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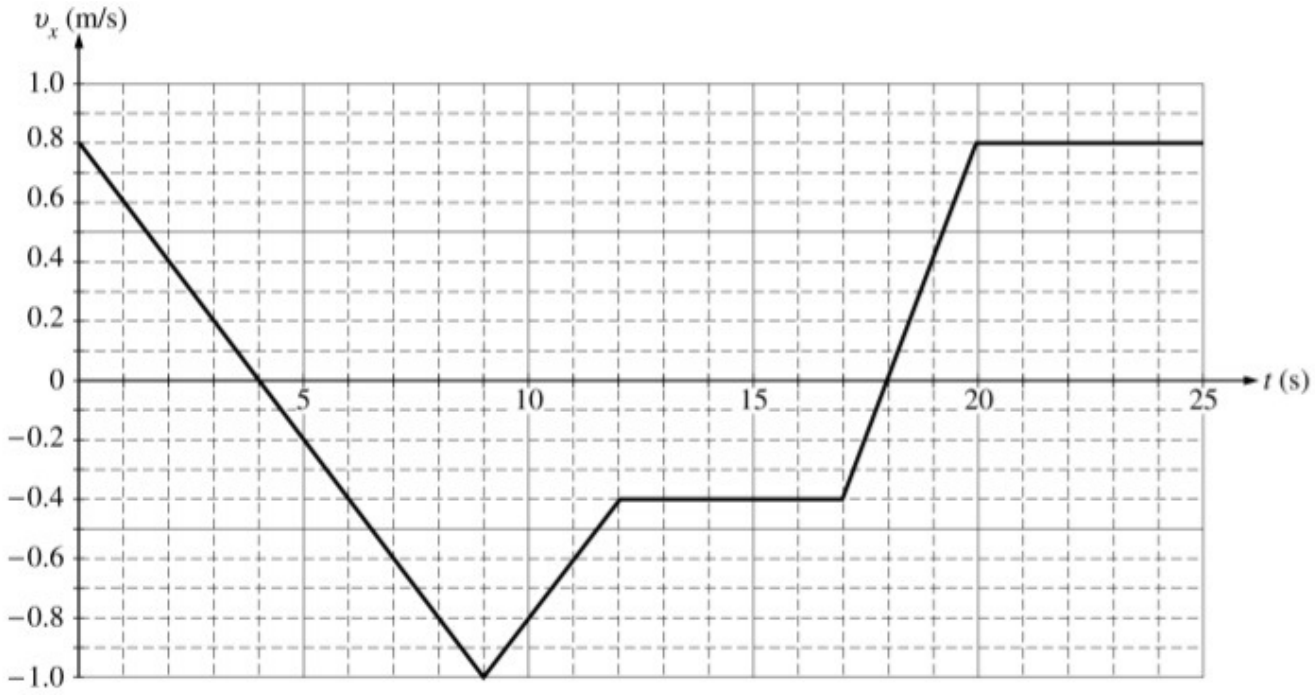
1. A 0.50 kg cart moves on a straight horizontal track. The graph of velocity v_x versus time t for the cart is given below.



a. Indicate every time t for which the cart is at rest.

b. Indicate every time interval for which the speed (magnitude of velocity) of the cart is increasing.

c. Determine the horizontal position x of the cart at $t = 9.0$ s if the cart is located at $x = 2.0$ m at $t = 0$.

d. On the axes below, sketch the acceleration a *versus* time t graph for the motion of the cart from $t = 0$ to $t = 25$ s.

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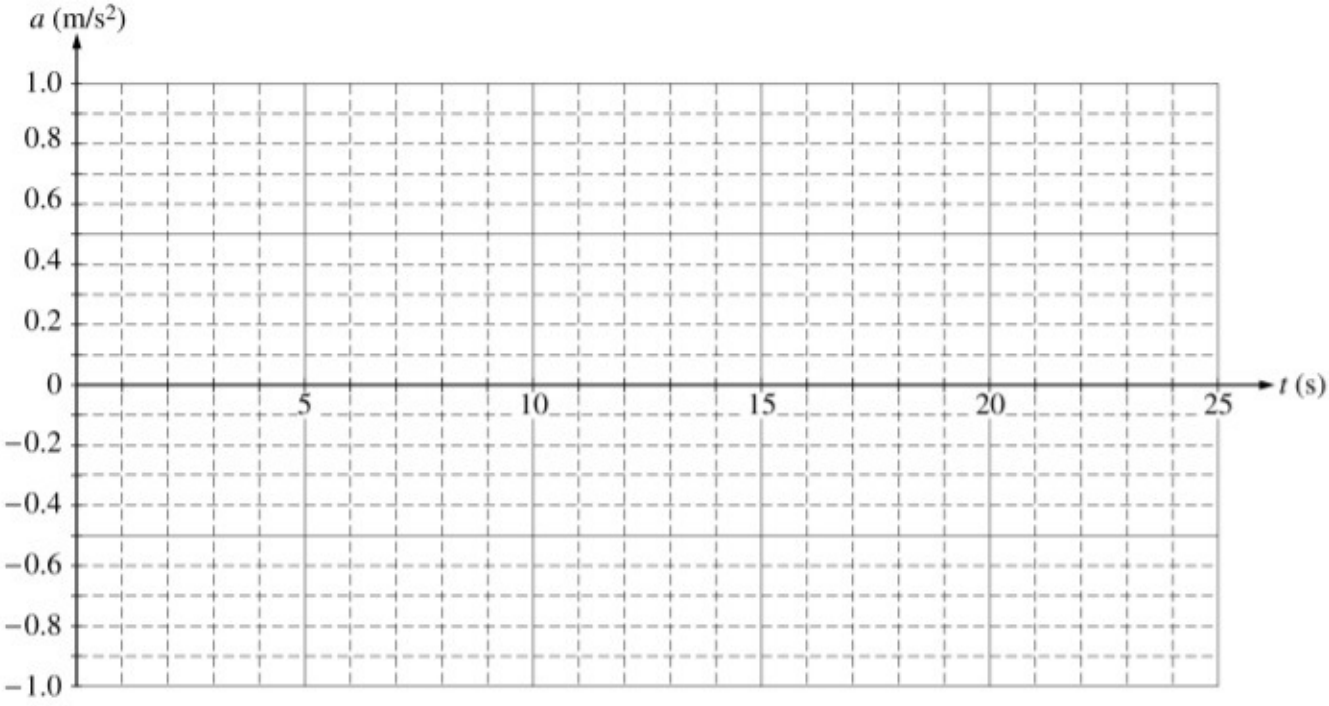

e. From $t = 25$ s until the cart reaches the end of the track, the cart continues with constant horizontal velocity. The cart leaves the end of the track and hits the floor, which is 0.40 m below the track. Neglecting air resistance, determine each of the following.

   i. The time from when the cart leaves the track until it first hits the floor

   ii. The horizontal distance from the end of the track to the point at which the cart first hits the floor

