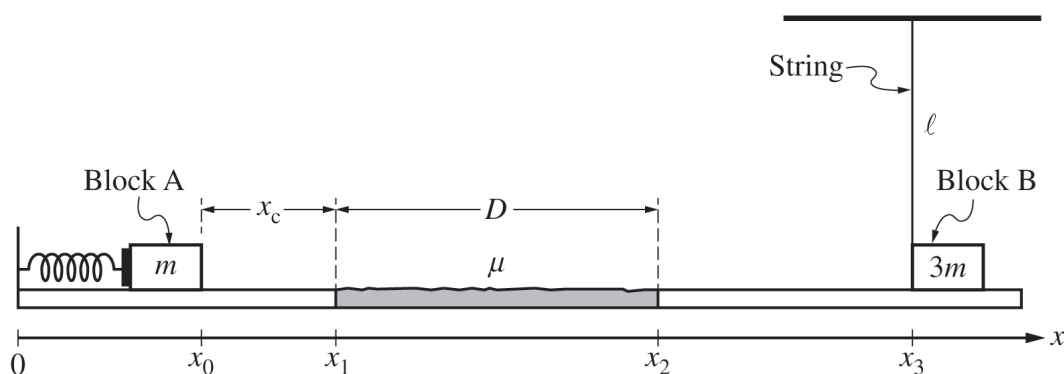


Begin your response to **QUESTION 1** on this page.**PHYSICS C: MECHANICS****SECTION II****Time—45 minutes****3 Questions**

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.



Note: Figure not drawn to scale.

Figure 1

1. Block A and Block B of masses m and $3m$, respectively, are arranged in a setup consisting of an ideal spring with spring constant k and a horizontal surface. Friction between the surface and the blocks is negligible except in a region of length D , where the coefficient of kinetic friction between Block A and the surface is μ . Block B is attached to a string of length ℓ and negligible mass, as shown in Figure 1. Block A is held against the spring, compressing the spring a distance x_c .

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

At time $t = 0$, Block A is located at position $x = x_0$ and is released from rest. After the block is released, the following occurs.

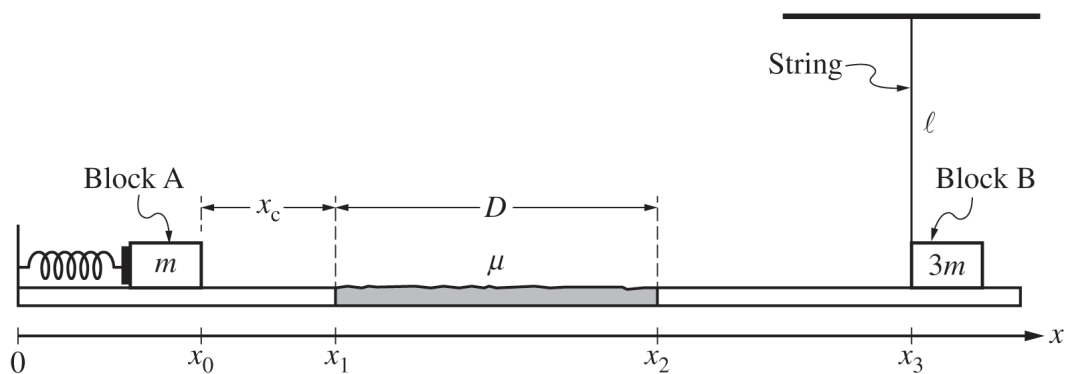
- At time $t = t_1$, Block A is at $x = x_1$ after traveling a distance x_c . Block A moves with speed v , and the spring is at its equilibrium position.
- At time $t = t_2$, the left side of Block A is at $x = x_2$ after passing through a distance D across the region with nonnegligible friction.
- At time $t = t_3$, Block A is at $x = x_3$ and Block A collides with and sticks to Block B.

(a) For parts (a)(i) and (a)(ii), express your answer in terms of m , k , D , μ , x_c , and physical constants, as appropriate.

i. **Derive** an expression for the speed v of Block A at time t_1 .

ii. **Derive** an expression for the speed $v_{A,B}$ of the two-block system immediately after the collision at time t_3 .

