2024

AP

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 3

☑ Scoring Guidelines

☑ Student Samples

☑ Scoring Commentary

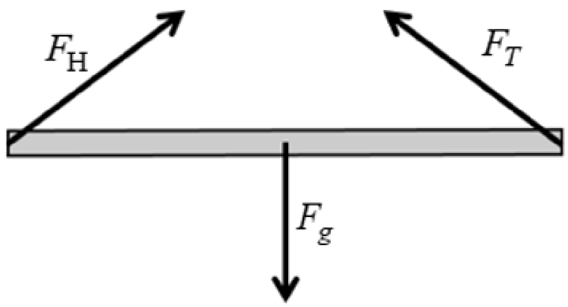
Question 3: Qualitative/Quantitative Translation — 12 points

(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 "$F_{T2} > F_{T1}$" 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**

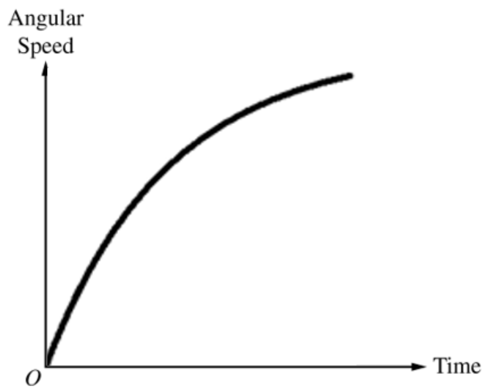
Example Response

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 3

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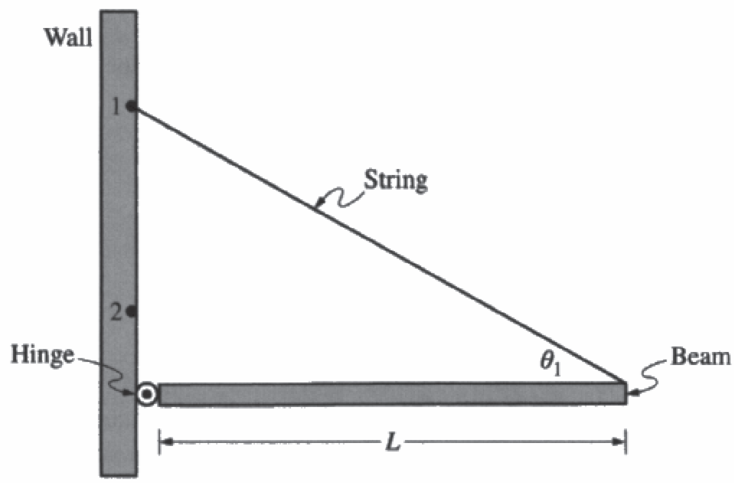
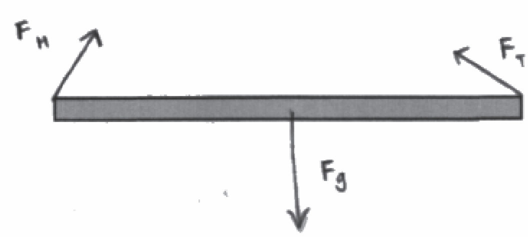


Figure 1

3. (12 points, suggested time 25 minutes)

The left end of a uniform beam of mass M and length L is attached to a wall by a hinge, as shown in Figure 1. One end of a string with negligible mass is attached to the right end of the beam. The other end of the string is attached to the wall above the hinge at Point 1. The beam remains horizontal. The hinge exerts a force on the beam of magnitude F_H, and the angle between the beam and the string is $\theta = \theta_1$.

(a) The following rectangle represents the beam in Figure 1. On the rectangle, **draw** and **label** the forces (not components) exerted on the beam. Draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted.