   iii. The kinetic energy of the cart immediately before it hits the floor

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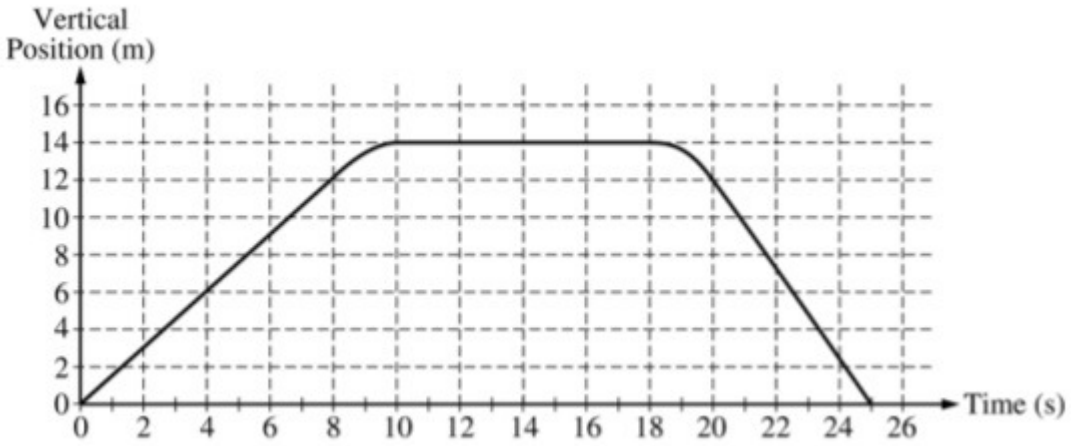
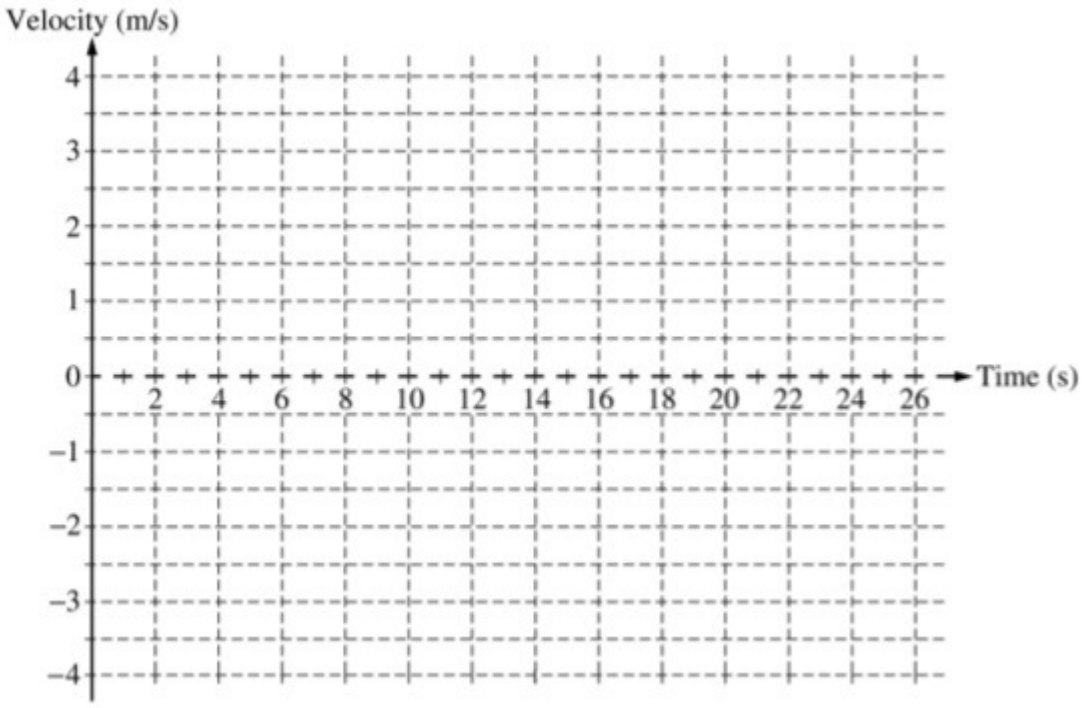
2.



The vertical position of an elevator as a function of time is shown above.

a. On the grid below, graph the velocity of the elevator as a function of time.



b. i. Calculate the average acceleration for the time period $t = 8$ s to $t = 10$ s.

ii. On the box below that represents the elevator, draw a vector to represent the direction of this average acceleration.



c. Suppose that there is a passenger of mass 70 kg in the elevator. Calculate the apparent weight of the passenger at time $t = 4$ s.

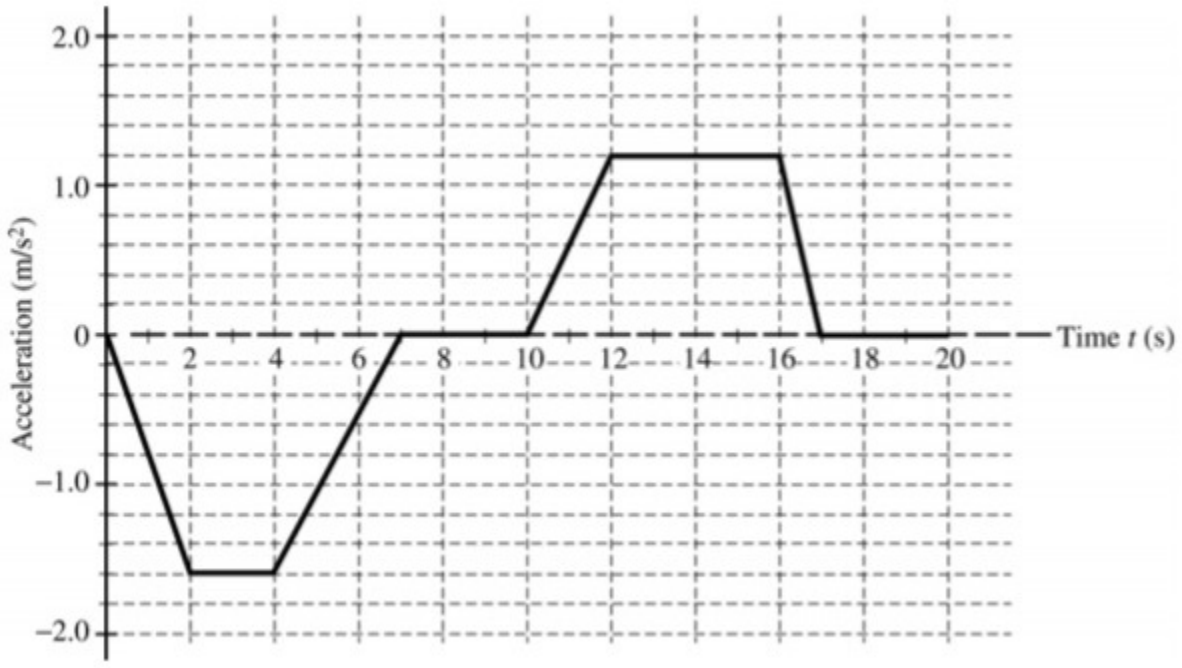
3. A student of mass m stands on a platform scale in an elevator in a tall building. The positive direction for all vector quantities is upward.

a. Draw a free-body diagram showing and labeling all the forces acting on the student, who is represented by the dot below.



b. Derive an expression for the reading on the scale in terms of the acceleration a of the elevator, the mass m of the student, and fundamental constants.

An inspector provides the student with the following graph showing the acceleration a of the elevator as a function of time t.



c. i. During what time interval(s) is the force exerted by the platform scale on the student a maximum value?

ii. Calculate the magnitude of that maximum force for a 45 kg student.

d. During what time interval(s) is the speed of the elevator constant?

1frq

4. **PHYSICS 1**

Section II

Time - 1 hour and 30 minutes

5 Questions

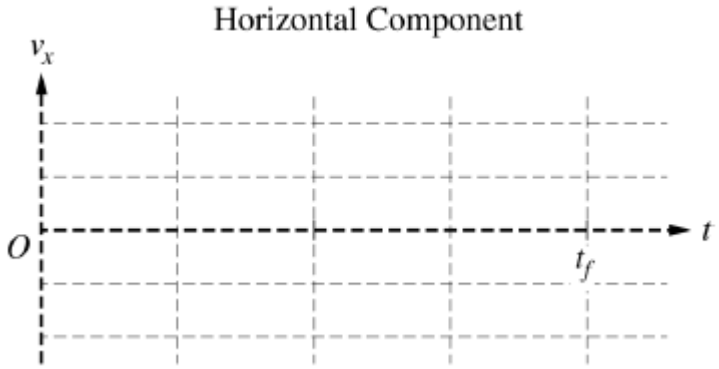
Directions: This question is a short free-response question. Show your work for each part of the question.



1. (7 points, suggested time 13 minutes)

A toy consists of two identical solid spheres connected by a string with negligible mass. The toy is thrown at an angle above the horizontal (not straight up) such that the string remains taut and both spheres are revolving counterclockwise in a vertical plane around the center of the string, as shown above.

(a) Sketch graphs of the horizontal and vertical components of the velocity of the center of the string as a function of time, from the instant the spheres are released at time $t = 0$ until the instant the system returns to its initial height at time t_f. Take the positive direction to be toward the right for the horizontal component and the positive direction to be upward for the vertical component.



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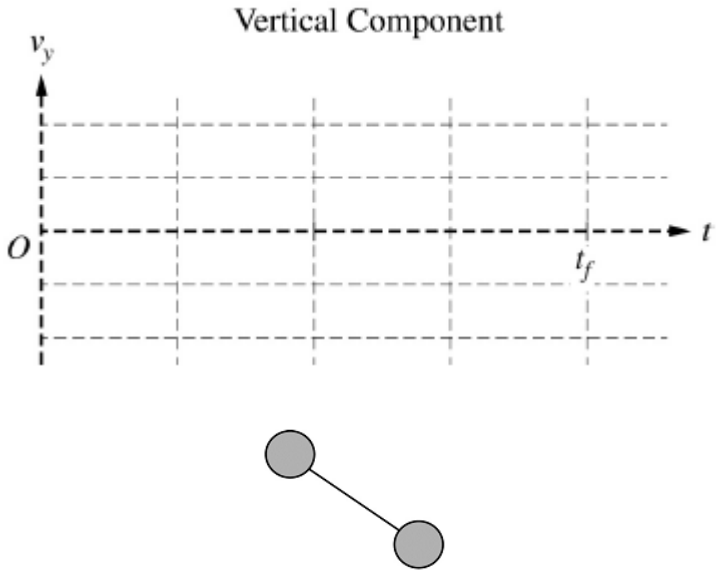
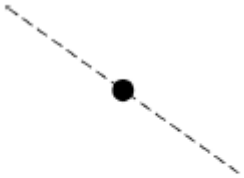


(b) The figure above shows the toy at the instant the center of the string reaches the top of its trajectory. This is a side view: the sphere on the left is higher than the sphere on the right.

i. On the dot below, which represents the left sphere only, draw and label the forces (not components) exerted on the left sphere at this instant. Represent each force by a distinct arrow starting on, and pointing away from, the dot. The dashed line is drawn at the same angle as the string.