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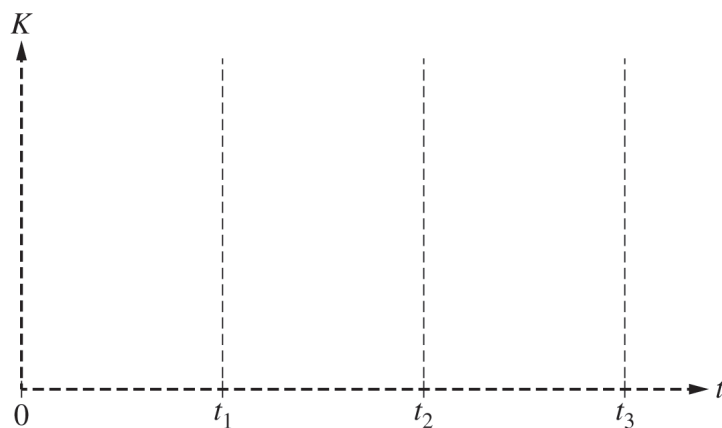
Continue your response to **QUESTION 1** on this page.

Note: Figure not drawn to scale.

Figure 1

(b)

- i. On the following axes, **sketch** a graph of the kinetic energy K of Block A as a function of time t from time $t = 0$ to time t_3 .



- ii. Use principles of work and energy to **justify** the graph drawn in part (b)(i) for the time interval $t = 0$ to $t = t_1$. Explicitly reference features of the shape of the graph you drew in part (b)(i).

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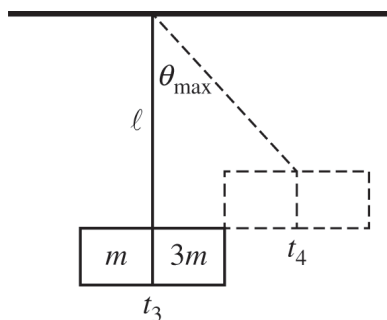
Continue your response to **QUESTION 1** on this page.Note: Figure not drawn to scale.

Figure 2

After the collision, the two-block system instantaneously comes to rest at time t_4 , which occurs when the string makes a small angle $\theta_{\max}$ with the vertical, as shown in Figure 2. For times $t > t_4$, the system oscillates with frequency f_ℓ . The support holding the string is raised, and the procedure is then repeated using a new string of length 2ℓ .

(c) **Indicate** how the new frequency of oscillation $f_{2\ell}$ of the system on the new string of length 2ℓ will compare to the frequency of oscillation f_ℓ from the original procedure.

_____ $f_{2\ell} > f_\ell$ _____ $f_{2\ell} < f_\ell$ _____ $f_{2\ell} = f_\ell$

Briefly **justify** your answer.

GO ON TO THE NEXT PAGE.

PHYSICS C: MECHANICS**SECTION II****Time—45 minutes****3 Questions**

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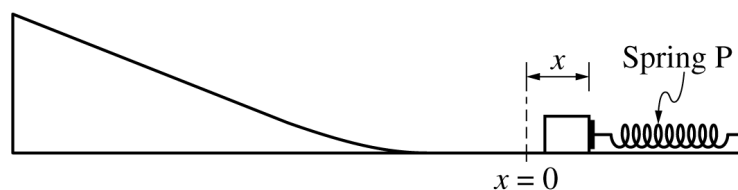


Figure 1

A block sitting on a horizontal surface is pushed against a spring, Spring P, that is attached to a wall, compressing the spring a distance x , as shown in Figure 1. The block is then released from rest. The block slides along the horizontal surface and up a ramp, reaching a maximum height $h_{\text{max,P}}$. Frictional forces between the block and all surfaces are negligible.

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

A student compares $h_{\max,P}$ for Spring P with the maximum height $h_{\max,Q}$ achieved with a different spring, Spring Q. Each spring exerts a force of magnitude F on the block that varies as a function of the distance x that the spring is compressed, as shown in Figure 2. For Spring P, $F_P(x) = kx$, where $k = 100.0 \text{ N/m}$, and for Spring Q, $F_Q(x) = Cx^{1/2}$, where $C = 20.0 \text{ N/m}^{1/2}$.

