

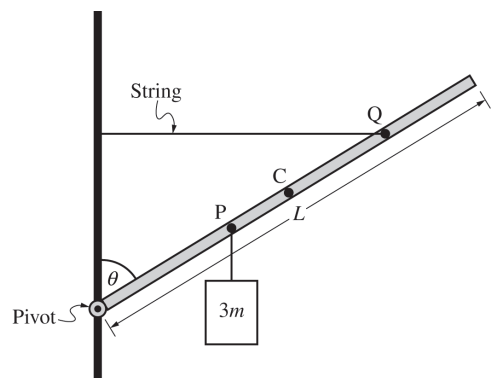
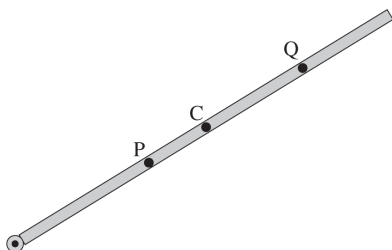
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Figure 1

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.

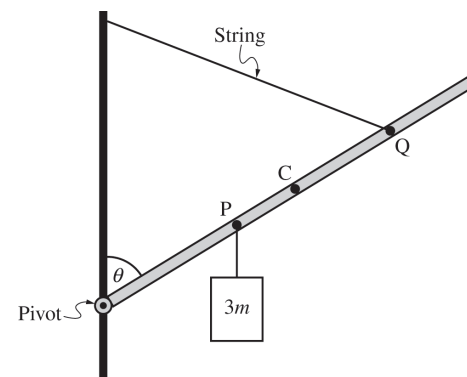


Figure 2

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 $F_{T, \text{new}}$ 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.

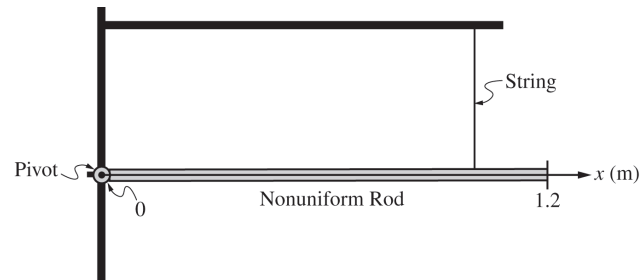


Figure 3

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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END OF EXAM

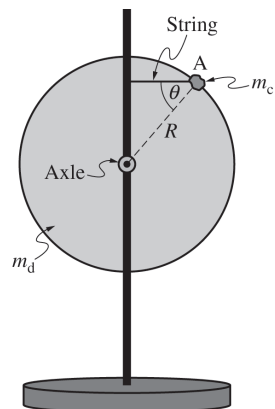
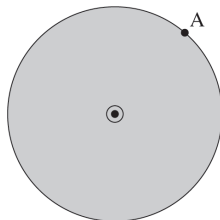
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Figure 1

Note: Figure not drawn to scale.

3. A uniform disk of radius R and mass m_d is attached to a vertical pole by a horizontal axle that passes through the center of the disk. Friction between the axle and the disk is negligible. A lump of clay of mass m_c is attached to the edge of the disk at Point A. The size of the lump of clay is small compared with the radius of the disk. A horizontal string is connected from the pole to the edge of the disk at Point A. The string makes an angle θ with the line between Point A and the axle, as shown in Figure 1.

- (a) On the following representation of the clay-disk system, **draw** and **label** the external forces (not components) exerted on the system. 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 system.

**GO ON TO THE NEXT PAGE.**Continue your response to **QUESTION 3** on this page.

- (b) **Derive** an expression for the tension F_T in the string when the clay is at Point A, as shown in Figure 1, in terms of R , m_d , m_c , θ , and physical constants, as appropriate.

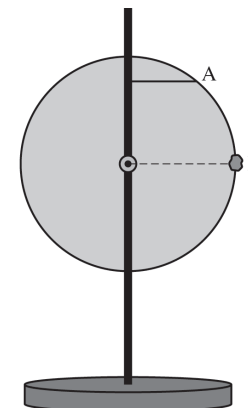


Figure 2

Note: Figure not drawn to scale.

- (c) The string remains connected to the edge of the disk at Point A. The clay is moved to Point B, which is horizontally in line with the axle, as shown in Figure 2. How does the new tension $F_{T, \text{new}}$ compare with tension F_T from part (b)? **Justify** your reasoning.