Left Sphere

ii. On the dot below, which represents the whole toy (the spheres-string system), draw and label the forces (not components) that act on the system at this instant. Represent each force by a distinct arrow starting on, and pointing away from, the dot. The dashed line is drawn at the same angle as the string.

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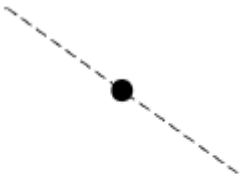

Whole Toy

iii. When the toy was released, the center of the string was moving with an initial speed of $15\ \mathrm{m/s}$ at a 60° angle above the horizontal. Calculate the speed of the center of the string at the instant shown above, when the center of the string reaches the top of its trajectory.

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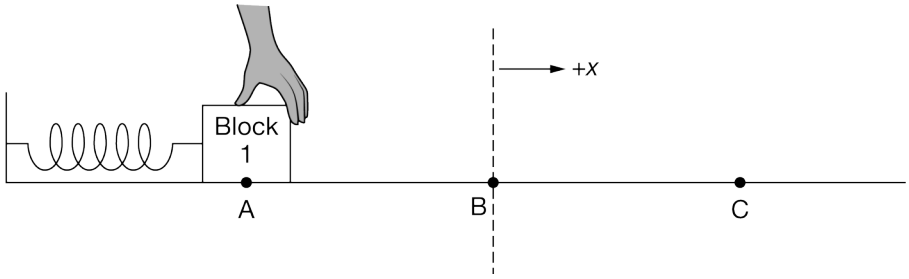
5. This question is a short free-response question. Show your work for each part of the question.



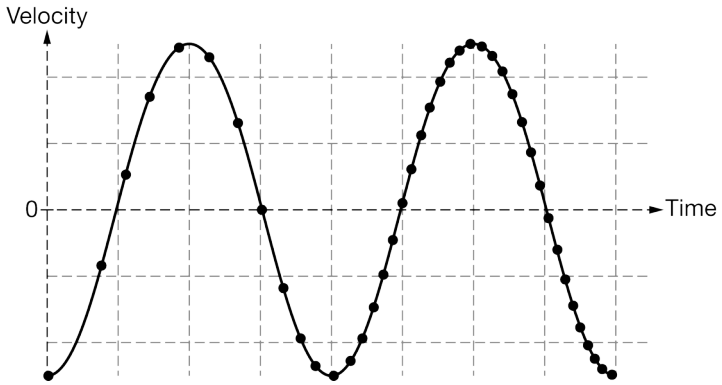
(7 points, suggested time 13 minutes)

Block 1 is at rest on a horizontal surface and is connected to a wall by an ideal spring. Friction between block 1 and the surface is negligible. Block 1 is held at rest at point A, to the left of point B which is the equilibrium position of the spring-block system, as shown in the figure. Block 1 is then released and allowed to oscillate. Some time later, block 1 is momentarily at rest at point C. Consider the positive horizontal direction to be toward the right.

(a) The dot below represents block 1 just after it is released. On the dot, draw an arrow indicating the direction of the net force exerted on the block just after it is released. The arrow should start on, and point away from, the dot.



Net Force on Block 1

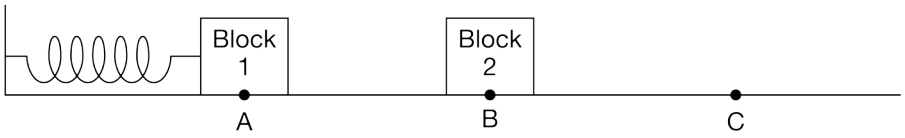


After the block has been oscillating on the table, a motion detector is turned on and the velocity of block 1 as a function of time is measured and plotted in a graph. The students correctly draw a best-fit curve that represents the

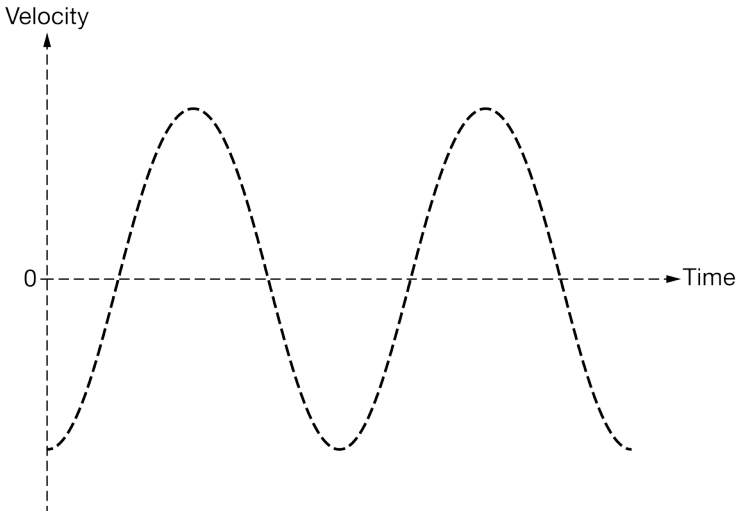
collected data, as shown above.

(b) A student looking at the graph of velocity as a function of time makes the following claim.
"*The motion sensor was turned on when the block was at point A and was moving to the left*."

Does the data in this graph support the student's claim about the location AND the direction of the block's motion when the motion sensor was turned on? For any incorrect claims, if any, state the correct position and/or direction of motion. Justify your answer.



(c) Block 1 is stopped, and again block 1 is held at rest at point A. A second identical block, block 2, is placed at point B. Block 1 is released from rest, and then collides with and sticks to Block 2. After the collision, the two blocks oscillate together on the spring. On the graph below, sketch a curve to indicate the new velocity as a function of time of the two blocks after the collision. For reference, the dashed curve represents the students' best-fit curve of the velocity as a function of time described in part (b).



Note: Do any scratch (practice) work on the graph below. Sketches made below will NOT be graded.

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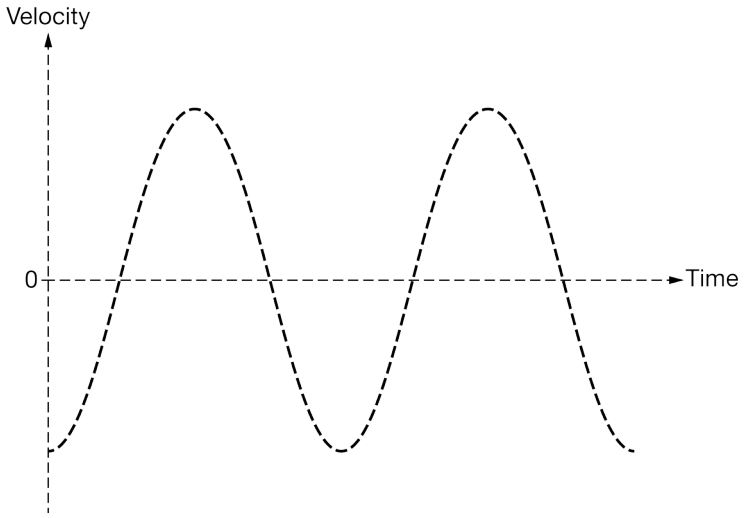

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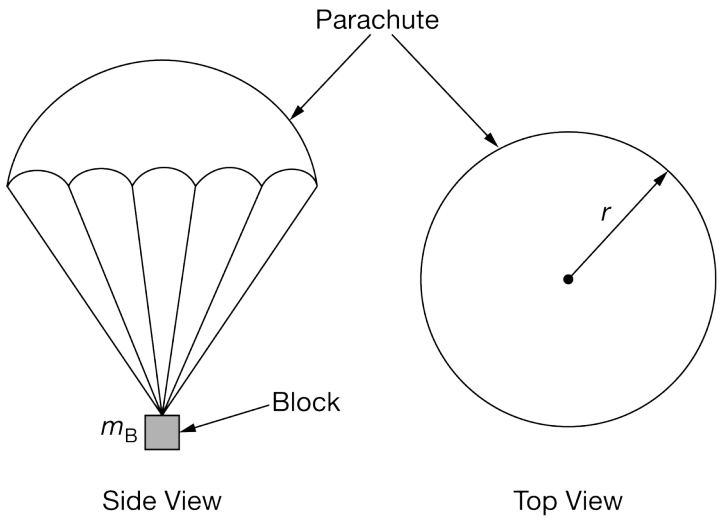
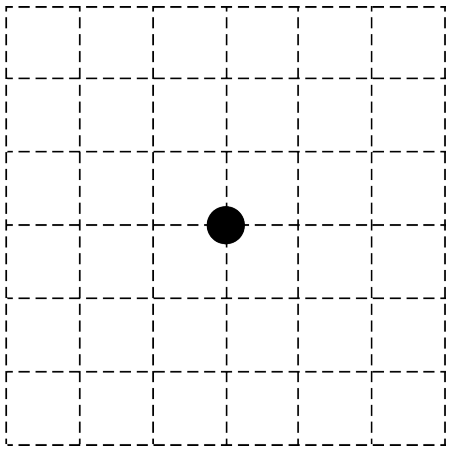
6. This question is a long free-response question. Show your work for each part of the question.