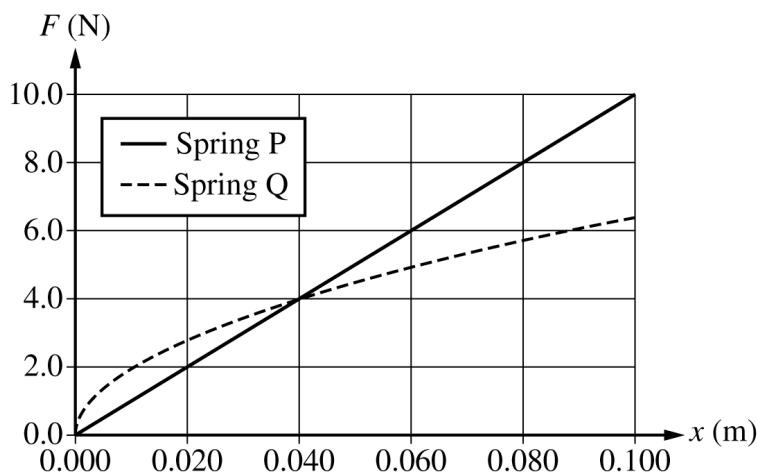
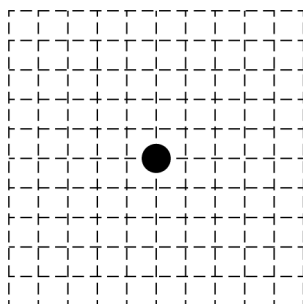
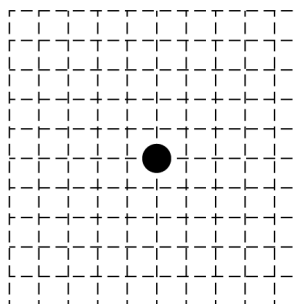


Figure 2

- (a) For the experiment, the block is pushed against one of the springs, compressing the spring a distance $x = 0.010 \text{ m}$. The block is then released from rest. In Trial 1, Spring P is used, and in Trial 2, Spring Q is used. On the following dots, representing the block in Trials 1 and 2, draw and label the forces (not components) that are exerted on the block at the instant the block is released. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. The lengths of the horizontal vectors should represent the relative magnitude of the horizontal forces and the lengths of the vertical vectors should represent the relative magnitude of the vertical forces.

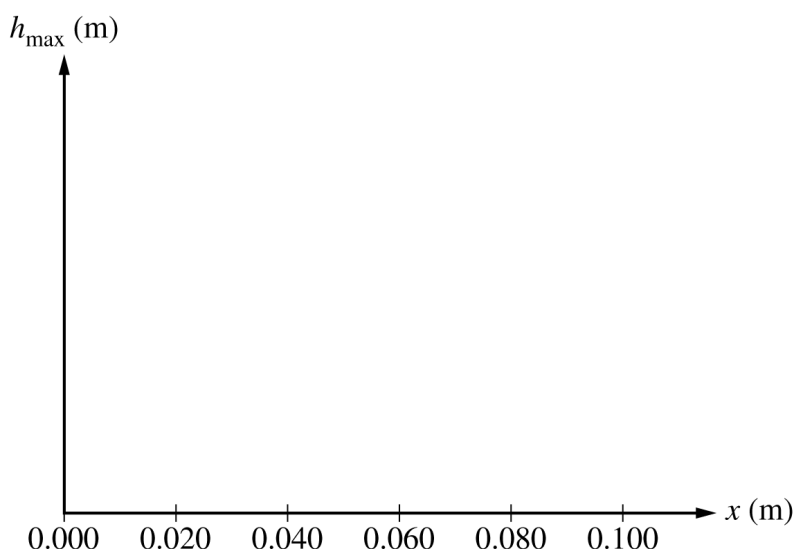
Trial 1
(Spring P)Trial 2
(Spring Q)**GO ON TO THE NEXT PAGE.**

(b)

i. What feature(s) of the graph in Figure 2 could be used to estimate the work done on the block by each spring as each spring is compressed?

ii. There is one compression distance x_0 for which the maximum height $h_{\max}$ reached by the block is the same regardless of which spring, Spring P or Spring Q, is used. Predict whether the value of x_0 is greater than, less than, or equal to 0.040 m. Use the graph in Figure 2 to justify your answer.

iii. On the axes provided, for both Spring P and Spring Q, sketch a graph of the maximum height $h_{\max}$ reached by the block as a function of the distance each spring is compressed for values of x ranging from 0 to 0.100 m. Clearly label the curve for Spring P and Spring Q.



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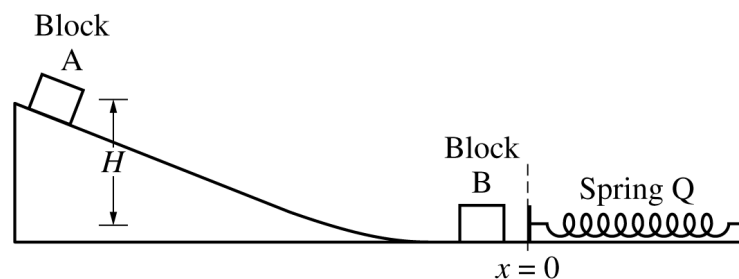
Continue your response to **QUESTION 1** on this page.