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

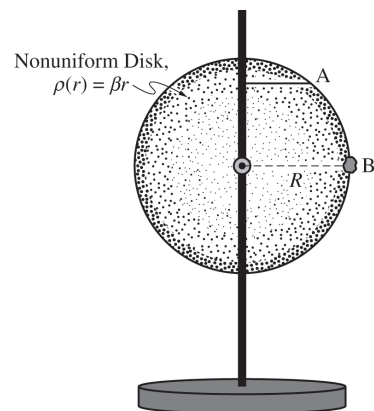


Figure 3

Note: Figure not drawn to scale.

- (d) A nonuniform disk is now attached to the axle. The lump of clay is attached to the disk at Point B, as shown in Figure 3. The clay has mass $m_c = 0.60 \text{ kg}$ and the disk has a radius $R = 0.30 \text{ m}$. The mass density of the disk varies radially and can be modeled by $\rho(r) = \beta r$, where r is the radial distance from the axle and $\beta = 4.0 \text{ kg/m}^3$.
- Calculate** the rotational inertia of the disk about the axle.

- The string connecting the disk to the pole is cut. **Calculate** the magnitude of the initial angular acceleration of the clay-disk system.

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END OF EXAM

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.

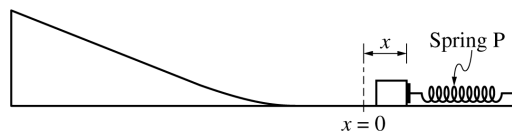


Figure 1

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 $h_{\max,P}$. 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 $C = 20.0 \text{ N/m}^{1/2}$.

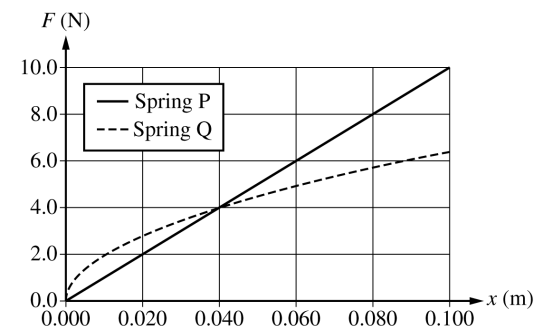
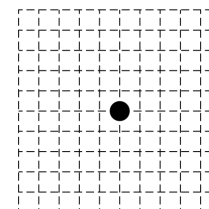
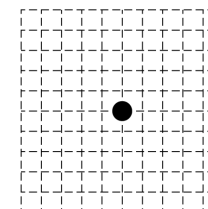


Figure 2

- (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)

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(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.

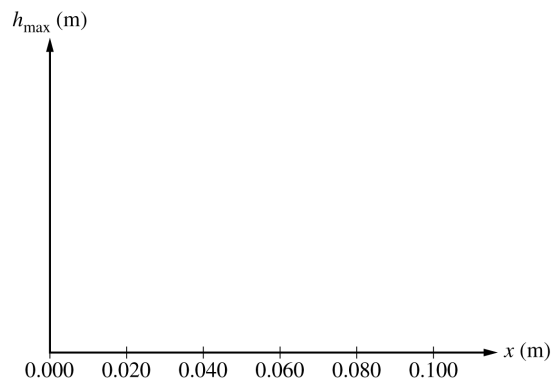
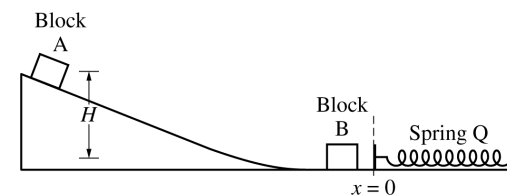
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Figure 3

(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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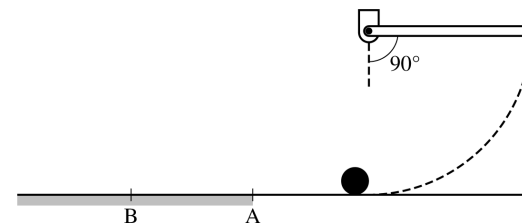
Continue your response to **Question 1** on this page.

- (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.

GO ON TO THE NEXT PAGE.

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

Note: Figure not drawn to scale.