(12 points, suggested time 25 minutes)

A block of mass m_B can be attached to a parachute of negligible mass and radius r, as shown in the two views above. When falling, the parachute experiences an upward force of air resistance. This force increases as the speed of the parachute increases. The falling block and parachute speed up at first but eventually reach a constant speed called terminal speed.

(a) The dot below represents the block-parachute system when it has reached its terminal speed and is falling at this constant speed. On the dot, draw and label the forces (not components) acting on the system. Represent each force by a distinct arrow starting on, and pointing away from, the dot.
Note: Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.



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A group of students has a collection of parachutes of different radii. They are curious about how the terminal speed depends on the radius of the parachute and find the following equation on the Internet.

$$F_{\text{air}} = Crv^2,$$

where F_{air} is the force exerted by air, r is the parachute's radius, v is the parachute's speed, and C is a constant that has appropriate units.

(b) Determine the units for C.

The units for C are _____ .

(c)

i. Based on the above equation for F_{air}, derive an equation for the system's constant terminal speed v_t in terms of r, C, physical constants, and other relevant quantities that can be measured with equipment usually found in a school physics laboratory, as appropriate. Assume the mass of the parachute is negligible and that the only nonnegligible forces acting on a block-parachute system are the block's weight $m_B g$ and the force of air resistance F_{air}.

ii. Indicate below what quantities could be measured and then graphed to determine whether the equation derived in part (c)(i) correctly relates the parachute's radius and the terminal speed of the block-parachute system.

Vertical axis: _____ Horizontal axis: _____

iii. On the axes below, sketch a graph showing the relationship between the two quantities indicated in part (c)(ii) and based on the equation derived in part (c)(i).



(d) Design an experimental procedure the students could use to collect the data needed to test whether or not the relationship between the parachute's radius and the terminal speed is described by the graph drawn in part (c)(iii). Assume equipment usually found in a school physics laboratory is available.

In the table below, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity, and also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement

Describe the overall procedure to be used, referring to the table. Provide enough detail so another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table. Include a simple diagram of the setup. As part of your description, be sure to explain how the students would know that they are measuring the constant terminal speed.

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Diagram of Experimental Setup Description of Experimental Procedure

(e) In another experiment, the students collect the following data showing the height of a block above the floor at different times, where the block is dropped from rest at time $t = 0$ with the attached parachute fully open.

Time (s)	Height of Block Above Floor (m)
0.00	1.35
0.10	1.30
0.20	1.18
0.30	1.01
0.40	0.82
0.50	0.63
0.60	0.43
0.70	0.23
0.80	0.03

Use the data shown above to determine the terminal speed of the block.

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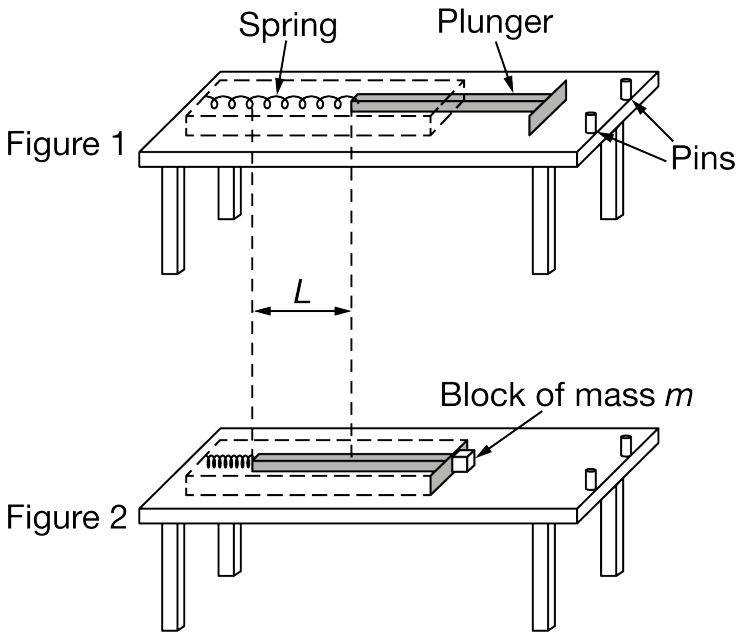
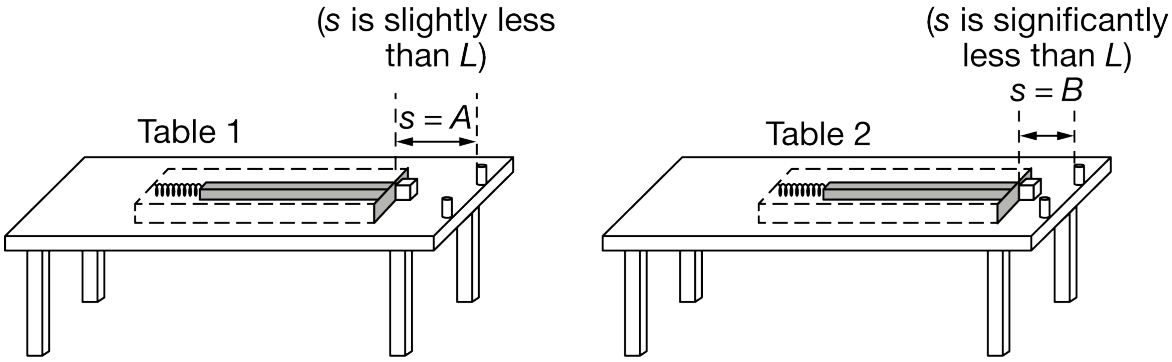
7. This question is a long free-response question. Show your work for each part of the question. (15 points, suggested time 25 minutes)



A spring-loaded launcher can be securely attached to a tabletop. When the spring is at its uncompressed length, the plunger is in the position shown above in Figure 1. A small wood block can be pressed against the end of the plunger, compressing the spring a distance L, as shown in Figure 2. When the block is released, the plunger pushes the block along the tabletop. Two pins are attached to the edge of the table to prevent the plunger from extending beyond the table. When the plunger hits the pins, the block then leaves the table. There is nonnegligible friction between the block and the tabletop.



The launcher can be moved closer to or farther from the edge of the tabletop. Students set up tables 1 and 2, as shown above, with tabletops that are made of the same material. On table 1, the launcher is positioned so that the distance $s = A$ between the launcher and the edge of the tabletop is slightly less than L. On table 2, the launcher is positioned so that the distance $s = B$ between the launcher and the edge of the tabletop is significantly less than L. On both tables, the block is released from rest and loses contact with the plunger at the moment the plunger reaches the pins. Tables 1 and 2 are the same height.

k is the spring constant of the spring.
m is the mass of the block.
L is the distance the spring is compressed.
μ (mu) is the coefficient of kinetic friction between the block and the tabletop.
s is the distance between the launcher and the edge of the tabletop.

Assume the spring is ideal, the plunger has negligible mass, the block loses contact with the plunger immediately after it reaches the end of the table, and there is non-negligible friction between the tabletops and the blocks.

(a) Without manipulating equations, explain why the block launched from table 1 could land farther from the table than the block launched from table 2 does.

(b) Does the block launched from table 1 spend more, less, or the same amount of time in the air than the block launched from table 2 does? Explain your reasoning.

(c) Consider the Earth-block system. Determine the change, if any, in the total mechanical energy of the system from the instant the block leaves the table to the instant immediately before it reaches the ground.

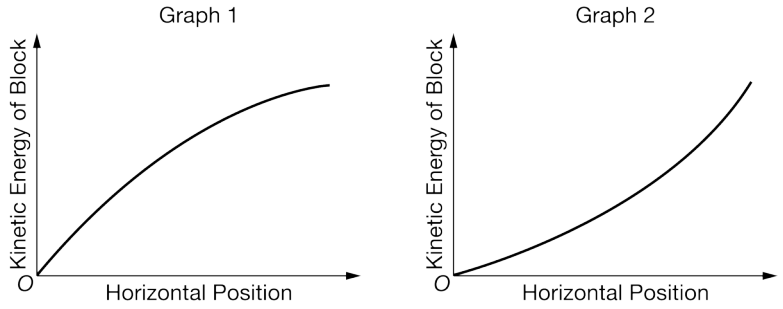
The students correctly derive an equation for the horizontal distance D from the edge of the tabletop that the block lands, in terms of s (the distance between the launcher and the edge of the tabletop):

$$D = t\sqrt{\frac{k}{m}(2Ls - s^2) - 2\mu g s},$$

where t is the time interval between the instant the block leaves the table and the instant immediately before it reaches the ground.