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Question 3

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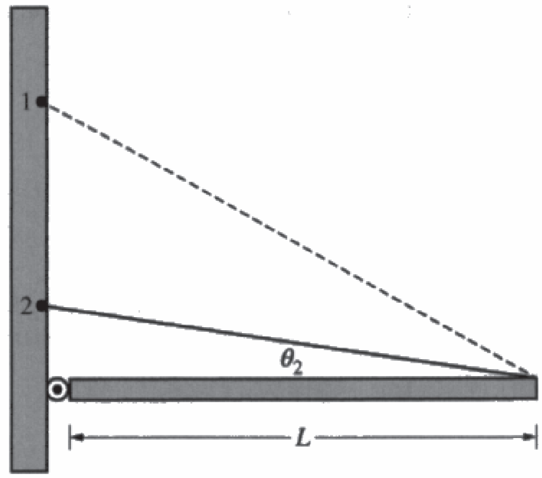

Figure 2

(b) The string is then attached lower on the wall, at Point 2, and the beam remains horizontal, as shown in Figure 2. The angle between the beam and the string is $\theta = \theta_2$. The dashed line represents the string shown in Figure 1.

The magnitude of the tension in the string shown in Figure 1 is F_{T1}. The magnitude of the tension in the string shown in Figure 2 is F_{T2}. **Indicate** which of the following correctly compares F_{T2} with F_{T1}.

_✓_ $F_{T2} > F_{T1}$ ____ $F_{T2} < F_{T1}$ ____ $F_{T2} = F_{T1}$

Briefly **justify** your answer, using qualitative reasoning beyond referencing equations.

When the string is attach lower, the vertical component of the tension force decreases, so the overall tension must increase to continue to counteract the torque from gravity and keep equilibrium.

(c) Starting with Newton's second law in rotational form, **derive** an expression for the magnitude of the tension in the string. Express your answer in terms of M, θ, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference book.

$\Sigma \tau = I\alpha$

$\Sigma \tau = 0 \quad (\alpha = 0)$

$F_T \sin\theta L - F_g \frac{L}{2} = 0$

$F_T \sin\theta L = F_g \frac{L}{2}$

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

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

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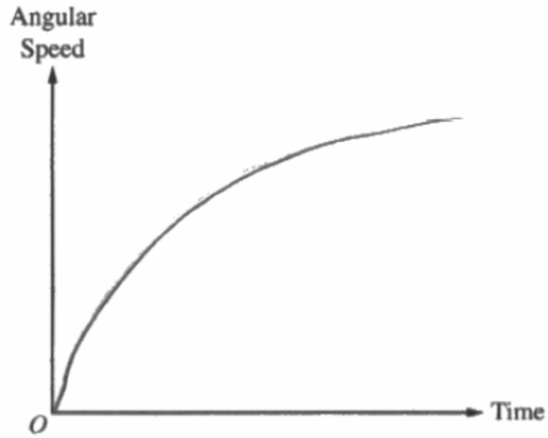
Question 3

Continue your response to **QUESTION 3** on this page.

(d) Is your derived equation in part (c) consistent with your justification in part (b) ? **Explain** your reasoning.

Yes, F_T is inversely related to θ. As θ decreases, $\sin\theta$ decreases, so the denominator decreases, and as a result, F_T increases. This supports what I said in (b) about tension force increasing when θ decreases.

(e) The string is cut, and the beam begins to rotate about the hinge with negligible friction. On the following axes, **sketch** the angular speed of the beam as a function of time for the time interval while the beam falls but before the beam becomes vertical.