Figure 1

3. A system consists of a small sphere of mass m and radius R at rest on a horizontal surface and a uniform rod of mass $M = 2m$ and length ℓ attached at one end to a pivot with negligible friction, where $R \ll \ell$. There is negligible friction between the surface and the sphere to the right of Point A and nonnegligible friction to the left of Point A. The rod is held horizontally as shown in Figure 1, then is released from rest. The total rotational inertia of the rod about the pivot is $\frac{1}{3}M\ell^2$ and the rotational inertia of the sphere about its center is $\frac{2}{5}mR^2$. After the rod is released, the rod swings down and strikes the sphere head-on. As a result of this collision, the rod is stopped, and the ball initially slides without rotating to the left across the horizontal surface.
- (a) Derive an expression for the angular speed of the rod just before striking the sphere in terms of the length ℓ and physical constants as appropriate.

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Continue your response to **QUESTION 2** on this page.

- (b) Derive an expression for the linear speed v_0 of the sphere immediately after colliding with the rod in terms of the length ℓ and physical constants as appropriate.

After sliding a short distance, at time $t = 0$ the sphere encounters a region of the horizontal surface with a coefficient of kinetic friction μ , beginning at Point A as indicated in Figure 1. The sphere begins rotating while sliding and eventually begins rolling without sliding at Point B, also as indicated.

- (c) In the following diagram, which represents the sphere while the sphere is traveling between Points A and B, draw and label the forces (not components) that act on the sphere. Each force must be represented by a distinct arrow starting on, and pointing away from, the point of application on the sphere.



- (d) Derive an expression for each of the following as the sphere is rotating and sliding between points A and B in terms of v_0 , μ , R , t , and physical constants as appropriate.

i. The linear velocity v of the center of mass of the sphere as a function of time t

ii. The angular velocity ω of the sphere as a function of time t

GO ON TO THE NEXT PAGE.Continue your response to **QUESTION 3** on this page.

(e)

- i. Derive an expression for the time it takes the sphere to travel from Point A to Point B in terms of v_0 , μ , and physical constants as appropriate.

ii. Derive an expression for the linear velocity of the sphere upon reaching Point B in terms of v_0 .

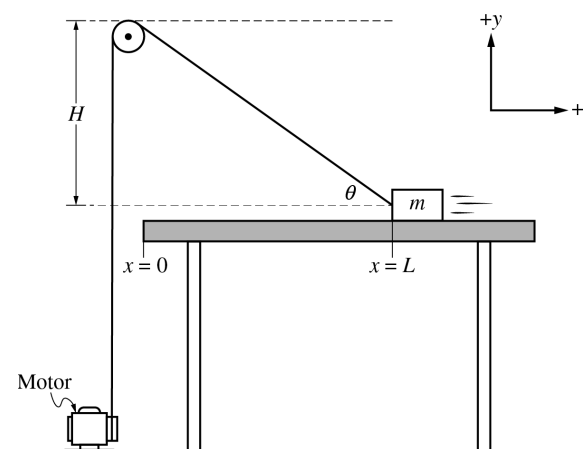
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STOP**END OF EXAM**

Begin your response to each question 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.

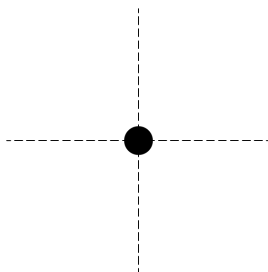


A block of mass m is pulled across a rough horizontal table by a string connected to a motor that is attached to the floor. The string passes over a pulley with negligible friction that is vertically aligned with the left edge of the table as shown. The string and pulley both have negligible mass. The 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 $x = 0$?

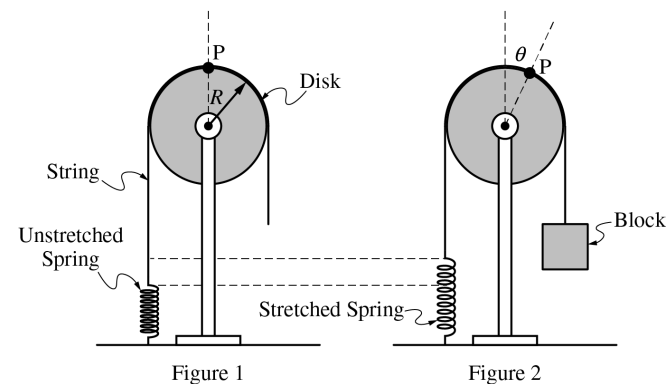
_____ More work when the block moves from $x = L$ to $x = \frac{L}{2}$

_____ 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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Begin your response to **QUESTION 2** on this page.

