Begin your response to **QUESTION 1** on this page.

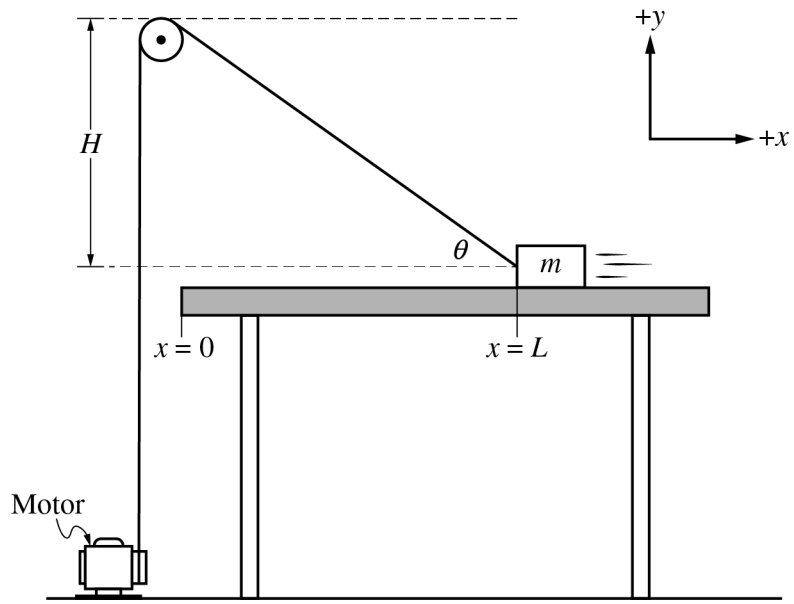
PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



1. A block of mass m is pulled across a rough horizontal table by a string connected to a motor that is attached to the floor. The string passes over a pulley with negligible friction that is vertically aligned with the left edge of the table as shown. The string and pulley both have negligible mass. The pulley is at height H above the table. The motor exerts a constant force of tension F_T on the string, and the block remains in contact with the table at all times as the block slides across the table from $x = L$ to $x = 0$. The coefficient of kinetic friction between the table and the block is μ_k. Express all algebraic answers in terms of m, H, F_T, x, μ_k, L, and physical constants as appropriate.

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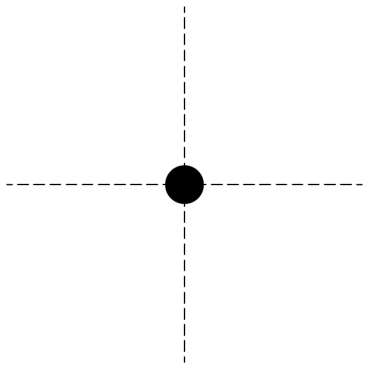
Continue your response to **QUESTION 1** on this page.

(a) On the dot below that represents the block, draw and label the forces (not components) that act on the block when the block is at $x = L$. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



(b) Derive an expression for the angle θ that the string makes with the horizontal as a function of x.

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Continue your response to **QUESTION 1** on this page.

(c)

i. Derive an expression for the normal force F_N exerted on the block by the table as a function of the block's position x.

ii. Derive an expression for the magnitude of the net horizontal force F_{net} exerted on the block as a function of the position x.

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Continue your response to **QUESTION 1** on this page.

(d) Write, but do not solve, an integral expression that could be used to solve for the work W done by the string on the block as the block moves from $x = L$ to $x = 0$.

(e) Does the string do more, less, or the same amount of work on the block as the block moves from $x = L$ to $x = \frac{L}{2}$ compared to when the block moves from $x = \frac{L}{2}$ to $x = 0$?

_____ More work when the block moves from $x = L$ to $x = \frac{L}{2}$

_____ Less work when the block moves from $x = L$ to $x = \frac{L}{2}$

_____ The same amount of work when the block moves from $x = L$ to $x = \frac{L}{2}$

Justify your answer.

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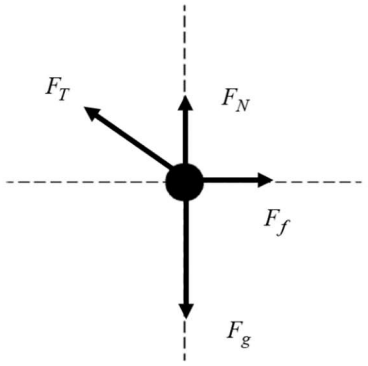
Question 1: Free-Response Question — 15 points

(a) For correctly drawing and labeling the force of gravity and the normal force on the block of mass m — **1 point**

For correctly drawing and labeling the force of friction on the block of mass m — **1 point**

For correctly drawing and labeling the force of tension on the block of mass m — **1 point**

Example Response



Scoring Notes:

- 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" $F_{\text{Earth on block}}$, $F_{E,Block}$. The labels G and g are not appropriate labels for the force due to gravity. F_n, F_N, N, "normal force," "ground force," or similar labels may be used for the normal force. F_{string}, F_s, F_T, $F_{Tension}$, T, "string force," "tension force," or similar labels may be used for the tension force exerted by the string.
- A response with extraneous forces or vectors can earn a maximum of two points.

Total for part (a) — 3 points

(b) For a trigonometric expression relating the angle to the horizontal distance of the block from the left corner of the table, x. — **1 point**

For any correct trigonometric expression for θ in terms of the given quantities — **1 point**

Example Responses

First Point	Second Point
$\sin\theta = \dfrac{H}{\sqrt{H^2 + x^2}}$	$\theta = \sin^{-1}\left(\dfrac{H}{\sqrt{H^2 + x^2}}\right)$
$\cos\theta = \dfrac{x}{\sqrt{H^2 + x^2}}$	$\theta = \cos^{-1}\left(\dfrac{x}{\sqrt{H^2 + x^2}}\right)$
$\tan\theta = \dfrac{H}{x}$	$\theta = \tan^{-1}\left(\dfrac{H}{x}\right)$

Total for part (b) — 2 points

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(e)	For selecting "More work …" with an attempt at a relevant justification	**1 point**
	For a correct justification relating the smaller angle to a larger component of the force of tension, thus resulting in greater work.	**1 point**

Example Response

F_T stays the same for both halves, the displacement is the same in both halves, but from $x = L$ to $x = L/2$ the angle is smaller, resulting in a larger component of the tension force that aligns with the displacement.

Total for part (e) 2 points

Total for question 1 15 points

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