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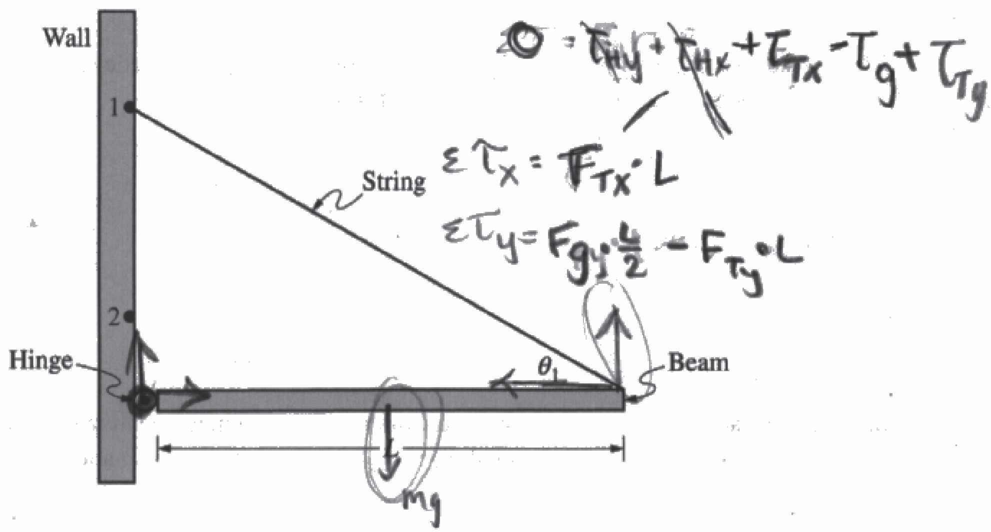
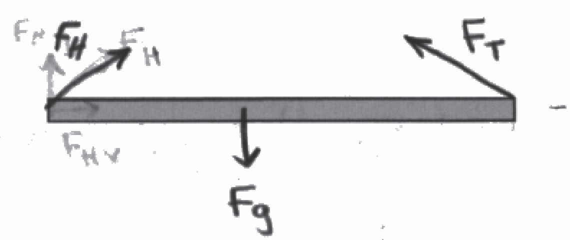


Figure 1

3. (12 points, suggested time 25 minutes)

The left end of a uniform beam of mass M and length L is attached to a wall by a hinge, as shown in Figure 1. One end of a string with negligible mass is attached to the right end of the beam. The other end of the string is attached to the wall above the hinge at Point 1. The beam remains horizontal. The hinge exerts a force on the beam of magnitude F_H, and the angle between the beam and the string is $\theta = \theta_1$.

(a) The following rectangle represents the beam in Figure 1. On the rectangle, **draw and label** the forces (not components) exerted on the beam. Draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted.



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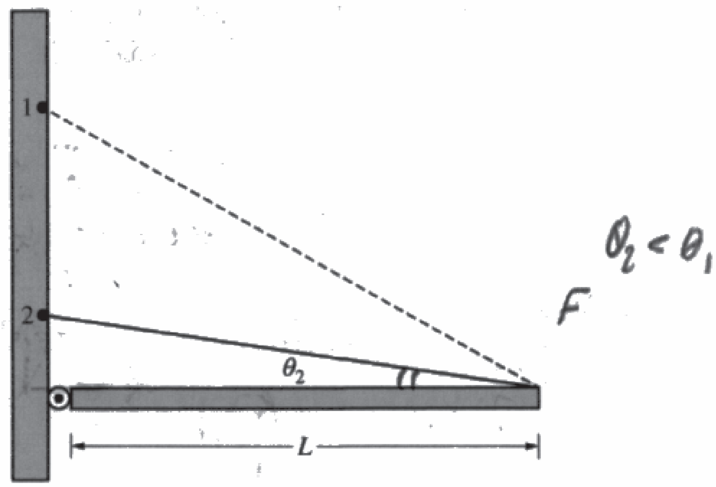

Figure 2

(b) The string is then attached lower on the wall, at Point 2, and the beam remains horizontal, as shown in Figure 2. The angle between the beam and the string is $\theta = \theta_2$. The dashed line represents the string shown in Figure 1.

The magnitude of the tension in the string shown in Figure 1 is F_{T1}. The magnitude of the tension in the string shown in Figure 2 is F_{T2}. **Indicate** which of the following correctly compares F_{T2} with F_{T1}.

____ $F_{T2} > F_{T1}$ ~~X~~ $F_{T2} < F_{T1}$ X $F_{T2} = F_{T1}$

Briefly **justify** your answer, using qualitative reasoning beyond referencing equations.

Even after the position of the string is lowered the beam remains at rest and horizontal. This means it remains in static equilibrium. So if F_{T1} keeps the beam at rest then F_{T2} must do the same as well making them equivalent.

(c) Starting with Newton's second law in rotational form, **derive** an expression for the magnitude of the tension in the string. Express your answer in terms of M, θ, and ~~physical constants~~, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference book.