Note: Figures not drawn to scale.

A solid uniform disk is supported by a vertical stand. The disk is able to rotate with negligible friction about an axle that passes through the center of the disk. The mass and radius of the disk are given by M_d and R , respectively. The rotational inertia of the disk is $I_d = \frac{1}{2} M_d R^2$. A string of negligible mass is draped over the disk and attached to the top of the disk at point P. One end of the string is connected to an unstretched ideal spring of spring constant k , which is fixed to the ground as shown in Figure 1.

A block of mass m_B is then attached to the string on the right side of the disk. The block is slowly lowered until the spring-disk-block system reaches equilibrium, as shown in Figure 2. In this equilibrium position, the disk has rotated clockwise through a small angle θ .

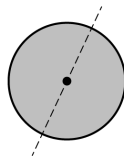
Give all algebraic answers in terms of M_d , R , k , θ , and physical constants, as appropriate.

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

(a) Derive an expression for the mass m_B of the block.

(b) At time $t = 0$, the string on the right side of the disk is cut and the block falls to the ground. On the circle below, which represents the disk, draw and label the forces (not components) that act on the disk immediately after the string is cut and the block is falling to the ground. Each force should be represented by an arrow that starts on and is directed away from the point of application.

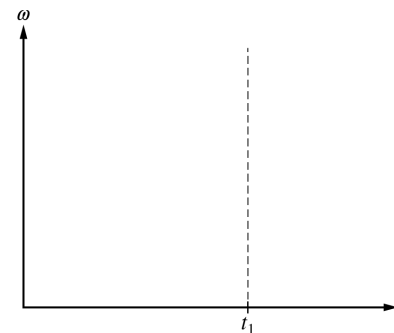


(c) Derive an expression for the angular acceleration α of the disk immediately after the string is cut.

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

(d) At $t = t_1$, the disk has rotated and point P is again directly above the axle. Sketch a graph of the magnitude of the angular velocity ω of the disk as a function of time t from $t = 0$ to $t = t_1$.



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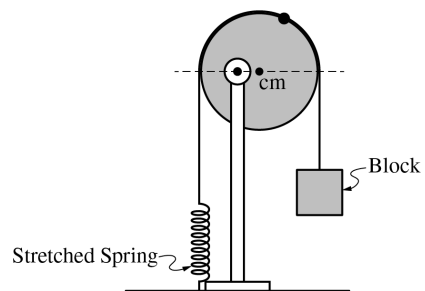


Figure 3

Note: Figure not drawn to scale.

- (e) The disk is adjusted on the support so that the axle does not pass through the center of mass of the disk. The block is again hung on the right side of the disk and the spring-disk-block system comes to equilibrium, as shown in Figure 3. The axle does not exert a torque on the disk. For each force on the disk, indicate whether the magnitude of the torque about the axle caused by that force increases, decreases, or stays the same relative to part (b).

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END OF EXAM

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

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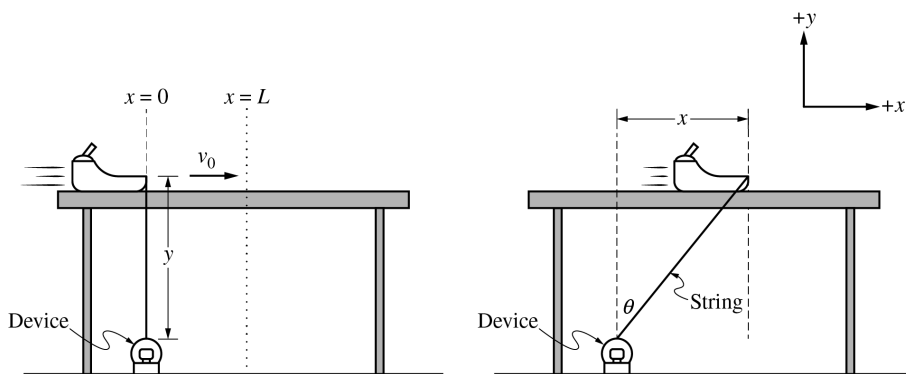


Figure 1

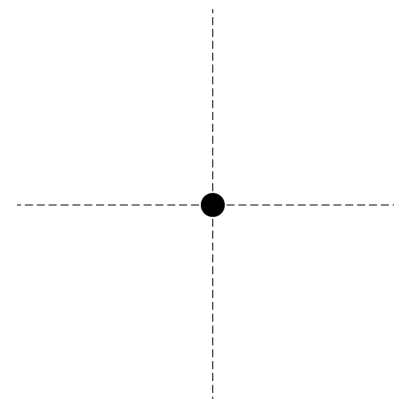
Figure 2

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 .