(d) Does this equation for D support your argument from part (a) that the block launched from table 1 could land farther from the table than the block launched from table 2? Briefly explain why or why not.

(e) The students now use the same setups to launch blocks that are identical to each other but more massive than the original blocks. The blocks are made of the same material as the original blocks. Does this change in the mass of the blocks make it more likely or less likely that the block launched from table 1 goes farther than the block launched from table 2 does? Briefly explain your reasoning.



(f) Two students each try to sketch a graph of the kinetic energy of the block as a function of its position from launch to the time the block reaches the edge of the table. Their graphs are shown above. Which graph best represents the kinetic energy of the block? Justify your selection.

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8. This question is a long free-response question. Show your work for each part of the question. (15 points, suggested time 25 minutes)

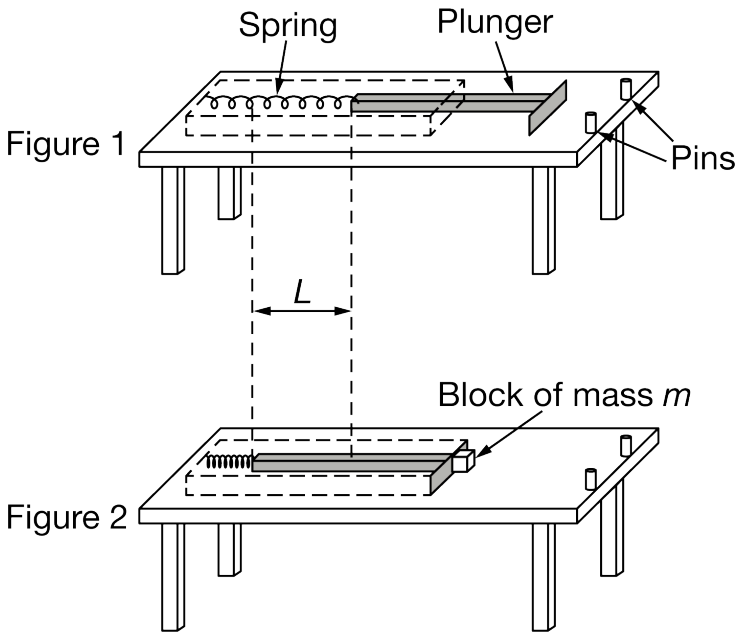
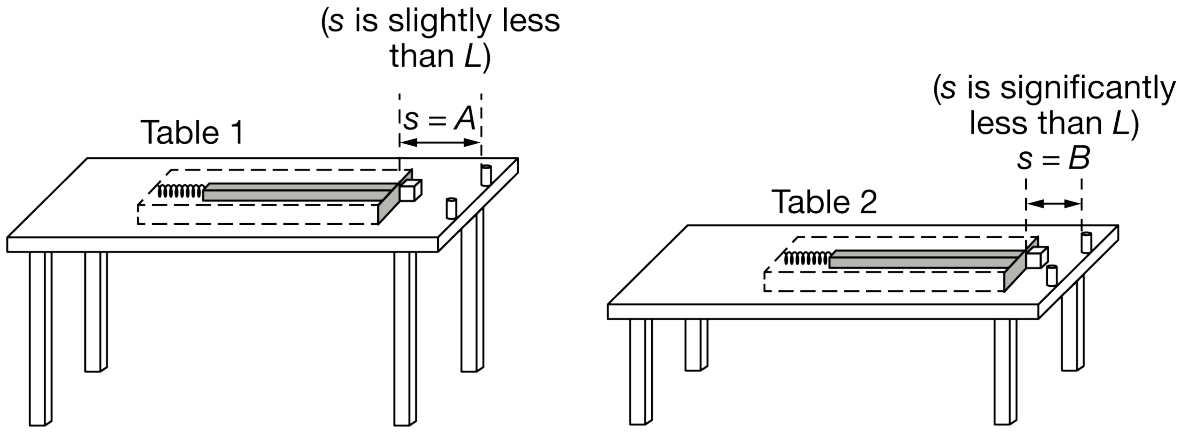


Figure 1

Figure 2

A spring-loaded launcher can be securely attached to a tabletop. When the spring is at its uncompressed length, the plunger is in the position shown above in Figure 1. A small wood block can be pressed against the end of the plunger, compressing the spring a distance L as shown in Figure 2. When the block is released, the plunger pushes the block along the tabletop. Two pins are attached to the edge of the table to prevent the plunger from extending beyond the table. When the plunger hits the pins, the block then leaves the table. There is nonnegligible friction between the block and the tabletop.



Taller Table

Shorter Table

The launcher can be moved closer to or farther from the edge of the tabletop. Students set up tables 1 and 2, as shown above, with tabletops that are made of the same material. On table 1, which is taller than table 2, the

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launcher is positioned so that the distance $s = A$ between the launcher and the edge of the tabletop is slightly less than L. On table 2, the launcher is positioned so that the distance $s = B$ between the launcher and the edge of the tabletop is significantly less than L. On both tables, the block is released from rest and loses contact with the plunger at the moment the plunger reaches the pins.

k is the spring constant of the spring.
m is the mass of the block.
L is the distance the spring is compressed.
μ (mu) is the coefficient of kinetic friction between the block and the tabletop.
s is the distance between the launcher and the edge of the tabletop.

Assume the spring is ideal, the plunger has negligible mass, the block loses contact with the plunger immediately after it reaches the end of the table, and there is non-negligible friction between the tabletops and the blocks.

(a) Without manipulating equations, explain why the block launched from table 2 could have a greater speed when it leaves the table than the block launched from table 1 does.

(b) Does the block launched from table 2 spend more, less, or the same amount of time in the air than the block launched from table 1 does? Explain your reasoning.

(c) Consider the system consisting of only the block. Determine the change, if any, in the total mechanical energy of the system from the instant the block leaves the table to the instant immediately before it reaches the ground.

The students correctly derive an equation for the speed v of the block when it is at the edge of the tabletop, in terms of s (the distance between the launcher and the edge of the tabletop):

$v = \sqrt{\frac{k}{m}(2Ls - s^2) - 2\mu g s}$.

(d) Does this equation for v support your argument from part (a) that the block launched from table 2 could have a larger speed when it leaves the table than the block on table 1 does? Briefly explain why or why not.

(e) The students now repeat the scenario with identical setups except that the coefficient of kinetic friction between the blocks and the table is larger. Does this change in the coefficient of friction make it more likely or less likely that the block launched from table 1 has a greater speed when it leaves the table than the block on table 2 does? Briefly explain your reasoning.

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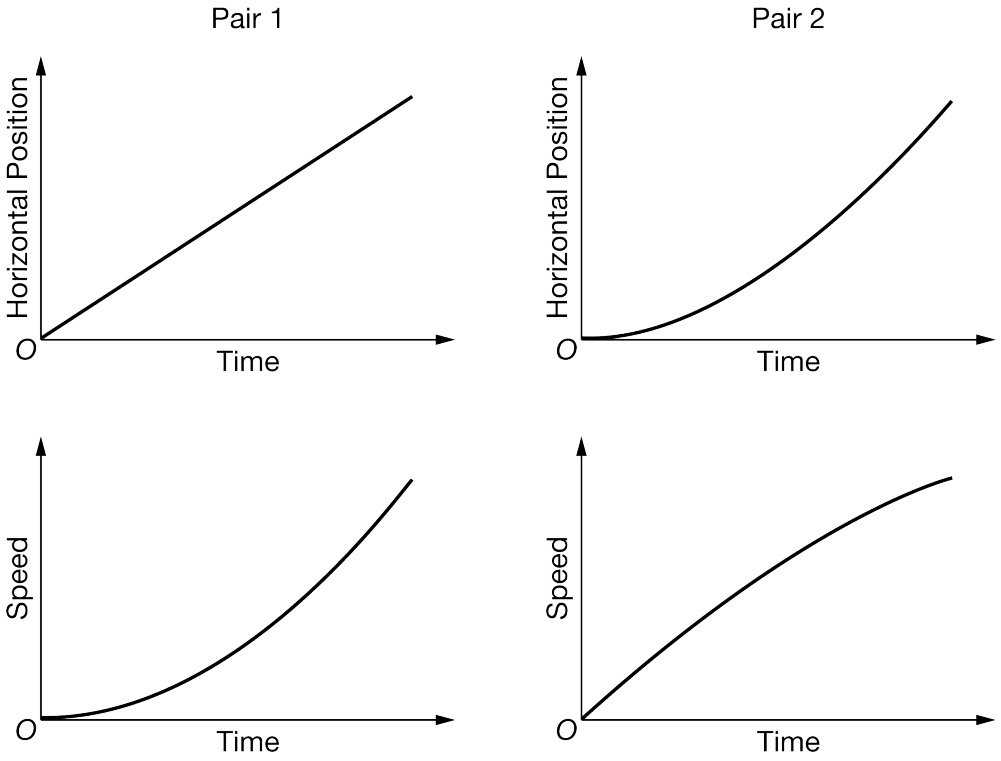

(f) Two students each try to sketch a graph of the horizontal position and speed of the block as a function of time while the block is being pushed by the plunger. Their graphs are shown above. In which pair of graphs are the two graphs consistent with each other? Justify your selection.