Figure 3

(c) Spring Q is attached to the wall and is at equilibrium, as shown in Figure 3. Block A has a mass of 0.120 kg and Block B has a mass of 0.070 kg. Block A is held at rest at the top of the ramp and Block B is at rest on the horizontal surface. The student releases Block A, and it moves down the ramp and collides with Block B. The change in vertical height of Block A is $H = 0.75$ m. After the collision, the blocks stick together and move to the right, compressing the spring. Frictional forces between the blocks and all surfaces are negligible.

i. Calculate the velocity of the two-block system immediately after the collision between Blocks A and B.

ii. Calculate the maximum compression of the spring.

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- (d) Spring Q where $F_Q(x) = Cx^{1/2}$ is replaced by a different nonlinear spring, Spring R, and the procedure described in part (c) is repeated. For Spring R, $F_R(x) = Dx^{1/2}$. The maximum compression of Spring R is greater than the maximum compression of Spring Q. Which of the following correctly compares the constants C and D ?

_____ $C < D$ _____ $C > D$ _____ $C = D$

Briefly justify your answer.

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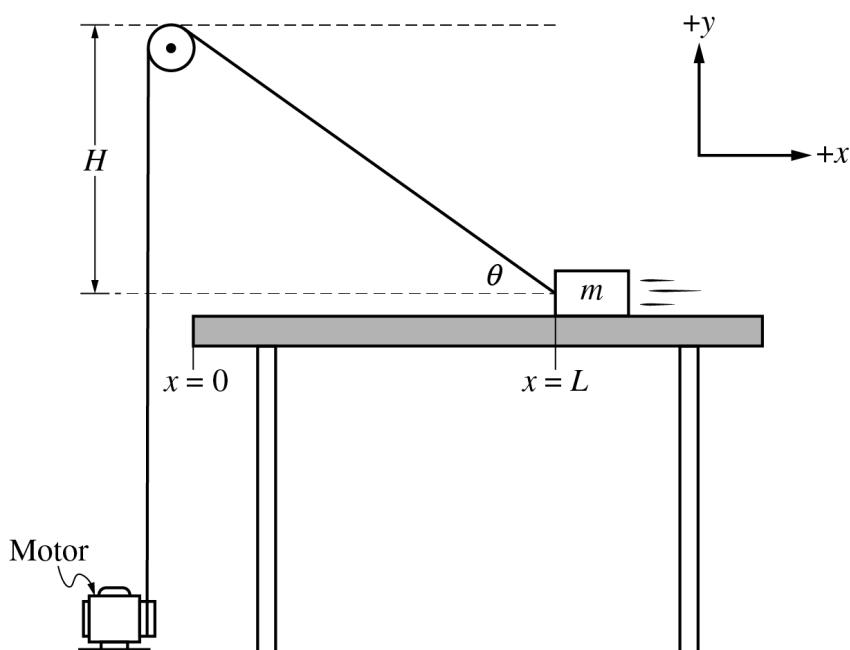
PHYSICS C: MECHANICS

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.

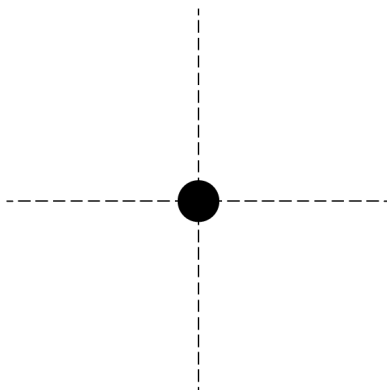


A block of mass m is pulled across a rough horizontal table by a string connected to a motor that is attached to the floor. The string passes over a pulley with negligible friction that is vertically aligned with the left edge of the table as shown. The string and pulley both have negligible mass. The 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.

GO ON TO THE NEXT PAGE.

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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Name:

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 .

GO ON TO THE NEXT PAGE.

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.

GO ON TO THE NEXT PAGE.

PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

3 Questions

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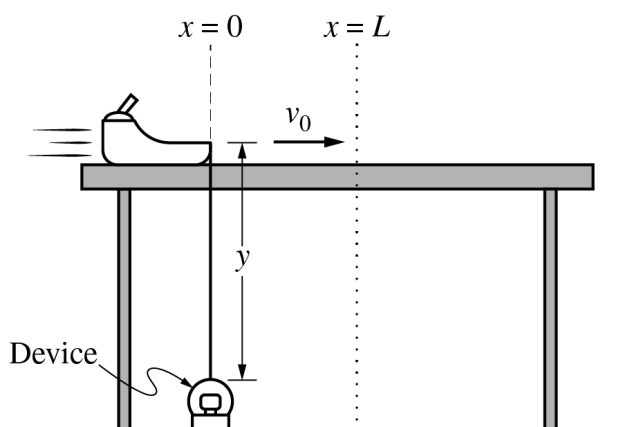


Figure 1

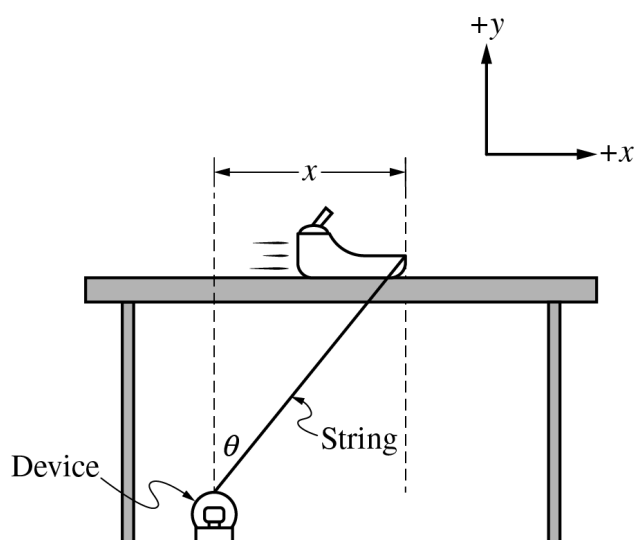


Figure 2

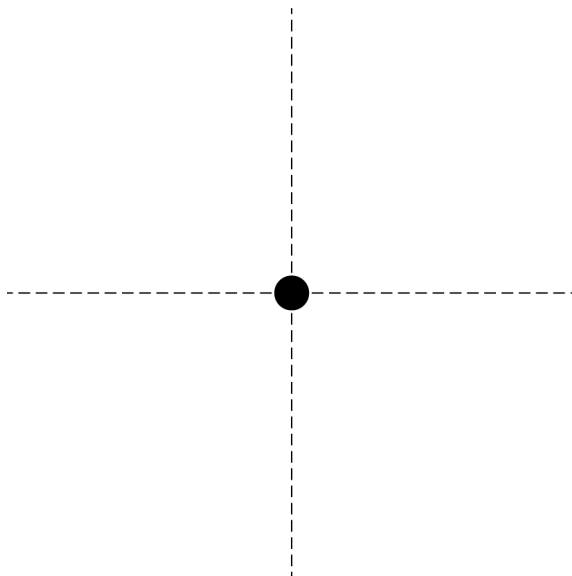
Note: Figures not drawn to scale.

A small sled slides across a rough horizontal table with an initial velocity v_0 . The coefficient of kinetic friction between the sled and the table is μ_k . A string connects the sled to a device on the ground. The device maintains constant tension F_T in the string by unwinding the string as the sled slides to the right. The total mass of the sled is m . The string is attached to the device at $x = 0$ and at a height of y , as shown in Figure 1. The horizontal position of the sled is represented by x , as shown in Figure 2. Express all algebraic answers in terms of m , μ_k , F_T , x , y , and physical constants, as appropriate.

GO ON TO THE NEXT PAGE.

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

- (a) On the dot below that represents the sled, draw and label the forces (not components) that are exerted on the sled a short time after $t = 0$ but before the sled has come to rest. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



- (b) Determine an expression for the angle θ that the string makes with the vertical when the sled has traveled a horizontal distance 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 sled by the table as a function of the position x .
- ii. Derive an expression for the magnitude of the net horizontal force F_{net} exerted on the sled as a function of the position x .

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

GO ON TO THE NEXT PAGE.

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

(d) Derive an expression for the work W done by the string on the sled as the sled moves from $x = 0$ to $x = L$.

(e) The sled comes to rest after traveling a horizontal distance $x = 2L$. As the system slides from $x = 0$ to $x = L$, the energy dissipated by friction is E_1 . As the sled slides from $x = L$ to $x = 2L$, the energy dissipated by friction is E_2 . Is E_1 greater than, less than, or equal to E_2 ?

___ $E_1 > E_2$ ___ $E_1 < E_2$ ___ $E_1 = E_2$

Justify your answer.

GO ON TO THE NEXT PAGE.