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.

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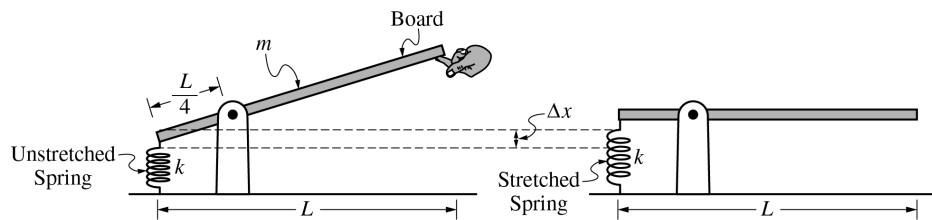


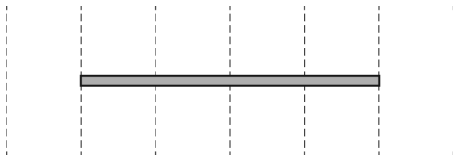
Figure 1

Figure 2

Note: Figures not drawn to scale.

A uniform board of length L and mass m is attached to a pivot $\frac{L}{4}$ from the left end of the board. The left end of the board is attached to an ideal spring of spring constant k that is attached to the ground. The right end of the board is initially held by a student so that the spring is unstretched, as shown in Figure 1. The student slowly lowers and then releases the board. The board remains at rest in the horizontal position, with the spring stretched, as shown in Figure 2. The rotational inertia of the board about the pivot is I .

- (a) On the rectangle below, which represents the board, draw and label the forces (not components) that act on the board while the board-spring system is in equilibrium. Each force should be represented by an arrow that starts on, and points away from, the board, and should represent the location at which that force acts.

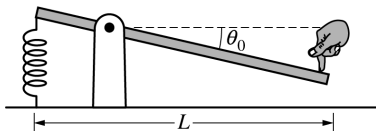


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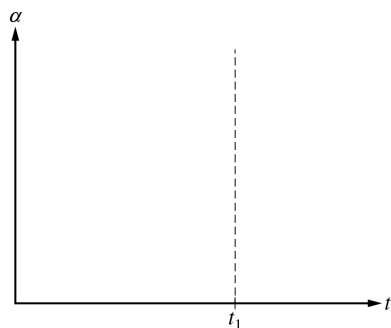
- (b) Derive an expression for the distance the spring stretches, Δx , when the board is in equilibrium. Express your answer in terms of k , L , m , and physical constants, as appropriate.

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Continue your response to **QUESTION 3** on this page.Note: Figure not drawn to scale.

- (c) A student pushes the board down on the right side, stretching the spring a new distance Δx_2 from the unstretched position. The board is held at a small angle θ_0 with the horizontal, as shown. The student then releases the board from rest.

- i. At time $t = 0$, the board is released. At $t = t_1$, the board first crosses the horizontal. Sketch a graph of the magnitude of the angular acceleration α of the board as a function of time t from $t = 0$ to $t = t_1$.

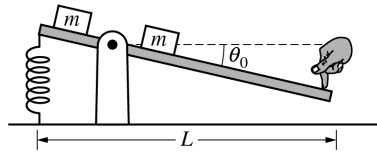


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Continue your response to **QUESTION 3** on this page.

- ii. Derive an expression for the angular acceleration α_0 of the board immediately after the board is released. Express your answer in terms of k , L , m , I , Δx_2 , θ_0 , and physical constants, as appropriate.

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Continue your response to **QUESTION 3** on this page.Note: Figure not drawn to scale.

- (d) Two blocks of equal mass m are attached to the board equal distances from the pivot point, as shown. The board is again pushed down on the right side so that the spring stretches the same distance Δx_2 as in part (c). The board is then released. How does the new angular acceleration α' when the blocks are attached compare to the angular acceleration α_0 from part (c) ?

___ $\alpha' > \alpha_0$ ___ $\alpha' < \alpha_0$ ___ $\alpha' = \alpha_0$

Justify your answer.