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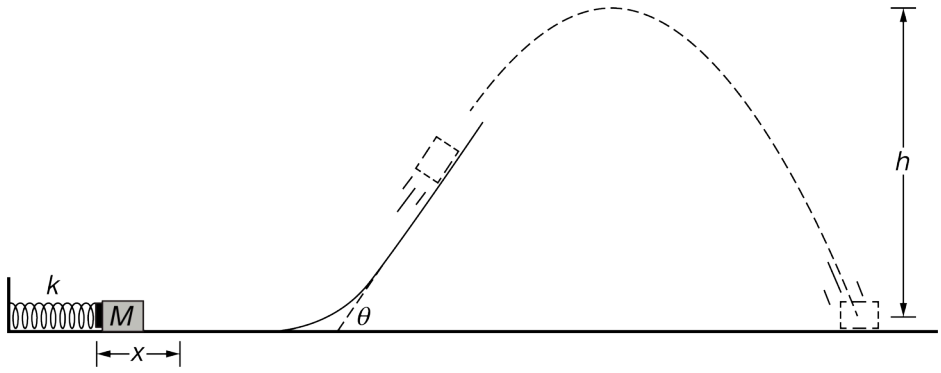
9. This question is a long free-response question. Show your work for each part of the question. (15 points, suggested time 25 minutes)



A box is pressed against a horizontal spring, compressing the spring from its relaxed length. The box is then released, and the spring launches the box horizontally along a track that ends in a ramp, as shown above. The box has enough speed to leave the ramp, and the box reaches a maximum vertical height above the floor. Assume there is negligible friction between the box and the track and air resistance is negligible.

k is the spring constant of the spring.
x is the distance the spring is compressed.
M is the mass of the box.
θ (theta) is the angle of the ramp from the horizontal.
h is the maximum height reached by the box.

The scenario is repeated using a stiffer spring with a spring constant that has a greater value for k than that of the original spring. The stiffer spring is compressed the same distance x, and the same box is used.

(a) Indicate how using a stiffer spring would affect the maximum height reached by the box, and explain why without mathematically deriving a relation for h.

(b) Students derive an equation for the maximum height, $h = \frac{(\sin^2\theta)kx^2}{2Mg}$, which may or may not be correct. Is this equation consistent with your claim in part (a)? Explain why or why not.

Two students are discussing the motion of the box when it is at its maximum height and make the following statements:

Student 1: The speed of the block at its maximum height is zero because the kinetic energy is a minimum at the top of the trajectory.

Student 2: Only the vertical component of the velocity is zero at the maximum height, because the vertical component of the acceleration is zero at the top of the trajectory.

(c) Which underlined phrase or phrases in student 1's statement are ***correct***, if either? If neither phrase is ***correct***, write "none."

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(d) Which underlined phrase or phrases in student 1's statement are ***incorrect***, if either? If neither phrase is ***incorrect***, write "none."

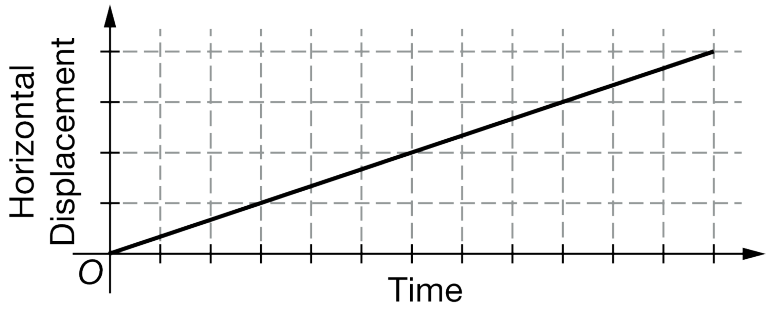
(e) Which underlined phrase or phrases in student 2's statement are ***correct***, if either? If neither phrase is ***correct***, write "none."

(f) Which underlined phrase or phrases in student 2's statement are ***incorrect***, if either? If neither phrase is ***incorrect***, write "none."

(g) Consider the system consisting of the box and the spring, but not Earth. How does the energy of the system when the spring is fully compressed compare to the energy of the system at the moment immediately before the box hits the ground? Justify your answer.

(h) If the friction between the track and the box were not negligible, state one way in which the setup could be changed such that the maximum height of the box was the same as in the original setup.

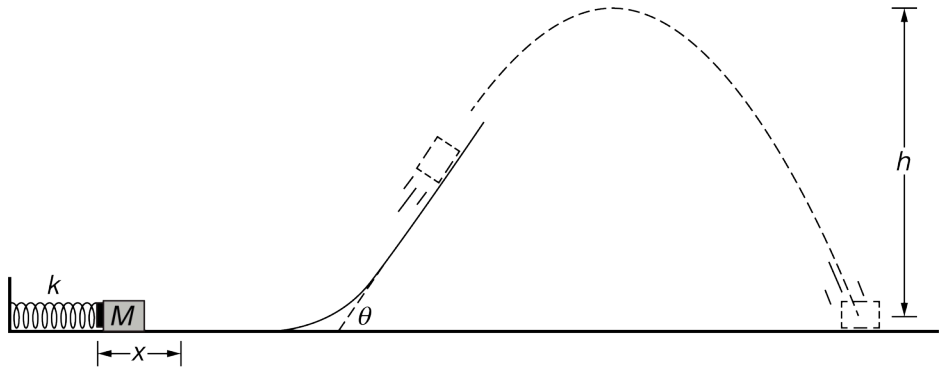
The graph below shows the horizontal component of the displacement of the box as a function of time. The graph represents the entire time the box is in the air after the box is launched from the ramp at an angle θ to the horizontal.



(i) How would the slope of the graph be different, if at all, if the ramp angle were larger than θ, but less than 90 degrees, and the height of the end of the ramp were the same? Justify your response.

1frq

10. This question is a long free-response question. Show your work for each part of the question. (15 points, suggested time 25 minutes)



A box is pressed against a horizontal spring, compressing the spring from its relaxed length. The box is then released and the spring launches the box horizontally along a track that ends in a ramp, as shown above. The box has enough speed to leave the ramp, and the box reaches a maximum vertical height above the floor. Assume there is negligible friction between the box and the track and air resistance is negligible.

k is the spring constant of the spring.
x is the distance the spring is compressed.
M is the mass of the box.
θ (theta) is the angle of the ramp from the horizontal.
h is the maximum height reached by the box.

The scenario is repeated with the box compressing the spring a distance that is larger than the original distance x.

(a) Indicate how h in this second scenario compares to h in the original scenario, and explain why without mathematically deriving a relation for h.

(b) Students derive an equation for the maximum height h in the original scenario, $h = \frac{(\sin^2\theta)kx^2}{2Mg}$, which may or may not be correct. Is this equation consistent with your claim in part (a)? Explain why or why not.

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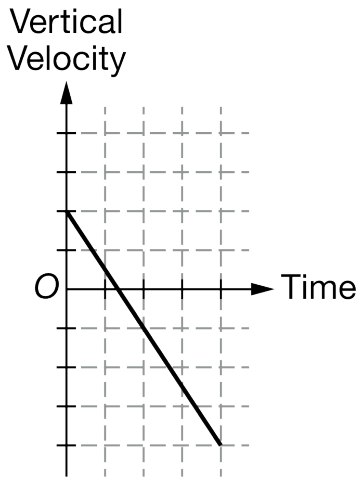

Two students, student 1 and student 2, are discussing the graph shown above, which shows the vertical component of the velocity of the box from when it leaves the ramp to immediately before it hits the floor. The students make the following statements.

Student 1: This graph shows that the vertical acceleration of the box is constant, and that the box's speed decreases for the entire time shown.

Student 2: The area between the graph and the time axis is the box's vertical displacement, but the graph is incorrect because the positive displacement should be equal to the negative displacement.

(c) Which underlined phrase or phrases in student 1's statement are ***correct***, if either? If neither phrase is ***correct***, write "none."

