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

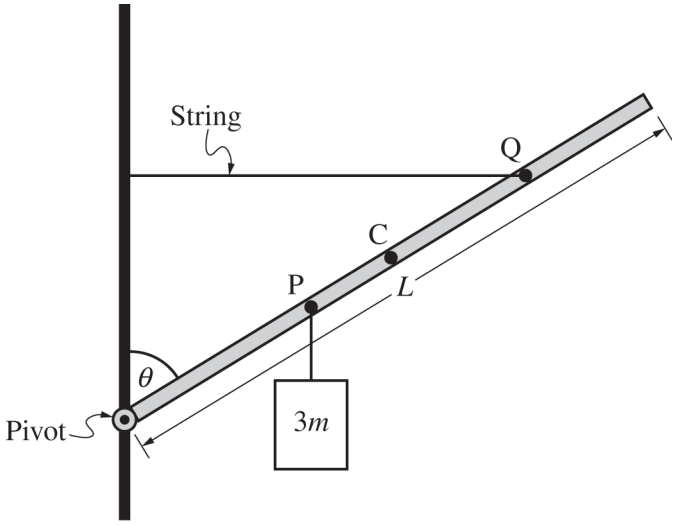
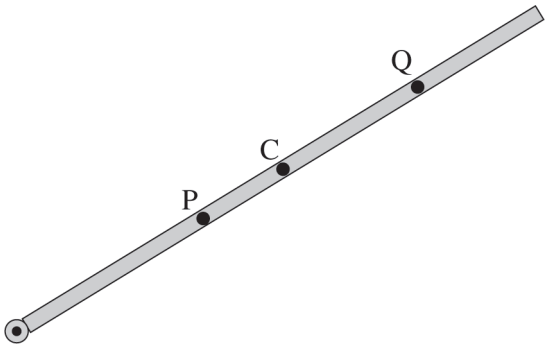


Figure 1

Note: Figure not drawn to scale.

3. A uniform rod of length L and mass m is attached to a pivot on a vertical pole, as shown in Figure 1. There is negligible friction between the rod and the pivot. A horizontal string connects Point Q on the rod to the pole. The rod makes an angle θ with the pole. A block of mass $3m$ hangs from the rod at Point P. The center of mass of the rod is located at Point C.

   (a) On the following representation of the rod, **draw** and **label** the forces (not components) that are exerted on the rod. Each force must be represented by a distinct arrow that starts on and points away from the point at which the force is exerted on the rod.



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

(b) In Figure 1, Point P is located $\frac{3}{8}L$ from the pivot and Point Q is located $\frac{6}{8}L$ from the pivot. **Derive** an equation for the tension F_T in the horizontal string in terms of L, m, θ, and physical constants, as appropriate.

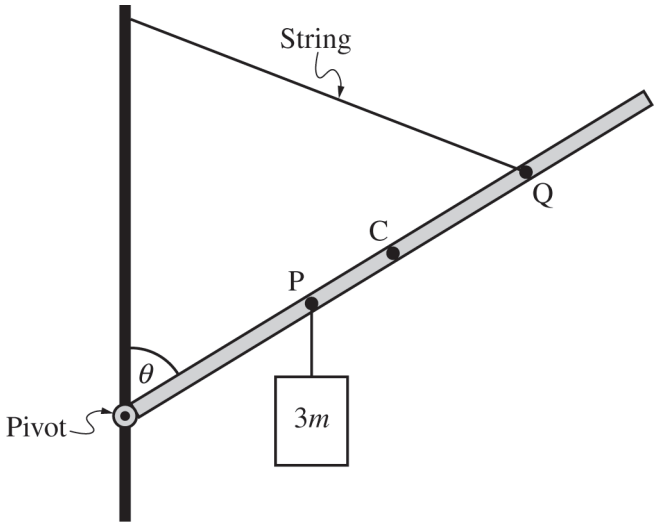

Figure 2

Note: Figure not drawn to scale.

(c) The original string is replaced with a longer string that connects Point Q to a higher location on the vertical pole, as shown in Figure 2. The angle θ remains the same. How does the new tension $F_{T,\,new}$ compare with the original tension F_T from part (b) ? **Justify** your reasoning.

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

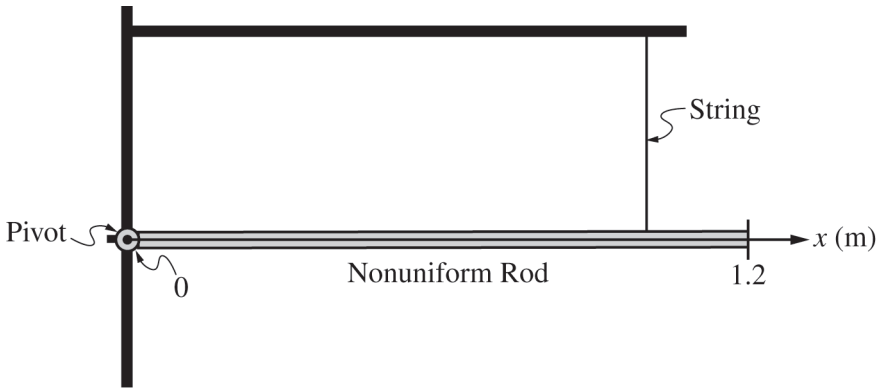

Figure 3

Note: Figure not drawn to scale.