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PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

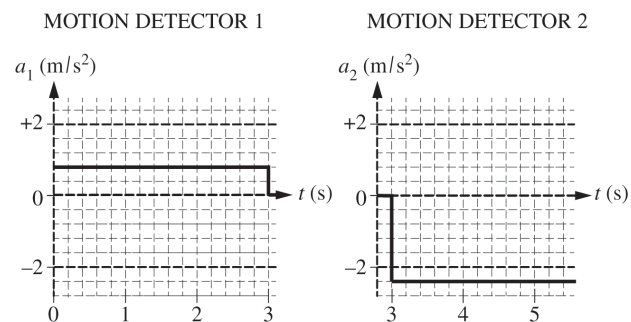
3 Questions

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.



Note: Figure not drawn to scale.

1. A 0.50 kg fan cart is placed on a level, horizontal track of negligible friction, as shown. The fan is turned on, and the fan cart is released from rest and moves to the right. The cart travels along the horizontal track and then down an incline. Motion detector 1 measures the acceleration a of the cart from time $t = 0$ to $t = 3$ s. At $t = 3$ s, the cart makes a smooth transition to the incline, and motion detector 2 measures the acceleration of the cart after $t = 3$ s. The fan exerts the same magnitude of force on the cart during the entire motion. The graphs below show a as functions of t . For each motion detector, the positive direction is away from the detector.



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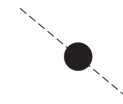
Use a pencil or pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.

- (a) On the dots below that represent the cart at two different locations, draw and label the forces (not components) that act on the cart at each location. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

Cart on Horizontal Track



Cart on Incline



- (b) Calculate the magnitude of the net force exerted on the fan cart when it is on the horizontal track.

- (c) Calculate the angle θ of the incline.

- (d) Suppose careful measurement determines the angle of the incline to be 3° larger than that calculated in part (c). Consider the following explanation.

“The scale used to measure the mass of the fan cart was not calibrated properly before the measurement, and this could account for the observed difference in the angle.”

Does the explanation sufficiently account for the observed discrepancy?

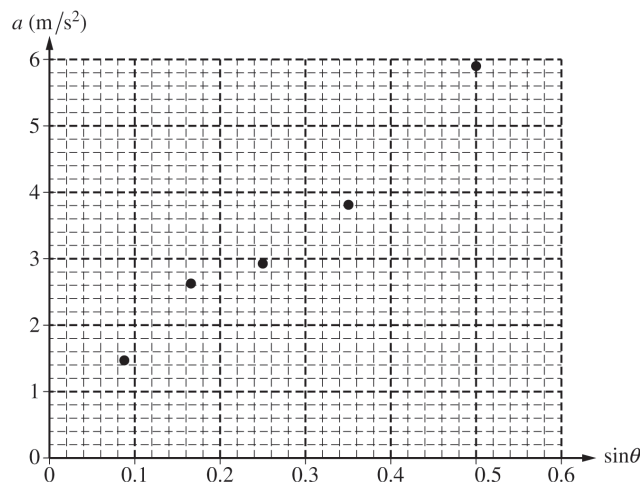
☐ Yes ☐ No

Justify your answer.

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The experiment is repeated for several trials, each with a different angle for the incline. The acceleration of the cart down the incline is measured for each angle. The graph below shows the plot of the acceleration a of the cart as a function of the sine of the angle $\sin \theta$.



(e)

- i. Draw a best-fit line for the data.
- ii. Using the straight line, calculate an experimental value for the acceleration due to gravity g .

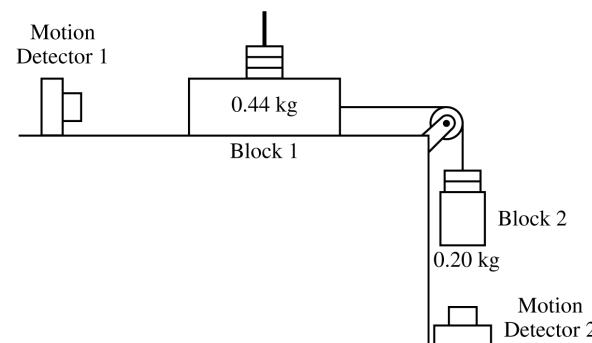
(f) If the cart were replaced with a second cart of mass 1.0 kg that has a fan that exerts the same magnitude of force as the original fan, explain how the graph given in part (e) would change.