$\Sigma\tau = 0$

$\tau = Fr\sin\theta$

$\Sigma\tau = \tau_{Hy} + \tau_{Hx} + \tau_{Tx} - \tau_g + \tau_{Ty}$ ($r=0$; not $\perp$)

$0 = F_g\frac{L}{2} - F_T\sin\theta_2 \cdot L$

$F_T\sin\theta \cdot L = \frac{MgL}{2} = \frac{F_T\sin\theta_2}{\sin\theta_2} = \frac{Mg}{2}\cdot\frac{1}{\sin\theta}$

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

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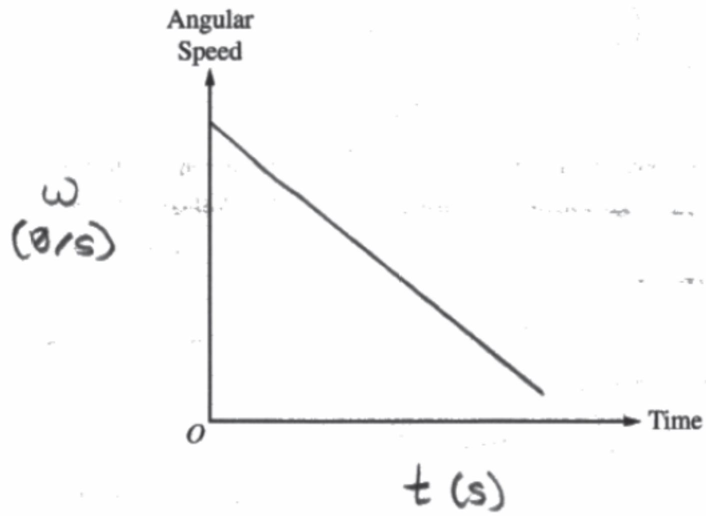
Question 3

Continue your response to QUESTION 3 on this page.

(d) Is your derived equation in part (c) consistent with your justification in part (b) ? **Explain** your reasoning.

No, my equation is not consistent because based off of my derivation, when the θ increases the denominator will increase meaning F_T will decrease. My justification explains that $F_{T1} = F_{T2}$ as both forces keep the beam in static equilibrium.

(e) The string is cut, and the beam begins to rotate about the hinge with negligible friction. On the following axes, **sketch** the angular speed of the beam as a function of time for the time interval while the beam falls but before the beam becomes vertical.



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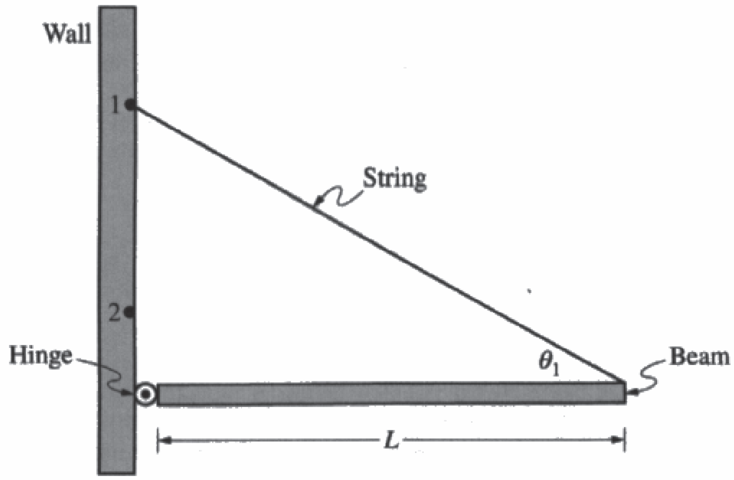
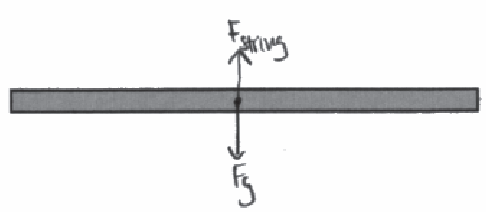


Figure 1

3. (12 points, suggested time 25 minutes)

The left end of a uniform beam of mass M and length L is attached to a wall by a hinge, as shown in Figure 1. One end of a string with negligible mass is attached to the right end of the beam. The other end of the string is attached to the wall above the hinge at Point 1. The beam remains horizontal. The hinge exerts a force on the beam of magnitude F_H, and the angle between the beam and the string is $\theta = \theta_1$.

