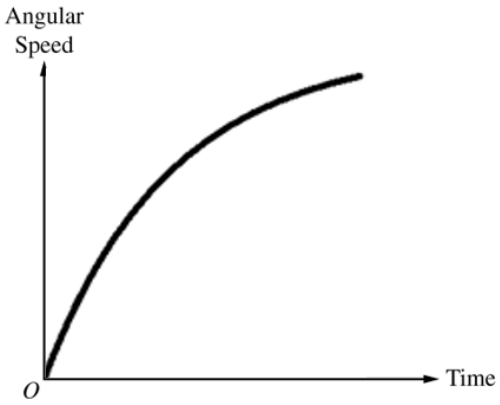
Example Response

The equation agrees with my explanation because my equation shows that the tension is inversely proportional to $\sin\theta$ *and for* $\theta < 90^\circ$, $\sin\theta$ *decreases as* θ *decreases, so the tension would be greater for smaller angles.*

Total for part (d) 2 points

(e)	For drawing a graph that is monotonically increasing	**1 point**
	For drawing a concave down curve	**1 point**

Example Response



Total for part (e) 2 points

Total for question 3 12 points

Question 5: Short Answer — 7 points

(a)(i) For indicating "Frame C" with correct reasoning about the magnitude of the torque being the greatest — **1 point**

Accept **one** of the following:

- This is the instant when the lever arm is greatest.
- This is when the angle between radius vector and weight force vector is most perpendicular.

For correctly relating torque and angular acceleration: $\alpha \propto \tau$ — **1 point**

Example Response

The angular acceleration is greatest in Frame C because angular acceleration is proportional to torque, and in Frame C the gravitational force vector is directed perpendicular to the rod (lever arm) which means this is where the torque will be the greatest.

(a)(ii) For indicating "Frame E" with correct reasoning — **1 point**

Accept **one** of the following:

- Work or energy (e.g., this is when the maximum work has been done on the system by gravity.)
- Angular momentum (e.g., the torque due to gravity is clockwise the entire time, causing the rod to gain angular momentum.)
- Kinematics (e.g., the rod speeds up the entire time.)

Example Response

The rotational kinetic energy is greatest in Frame E because this is where the rod-sphere system has the greatest rotational speed since the torque has been in the same direction as the motion the entire time.

Total for part (a) — **3 points**

(b)(i) For a multistep derivation that begins with conservation of energy **1 point**

$E_i = E_f$ **OR** $\Delta E = 0$ **OR** $U_{gi} + K_i = U_{gf} + K_f$

For indicating the change in height is equal to $\frac{3}{2}L$ **1 point**

$\Delta y = \frac{3}{2}L$

For an answer consistent with the height change indicated previously in the response **1 point**

$K_f = \frac{3}{2}MgL$

Scoring Note: A correct answer of $K_f = \frac{3}{2}MgL$ with no supporting work can earn only this point.

Example Response

$E_i = E_f$
$U_{gi} + K_i = U_{gf} + K_f$
$\Delta K = U_{gi} - U_{gf}$
$\Delta K = Mg\Delta y$
$\Delta y = \frac{3L}{4} + \frac{3L}{4} = \frac{3}{2}L$
$\Delta K = \frac{3}{2}MgL$

(b)(ii) For indicating that the gravitational force is the external force that does work on the rod-sphere system **1 point**

Example Response

The rod and sphere gain kinetic energy due to the positive work done by the gravitational force, which is an external force for the rod-sphere system.