(d) Which underlined phrase or phrases in student 1's statement are ***incorrect***, if either? If neither phrase is ***incorrect***, write "none."

(e) Which underlined phrase or phrases in student 2's statement are ***correct***, if either? If neither phrase is ***correct***, write "none."

(f) Which underlined phrase or phrases in student 2's statement are ***incorrect***, if either? If neither phrase is ***incorrect***, write "none."

(g) Consider the system consisting of only the box, but not the spring or Earth. How does the energy of the system when the spring is fully compressed compare to the energy of the system at the moment immediately before the box hits the ground? Justify your answer.

The angle of the ramp is changed such that it is larger than θ but less than 90 degrees, while the height of the end of the ramp remains the same.

(h) How would the maximum height of the box compare to the original scenario in which the ramp angle was equal to θ ? Justify your answer.

(i) Would the slope of the graph of vertical velocity as a function of time shown above part (c) be different for this scenario in which the box is launched from the larger angle? Justify your response.

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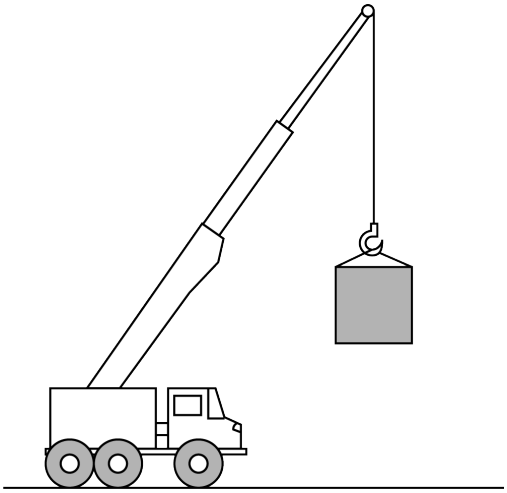
11. This question is a long free-response question. Show your work for each part of the question.

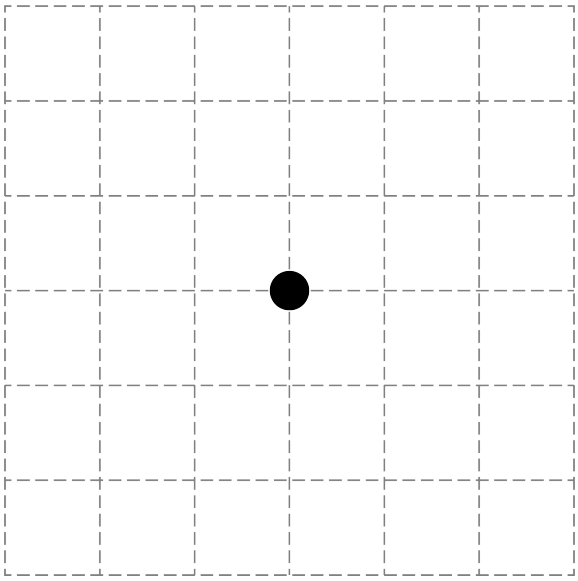


(12 points, suggested time 25 minutes)

A crane and box are both initially at rest. At time $t = 0$ s, the crane begins to drive forward at a constant speed of $0.5 \frac{\text{m}}{\text{s}}$, while also lifting the box with an upward acceleration of $1 \frac{\text{m}}{\text{s}^2}$. The box does not swing while being lifted by the crane.

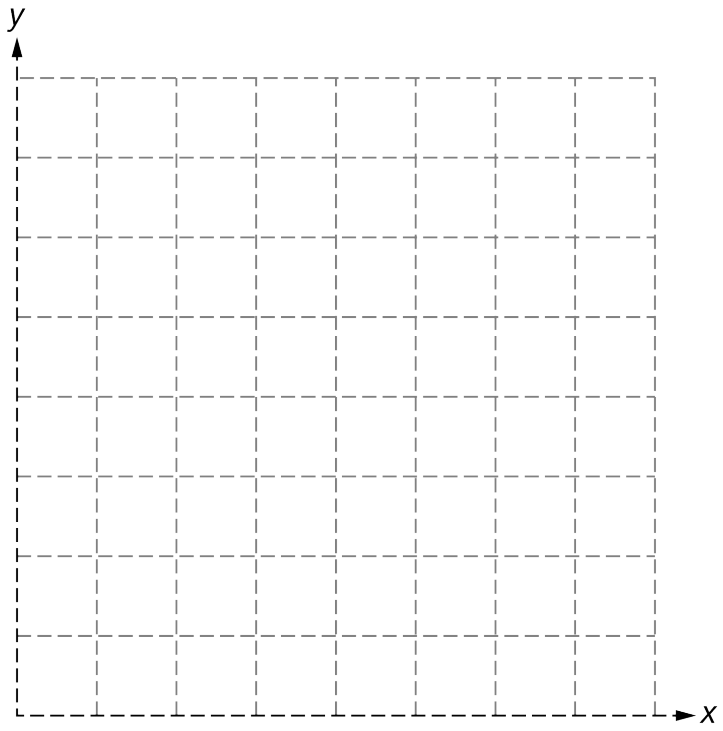
(a) On the dot below, which represents the box, draw and label the forces (not components) that are exerted on the box during the scenario described above. Represent each force by a distinct arrow starting on, and pointing away from, the dot.

Note: Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.



1frq

(b) On the grid below, sketch the shape of the path taken by the box as it is lifted by the crane as viewed by a stationary observer.



Justify the shape of the path you drew above.

(c) Assume that, at $t = 0$ s, the horizontal position of the box is $x = 0$ and it has a vertical position of $y = 0$. Derive an equation that describes the vertical position y of the box as a function of the horizontal position x of the box.

(d) Does your equation from part (c) agree with your sketch in part (b)? Justify your response.

At time $t = t_1$, the crane begins to accelerate forward, reaching a new constant velocity at time $t = t_2$. The box accelerates upward during the entire time interval $t_1 < t < t_2$.

(e) The dot below represents the box during the time interval $t_1 < t < t_2$. On the dot, draw an arrow indicating the direction of the net force exerted on the block during this interval. The arrow should start on, and point away from, the dot.

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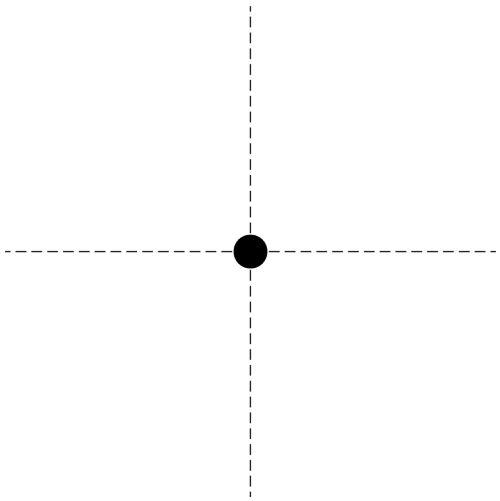

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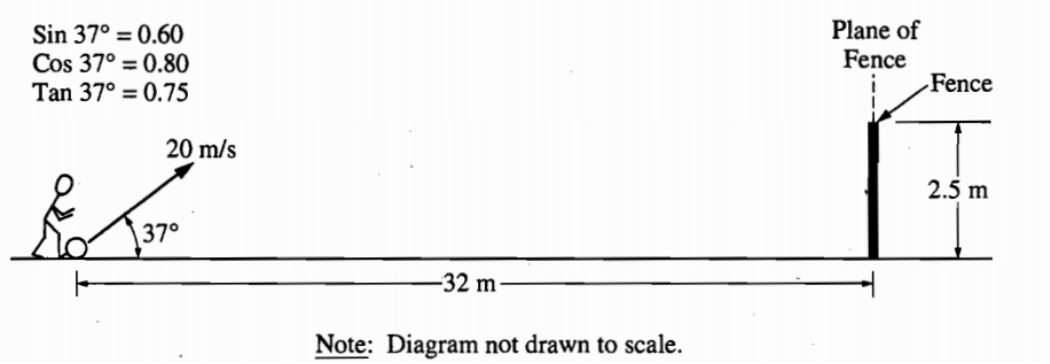
12.



A ball of mass 0.5 kilogram, initially at rest, is kicked directly toward a fence from a point 32 meters away, as shown above. The velocity of the ball as it leaves the kicker's foot is 20 meters per second at a angle of 37° above the horizontal. The top of the fence is 2.5 meters high. The kicker's foot is in contact with the ball for 0.05 second. The ball hits nothing while in flight and air resistance is negligible.

(a) Determine the magnitude of the average net force exerted on the ball during the kick.

(b) Determine the time it takes for the ball to reach the plane of the fence.

(c) Will the ball hit the fence? If so, how far below the top of the fence will it hit? If not, how far above the top of the fence will it pass?

(d) On the axes below, sketch the horizontal and vertical components of the velocity of the ball as functions of time until the ball reaches the plane of the fence.

