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

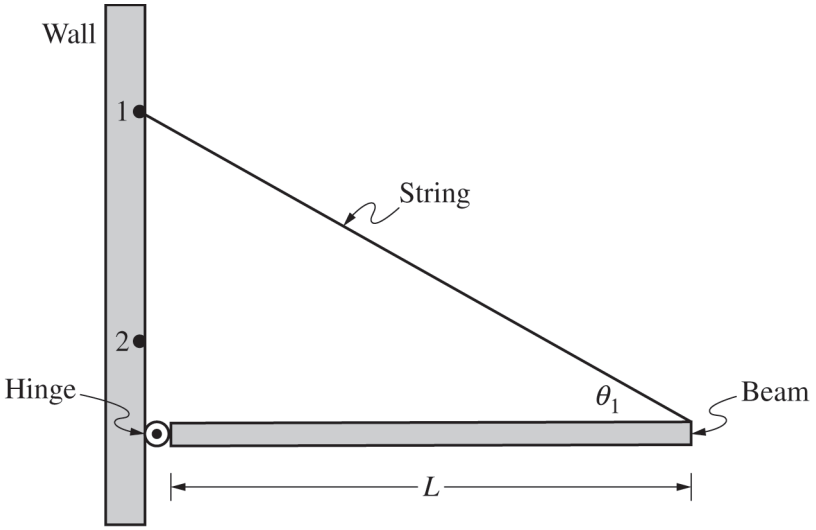

Figure 1

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

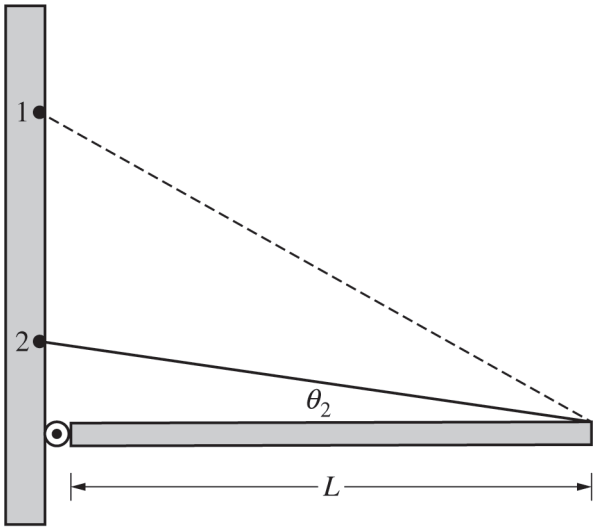


Figure 2

(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.

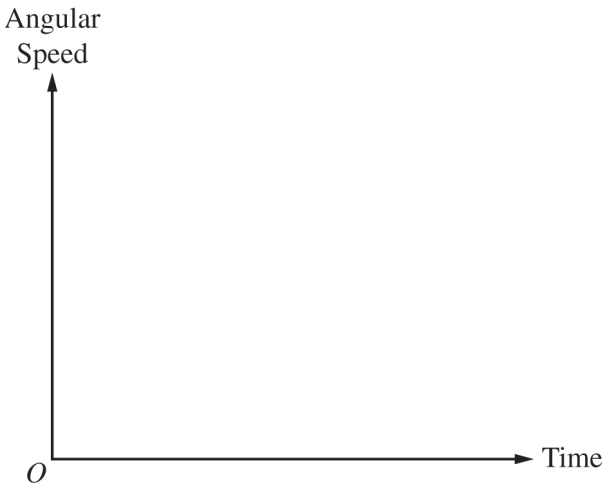
(c) Starting with Newton's second law in rotational form, **derive** an expression for the magnitude of the tension in the string. Express your answer in terms of M, θ, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference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

GO ON TO THE NEXT PAGE.

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.

(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: Qualitative/Quantitative Translation — 12 points

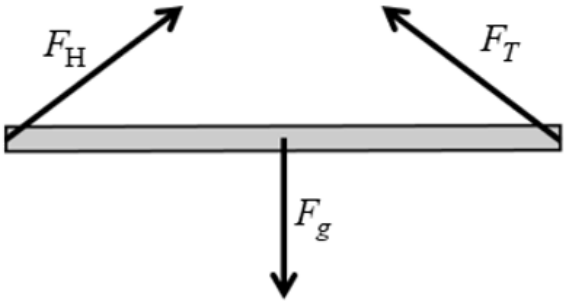
(a)

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

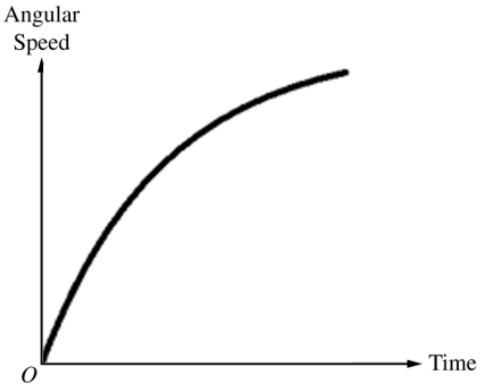
Example Response

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

(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