(a) The following rectangle represents the beam in Figure 1. On the rectangle, **draw** and **label** the forces (not components) exerted on the beam. Draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted.



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Question 3

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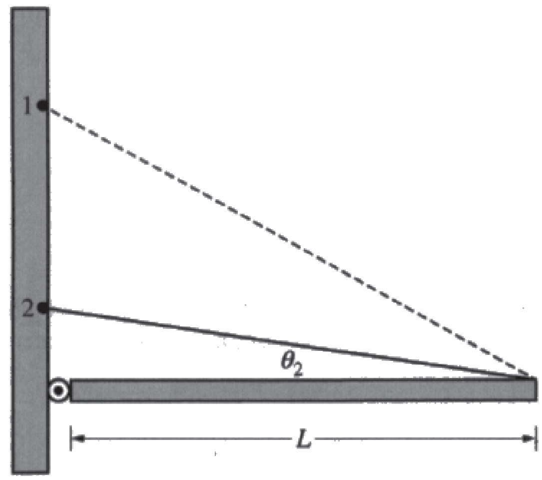


Figure 2

(b) The string is then attached lower on the wall, at Point 2, and the beam remains horizontal, as shown in Figure 2. The angle between the beam and the string is $\theta = \theta_2$. The dashed line represents the string shown in Figure 1.

The magnitude of the tension in the string shown in Figure 1 is F_{T1}. The magnitude of the tension in the string shown in Figure 2 is F_{T2}. **Indicate** which of the following correctly compares F_{T2} with F_{T1}.

✓ $F_{T2} > F_{T1}$ ✓ $F_{T2} < F_{T1}$ ____ $F_{T2} = F_{T1}$

Briefly **justify** your answer, using qualitative reasoning beyond referencing equations.

When lowering the angle from point 1 to point 2, there is less upward force from the force of tension making it much harder to maintain its upward force.

(c) Starting with Newton's second law in rotational form, **derive** an expression for the magnitude of the tension in the string. Express your answer in terms of M, θ, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference book.

$L = R$

$\tau = rF$

$F = \frac{\tau}{r}$

$Mg = \frac{\tau}{L}$

$F_T = Mg + \frac{\tau}{L}\sin\theta$

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

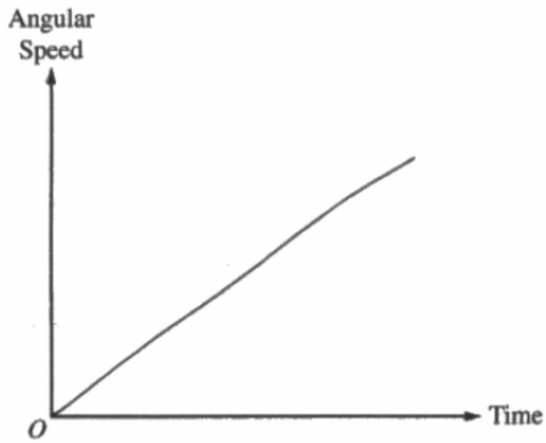
Question 3

Continue your response to **QUESTION 3** on this page.

(d) Is your derived equation in part (c) consistent with your justification in part (b) ? **Explain** your reasoning.

Yes because the force of tension is the upward vertical component of the String and the force of the beam due to gravity.

(e) The string is cut, and the beam begins to rotate about the hinge with negligible friction. On the following axes, **sketch** the angular speed of the beam as a function of time for the time interval while the beam falls but before the beam becomes vertical.



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Question 3

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

Overview

The responses were expected to demonstrate the ability to:

- Identify and label the forces exerted on a beam in equilibrium.
- Draw the directions of forces such that the net force and net torque sum to zero.
- Compare the relative magnitudes of the tension force provided by the string in two different scenarios using qualitative reasoning.
- Derive an expression for the tension in the string beginning with Newton's second law in rotational form.
- Evaluate consistency between stated reasoning based on a qualitative argument and a derived equation.
- Sketch the angular speed as a function of time for a rigid rod rotating about one end due to the gravitational force.