Total for part (b) 4 points

Total for question 5 7 points

Question 5: Short Answer — 7 points

(a) **i.** For correct expressions for the torques from the weight of each object — **1 point**

The torques are $m_0 g(2r_0)$ for object 1 and $(1.5m_0 g)r_0$ for object 2

For indicating that the two torques are exerted in opposite directions — **1 point**

$\tau_{\text{net}} = m_0 g(2r_0) - (1.5m_0 g)r_0$

For the derivation of a correct answer of $0.5m_0 g r_0$ — **1 point**

Example response for part (a)(i)

$\tau_{\text{net}} = \tau_1 - \tau_2$
$\tau_{\text{net}} = m_0 g(2r_0) - (1.5m_0 g)r_0$
$\tau_{\text{net}} = 0.5m_0 g r_0$

ii. For an explanation that object 1 exerts a larger torque than object 2 — **1 point**

Example response for part (a)(ii)

Object 1 is twice as far from the axle as object 2, while object 2 has only 1.5 times the weight of object 1. So, object 1 exerts a larger torque.

Total for part (a) 4 points

(b) Correct answer: "Opposite directions"

Scoring note: If the wrong answer is selected, the response is not graded.

For a correct answer and a correct explanation — **1 point**

Example response for part (b)

The objects exerted torques in opposite directions, with object 1 exerting a larger torque, so object 1 determines the net torque direction. With the torque from object 1 removed, the net torque and angular acceleration switch direction (becoming clockwise) to the torque from object 2. The angular velocity does not change direction immediately and is still counterclockwise.

(c) For a linear graph between 0 and t_C, with an initial angular velocity of zero and nonzero slope **1 point**

Scoring note: The slope can be positive or negative.

For a change in the sign of the slope at $t = t_C$ **1 point**

AND

no discontinuity.

Example response for part (c)

Total for part (c) 2 points

Total for question 5 7 points

2017

AP CollegeBoard

AP Physics 1: Algebra-Based

Scoring Guidelines

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 $10\ \text{m/s}^2$ 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.

2017 SCORING GUIDELINES

Question 1

7 points total **Distribution of points**

(a) 2 points

Correct ranking: $(A = D = E) > (B = C)$ OR $A = D = E,\ B = C$

Note: A ranking must be given for any points to be earned for the explanation.

Note: The ranking must be correct to earn the full 2 points for the explanation.

For indicating $A = D = E$ in the ranking, with a valid explanation 1 point

Example: "*A*, *D*, and *E* are all connected across the battery, so they must have the same ΔV as the battery."

For indicating $B = C$ in the ranking, with a valid explanation 1 point

Example: "The same current flows through both bulbs *B* and *C*, so they have the same voltage drop across them. By Kirchhoff's voltage rule, the sum of the voltages in this circuit must add to zero, so each bulb has half the battery voltage."

Example 1: For each of bulbs *A*, *D*, and *E*, current can go around the circuit passing through only that bulb and the battery, and hence the potential drop across all three bulbs equals the voltage of the battery (because $\Delta V = 0$ for a complete loop). In circuit 2, *B* and *C* are in series so the overall potential drop (equal to the battery's voltage) is "shared" equally between the two bulbs (because they are identical) and the potential difference across each is half is the battery's voltage.

Example 2: *A*, *D*, and *E* are all connected directly across the battery terminals and therefore "get" the full battery potential difference. By contrast, the potential drop across the *BC* part of the circuit is "split" between *B* and *C*, and split equally.

2017 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(b) 5 points

Correct answers: Circuit 3 runs out first, circuit 2 runs out last

Note: In the paragraph response, "energy dissipation" or "current" are acceptable substitutes for "power."

For indicating that all three circuits draw different amounts of power — 1 point

Note: This point may be earned by addressing only two circuits in the response.

For explaining that the battery in circuit 2 delivers the least power using correct physical reasoning by addressing potential difference OR resistance — 1 point

For explaining that the battery in circuit 3 delivers the most power using correct physical reasoning by addressing potential difference OR resistance — 1 point

For an implicit or explicit statement that greater power results in shorter battery life — 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: The battery in circuit 3 runs out first, then the battery in circuit 1, and finally the battery in circuit 2. The power (rate of energy loss) of a battery is $P = I\Delta V$, and all three batteries have the same potential difference. So the rate of energy loss, and hence the order in which the batteries "die," is given by the ranking of the currents through the batteries. Circuit 3 has the most current because the availability of two paths (loops) makes the overall resistance of this circuit the lowest. Circuit 2 has the least current because there is only one loop, and it contains two bulbs, making the overall resistance greater than that of circuit 1.