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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.



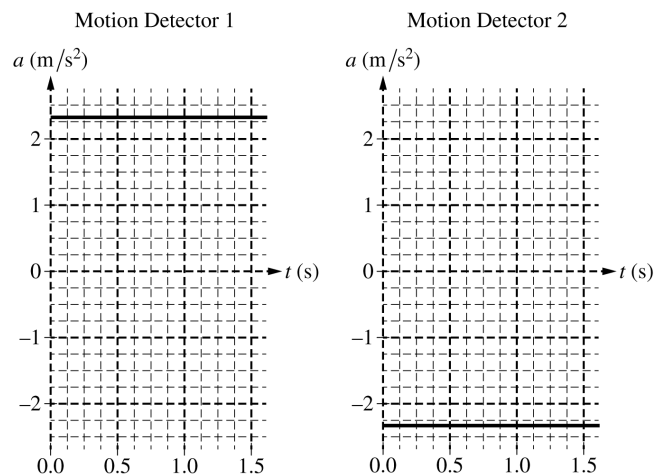
Students design an experiment using blocks of adjustable mass to investigate friction using the setup shown. Block 1 of initial mass 0.44 kg is placed on a rough horizontal surface and connected by a string to block 2 of initial mass 0.20 kg . The string extends over a pulley that has negligible mass and friction.

- (a) Calculate the minimum value of the coefficient of static friction μ_s that would keep the two-block system at rest.

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The coefficient of friction is such that when block 2 is released from rest, block 1 travels across the surface. The acceleration a of each block is recorded with motion detectors 1 and 2, as shown in the figure. The data for the motion detectors as functions of time t are shown on the graphs. For each motion detector, the positive direction is away from the detector.



(b) On the dots below, which represent the blocks, draw and label the forces (not components) that act on each block. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



(c) Calculate the coefficient of kinetic friction μ_k between block 1 and the table.

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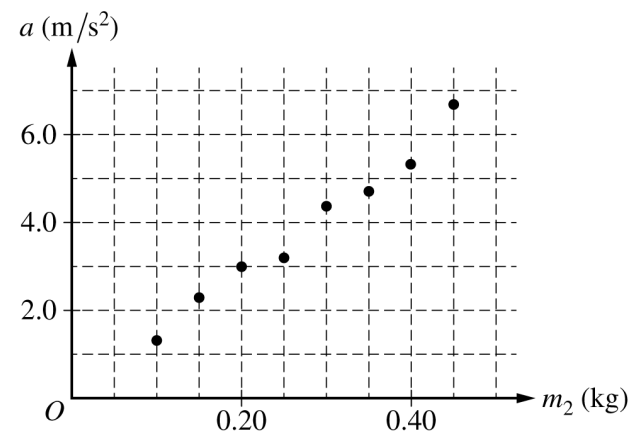
(d) Careful measurements determine that the coefficient of kinetic friction is larger than the value calculated in part (c). Does the following explanation sufficiently account for the observed discrepancy?

“The horizontal table was not perfectly level before the experiment was conducted. The observed difference in the angle accounts for the difference in the expected and calculated values of μ_k .”

_____ Yes _____ No

Justify your answer.

The experiment is moved to a surface with negligible friction and run for eight trials. In each trial, the students vary the masses m_1 and m_2 of blocks 1 and 2, respectively, while keeping the total mass $(m_1 + m_2) = 0.64$ kg constant. The data for the acceleration a of block 1 as a function of m_2 are shown on the graph below.



(e)

- Draw a best-fit line for the data points.
- Using the straight line, calculate an experimental value for the acceleration due to gravity g .

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Begin your response to QUESTION 3 on this page.

- (f) The students lift the left end of the surface so that the surface is inclined at an angle to the horizontal, and the experiment for $m_2 = 0.20 \text{ kg}$ is repeated. Would the acceleration of the system be greater than, less than, or equal to the acceleration of the system in the original experiment?

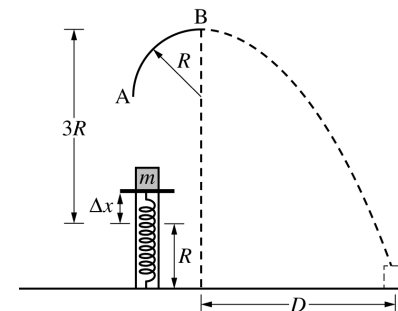
_____ Greater than _____ Less than _____ Equal to

Justify your claim.