(d) A nonuniform rod is now attached to the pivot, as shown in Figure 3. There is negligible friction between the nonuniform rod and the pivot. The rod has a length of 1.2 m and a linear mass density $\lambda(x) = A + Bx$, where x is the distance from the pivot, $A = 6.0\,\text{kg/m}$, and $B = 10.0\,\text{kg/m}^2$.

i. **Calculate** the mass of the rod.

ii. **Calculate** the rotational inertia of the rod about the pivot.

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Question 3: Free-Response Question — 15 points

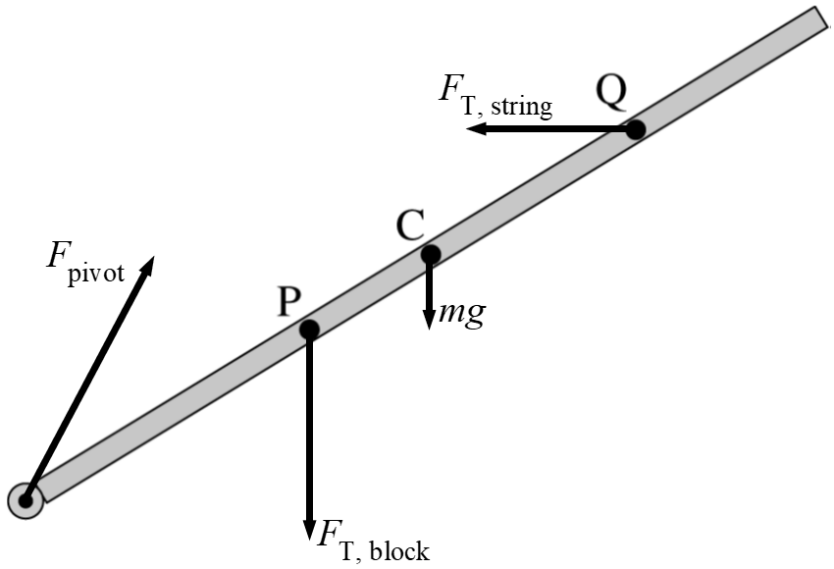
(a) For drawing and appropriately labeling the downward forces that are exerted on the rod at points P and C — **1 point**

Scoring Note: Labeling the downward force of tension as F_{block}, $3mg$, or similar, may earn this point.

For drawing and appropriately labeling a leftward force that is exerted on the rod at Point Q — **1 point**

For drawing and appropriately labeling a force that is directed up and to the right that is exerted on the rod at the pivot, and no extraneous forces are present — **1 point**

Example Response



Scoring Note: Examples of appropriate labels for the force due to gravity include: F_{G}, F_{g}, F_{grav}, W, mg, Mg, "grav force," "F Earth on block," "F on block by Earth," $F_{\text{Earth on block}}$, $F_{\text{E,Block}}$. The labels G and g are not appropriate labels for the force due to gravity.

Scoring Note: Examples of appropriate labels for the force from the pivot include: F_p, F_{pivot}, F_{n}, F_{N}, N, "normal force," "pivot force."

Scoring Note: Examples of appropriate labels for the tension force include F_t, F_{T}, T, F_{string}, and "Force from string."

Total for part (a) 3 points

(d)(ii) For a correct substitution of λ into an integral expression of rotational inertia **1 point**

Example Response

$$I = \int_0^{1.2\text{ m}} (A + Bx)x^2 dx$$

For a correct integration **1 point**

Example Response

$$I = \left(\frac{Ax^3}{3} + \frac{Bx^4}{4} \right) \Bigg|_0^{1.2\text{ m}}$$

For a correct numeric answer with correct units **1 point**

Example Response

$I = 8.64\text{ kg} \cdot \text{m}^2$

Example Solution

$I = \int r^2 dm \qquad dm = \lambda dr$ and $r = x$

$I = \int_0^{1.2\text{ m}} \lambda x^2 dx$

$I = \int_0^{1.2\text{ m}} (A + Bx)x^2 dx$

$I = \left(\frac{Ax^3}{3} + \frac{Bx^4}{4} \right) \Bigg|_0^{1.2\text{ m}}$

$I = \frac{(6.0\text{ kg/m})(1.2\text{ m})^3}{3} + \frac{\left(10.0\text{ kg/m}^2\right)(1.2\text{ m})^4}{4}$

$I = 8.64\text{ kg} \cdot \text{m}^2$

Total for part (d) 6 points

Total for question 3 15 points