2017 SCORING GUIDELINES

Question 2

12 points total | **Distribution of points**

(a)

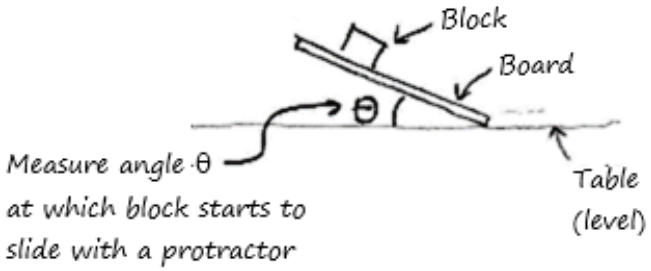
i. 3 points

For drawing a diagram of an experimental setup to measure the coefficient of friction that is feasible in a school physics lab — 1 point

For indicating the measurements necessary for calculating the coefficient of friction — 1 point

For indicating equipment necessary for measuring the quantities required to calculate the coefficient of friction — 1 point

Example:



ii. 3 points

For a description that is consistent with the diagram in part (a)(i), in enough detail that another student could replicate the experiment — 1 point

For a description that is a conceptually valid method to find quantities that would allow a calculation of a friction coefficient — 1 point

For including a valid method for reducing experimental error — 1 point

Example:

With the block at rest on the board, slowly lift one end of board until the block just begins to slide. Measure the angle between board and table and repeat several times with block at different locations on the board (with multiple trials at each location).

(b) 3 points

Note: In order to earn full credit for part (b), all terms (variables) must be indicated in the diagram and/or procedure of part (a).

For using Newton's second law (or reasoning in terms of zero net force) in one dimension, parallel to the board's surface, either explicitly or implicitly — 1 point

For using Newton's second law (or reasoning in terms of zero net force) in one dimension, perpendicular to the board's surface, either explicitly or implicitly — 1 point

Note: Replacing the normal force with *mg* is "implicit" use of Newton's second law in the perpendicular direction for a horizontal surface. For a tilted surface, the appropriate trigonometric term should be included.

For a correct derived expression of the coefficient of static friction in terms of quantities indicated in part (a) — 1 point

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Question 2 (continued)

Distribution of points

(c) 2 points

Correct answer: "The static and kinetic coefficients are not equal."
Reasoning cannot earn credit if the incorrect selection is made.

For identifying group 5's results as outliers, or indicating the presence of an outlier — 1 point
For a conclusion that coefficients are not the same, justified by either removing the outlier or noting the coefficients are different for each group — 1 point

(d) 1 point

For a valid argument that indicates the coefficient of static friction is a property of the two surfaces, and is consistent with the selected answer — 1 point

Example 1: Selects "Remain the same"
Referring to the equation in part (b), coefficient does not depend on mass.
Example 2: Selects "Remain the same"
The coefficient depends on the nature of the surfaces involved, not the masses or normal force of the objects involved.
Example 3: Selects "Decrease"
The increased normal force will cause smoothing of the surfaces, decreasing the coefficient of friction.
Example 4: Selects "Increase"
The increased normal force will cause the surfaces to become gouged, increasing the coefficient of friction.

2017 SCORING GUIDELINES

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.

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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 $m_{\text{disk}} v_0 x$ — 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: $I + m_{\text{disk}} x^2$ — 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.

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Question 4

7 points total **Distribution of points**

(a) 3 points

Correct answer: "No"
Note: If the wrong answer is selected, partial credit can be earned for the justification.

For attempting to use conservation of energy to compare the two blocks — 1 point
For explicitly or implicitly indicating that the launch velocities are different — 1 point
For stating or implying that the time to reach the ground is the same for both blocks — 1 point

Example: The amount of potential energy converted to kinetic energy is different for the two blocks. The potential energy is proportional to the change in height, which is smaller for block 2. Therefore, at the edge of the table, block 1 will have more kinetic energy than block 2, and hence a larger speed. The launches are both horizontal and from the same height, so the blocks will spend the same amount of time in the air. Because $d = vt$, the distances will be different for the two blocks (as the speeds are different).