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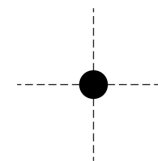
Begin your response to QUESTION 3 on this page.



Note: Figure not drawn to scale.

3. A block of mass m is placed on top of an ideal spring of spring constant k . The block is pushed against the spring, compressing the spring a distance Δx . The block is released from rest, leaves the spring at the position shown in the figure, travels upward, and enters a track with a constant radius of curvature R that has negligible friction. The block enters the track at point A, maintains contact with the track, and exits horizontally at point B, a distance $3R$ above the point the block was released. The block then falls to the ground and lands a horizontal distance D from the end of the track. Express all algebraic answers in terms of m , k , Δx , R , and physical constants, as appropriate. The size of the block is much smaller than the radius of curvature of the track.

- (a) On the dot below, which represents the block, draw and label the forces (not components) that act on the block while still in contact with the track at point B. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



Justify your choice of vectors.

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(b)

- i. Derive an expression for the speed v of the block at point B.
- ii. Derive an expression for the magnitude of the net force F on the block at point B.

(c) Derive an expression for the minimum value of $\Delta x_{\min}$ required in order for the block to maintain contact with the track through point B.

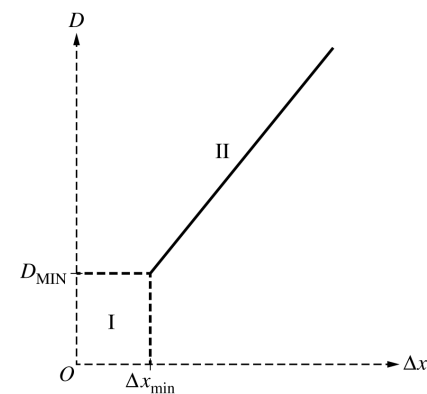
The procedure is repeated several times with the distance $\Delta x > \Delta x_{\min}$.

- (d) Calculate the distance D that the block travels.

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(e) The graph below shows the best-fit line drawn by the students through their data of D as a function of Δx .



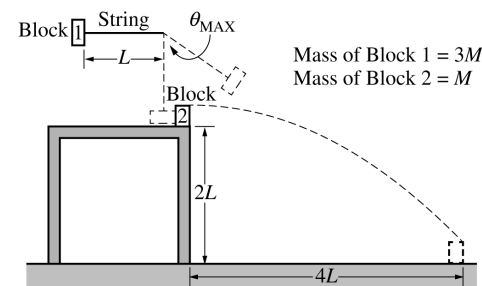
- i. Explain why there are no data for section I of the graph.
- ii. Explain the reason for the shape and minimum value of section II on the graph.

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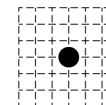
STOP

END OF EXAM



Note: Figure not drawn to scale.

2. A pendulum of length L consists of block 1 of mass $3M$ attached to the end of a string. Block 1 is released from rest with the string horizontal, as shown above. At the bottom of its swing, block 1 collides with block 2 of mass M , which is initially at rest at the edge of a table of height $2L$. Block 1 never touches the table. As a result of the collision, block 2 is launched horizontally from the table, landing on the floor a distance $4L$ from the base of the table. After the collision, block 1 continues forward and swings up. At its highest point, the string makes an angle θ_{MAX} to the vertical. Air resistance and friction are negligible. Express all algebraic answers in terms of M , L , and physical constants, as appropriate.
- (a) Determine the speed of block 1 at the bottom of its swing just before it makes contact with block 2.
- (b) On the dot below, which represents block 1, draw and label the forces (not components) that act on block 1 just before it makes contact with block 2. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. Forces with greater magnitude should be represented by longer vectors.



- (c) Derive an expression for the tension F_T in the string when the string is vertical just before block 1 makes contact with block 2. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

For parts (d)–(g), the value for the length of the pendulum is $L = 75$ cm.

- (d) Calculate the time between the instant block 2 leaves the table and the instant it first contacts the floor.
- (e) Calculate the speed of block 2 as it leaves the table.
- (f) Calculate the speed of block 1 just after it collides with block 2.
- (g) Calculate the angle θ_{MAX} that the string makes with the vertical, as shown in the original figure, when block 1 is at its highest point after the collision.