Sample: 3A
Score: 12

Part (a) earned 3 points. The first point was earned for correctly drawing a gravitational force vector at the center of the beam that is directed downward. The second point was earned for correctly drawing a tension force vector at the right end of the beam that is directed upward and leftward. The third point was earned for correctly including three force vectors that represent a system in equilibrium. Part (b) earned 2 points. The first point was earned for correctly selecting "$F_{T2} > F_{T1}$" with an attempt at a relevant justification. The second point was earned for correctly including a justification that relates the force needed to apply the same torque to the angle of the string. Part (c) earned 3 points. The first point was earned for including a multi-step derivation that begins with Newton's second law for rotation $\sum \tau = I\alpha$. The second point was earned for indicating the net torque is zero. The third point was earned for indicating the magnitude of the torque from the string is $(F_T \sin\theta)L$. The response indicates the magnitude of the torque from the weight of the beam is $Mg\frac{L}{2}$. The response indicates the correct answer, $F_T = \frac{Mg}{2\sin\theta}$. Part (d) earned 2 points. The first point was earned for attempting to use functional dependence to relate the derivation in part (c) to the reason used in part (b). The second point was earned for providing an explanation that correctly relates the derivation in part (c) to the reasoning used in part (b). Part (e) earned 2 points. The first point was earned for correctly drawing a graph that is monotonically increasing. The second point was earned for correctly drawing a graph that is concave down.

Sample: 3B
Score: 8

Part (a) earned 3 points. The first point was earned for correctly drawing a gravitational force vector at the center of the beam that is directed downward. The second point was earned for correctly drawing a tension force vector at the right end of the beam that is directed upward and leftward. The third point was earned for correctly including three force vectors that represent a system in equilibrium. Part (b) did not earn any points. The first point was not earned because the response incorrectly selects "$F_{T2} = F_{T1}$." The second point was not earned because the response incorrectly includes a justification that "if F_{T1} keeps the beam at rest then F_{T2} must do the same as well making them in equilibrium." Part (c) earned 3 points. The first point was earned for including a multi-step derivation that begins with Newton's second law for rotation by stating $\sum \tau = 0$. The second point was earned for indicating that the net torque is zero. The third point was earned for indicating the magnitude of the torque from the

Question 3 (continued)

weight of the beam is $Mg\frac{L}{2}$. Part (d) earned 2 points. The first point was earned for attempting to use functional dependence to relate the derivation in part (c) to the reasoning used in part (b) by relating the angle of the string to the tension force. The second point was earned for providing an explanation that correctly relates the derivation in part (c) to the reasoning used in part (b), even though that reasoning in part (b) was determined to be incorrect. Part (e) did not earn any points. The first point was not earned because the response does not correctly draw a graph that is monotonically increasing. The second point was not earned because the response does not correctly draw a curve with downward concavity.

Sample: 3C
Score: 3

Part (a) earned 1 point for correctly drawing a gravitational force vector at the center of the beam that is directed downward. The second point was not earned because the response incorrectly draws the tension force vector at the center of the beam. The third point was not earned because, although the system is in equilibrium, there are only two forces drawn, not three. Part (b) earned 1 point for correctly selecting "$F_{T2} > F_{T1}$" with an attempt at a relevant justification. The second point was not earned because the response does not provide a justification relating the increase in tension of the string to the weight of the beam or the torque provided by the string. Part (c) did not earn any points. The first point was not earned because the response does not include a multi-step derivation that includes Newton's second law for rotation or $\sum\tau = 0$. The second point was not earned because the response does not indicate the net torque is zero or that the net force is zero. The third point was not earned because the response does not indicate the magnitude of the torque from the string, the magnitude of the torque from the weight, or the correct answer. Part (d) did not earn any points. The first point was not earned because the response does not attempt to use functional dependence to relate the derivation in part (c) to the reasoning used in part (b). The second point was not earned because the response provides an explanation that incorrectly relates the derivation in part (c) to the reasoning used in part (b). Part (e) earned 1 point for drawing a graph that is monotonically increasing. The second point was not earned because the response does not correctly draw a curve with downward concavity.