(b)

i. 2 points

Correct answer: "The two blocks land the same distance from their respective tables."

For indicating that the change in potential energy from release to launch is the same for the two cases — 1 point
For an indication (explicit or implicit) that the launch velocities are the same — 1 point

ii. 2 points

Correct answer: "Block 1"

For indicating that the average speed or velocity on the slide is higher for Team 1, OR that block 1 reaches its maximum speed in less time — 1 point
For a valid explanation of why the average speed or velocity is higher for team 1, OR why block 1 reaches its maximum speed in less time — 1 point

Example: Because the ramp on Table 1 is initially steeper, block 1 has a higher average speed while it's on the ramp so it launches off the table before block 2.

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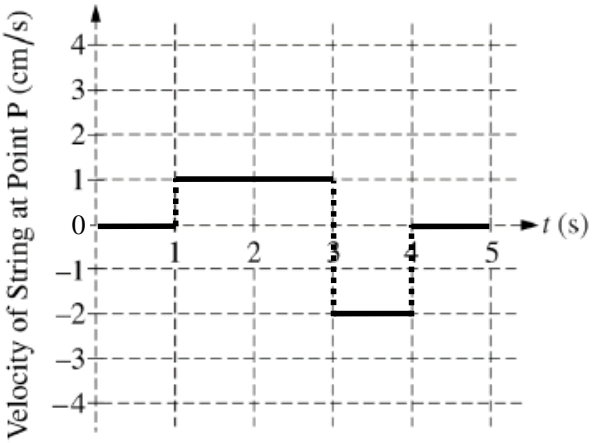
Question 5

7 points total **Distribution of points**

(a) 3 points

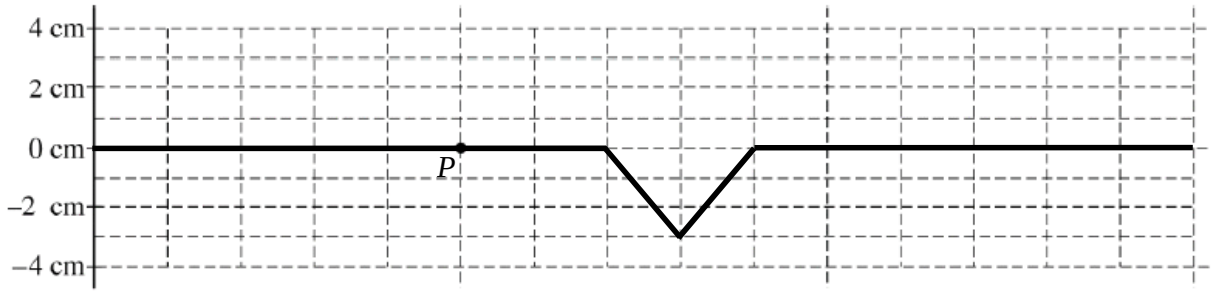


For indicating zero velocity for $0 < t < 1$ s and 4 s $< t < 5$ s — 1 point

For indicating two different non-zero constant velocities, one at the interval 1 s $< t < 3$ s and the other at the interval 3 s $< t < 4$ s — 1 point

For indicating a maximum velocity of $+1$ cm/s and a minimum velocity of -2 cm/s — 1 point

(b) 4 points



For drawing a single pulse and zero elsewhere — 1 point

For drawing a single pulse that is triangular (need not be isosceles or of two-unit extent) — 1 point

For drawing a single pulse with the correct maximum displacement from equilibrium of -3 cm — 1 point

For drawing a single pulse at the correct location that is two units wide between the 7th and 9th grid lines (i.e., 2 grid lines to the right of P to 4 grid lines to the right of P) and zero elsewhere — 1 point