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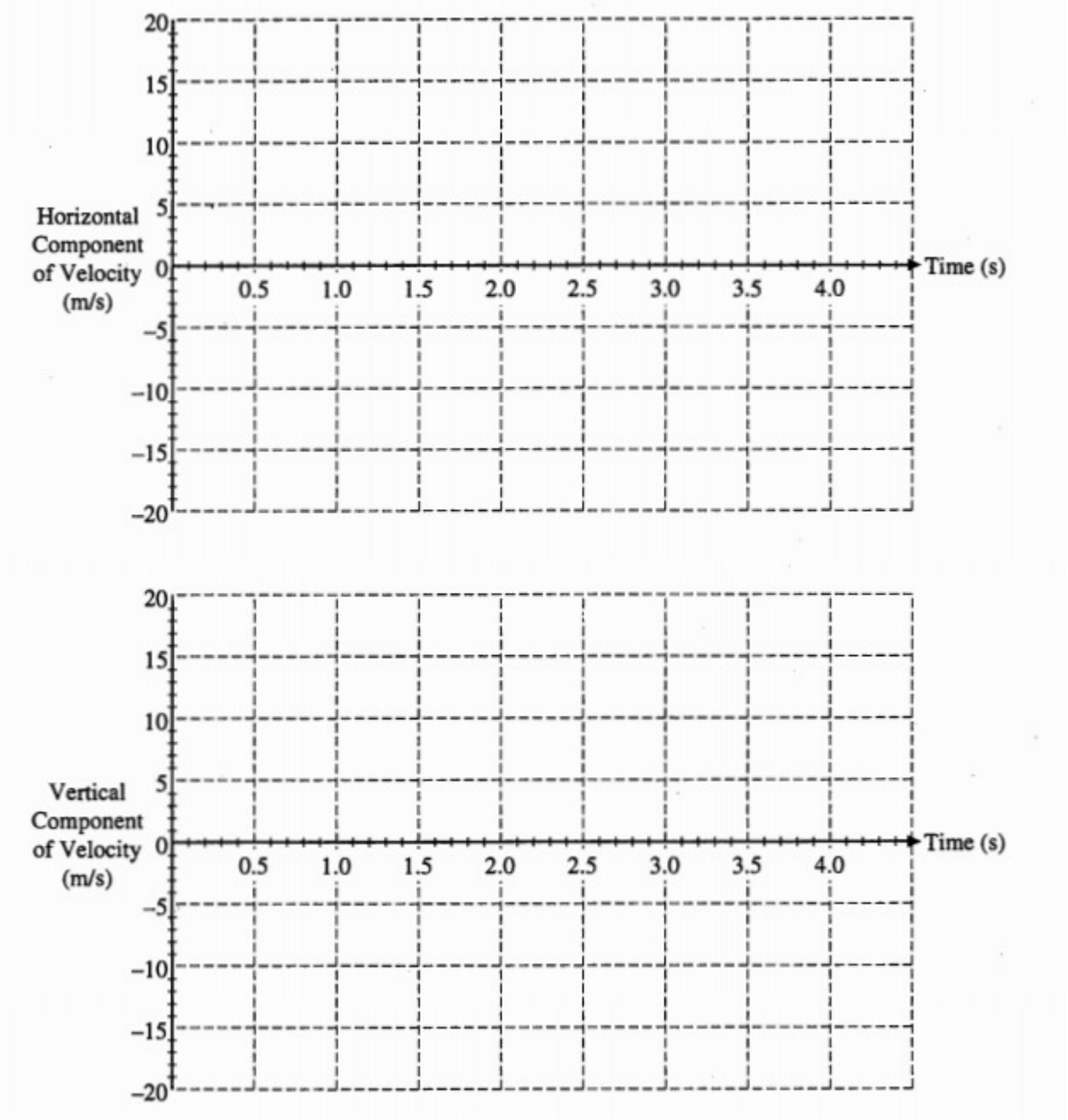
Horizontal Component of Velocity (m/s)
20
15
10
5
0
−5
−10
−15
−20
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time (s)
Vertical Component of Velocity (m/s)
20
15
10
5
0
−5
−10
−15
−20
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time (s)

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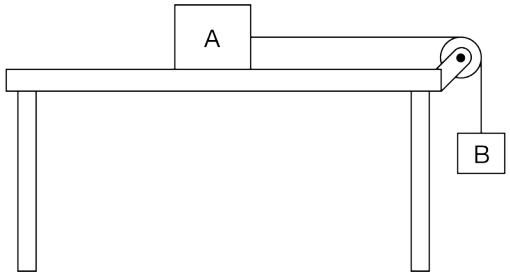
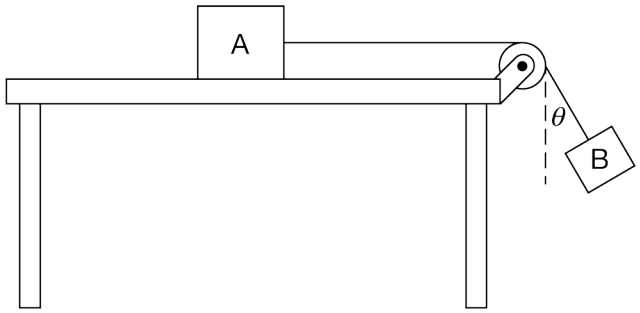
13. This question is a short free-response question. Show your work for each part of the question. (10 points, suggested time 15 minutes)



Block A with mass m_A rests on a horizontal tabletop, while block B with mass m_B hangs from a string of negligible mass that passes over a pulley and attaches to block A, as shown above. The pulley has negligible mass and rotates with negligible friction about its axle. The blocks are at rest due to friction between block A and the tabletop. The tension in the string while the blocks are at rest has magnitude T_1, and the coefficient of static friction between block A and the tabletop is μ (mu).

(a) What is the magnitude of the frictional force acting on block A? Justify your answer.



Note: Figure not drawn to scale.

Block B is displaced from the vertical such that the string makes a small angle θ with the vertical, as shown above. The string still has nonzero tension when block B is then released from rest.

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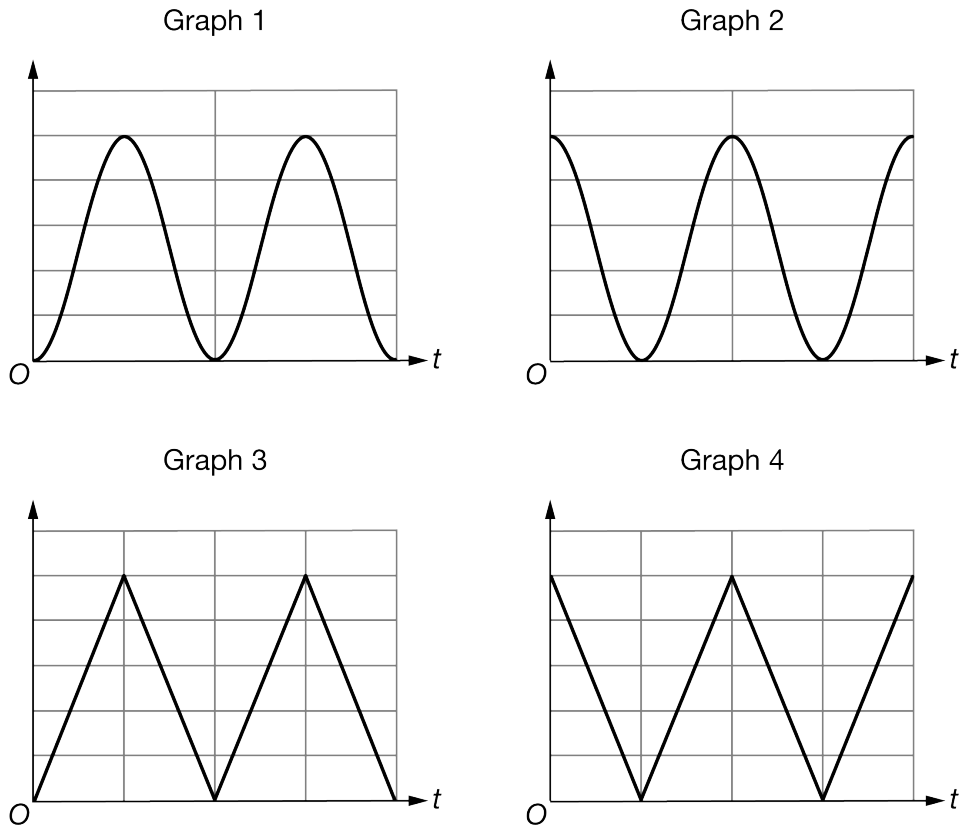

(b) Block A is held at rest while block B swings back and forth. Which of the graphs shown above best represents the kinetic energy of block B as a function of time *t* after it is released from rest at time $t = 0$? Explain your reasoning.

Block B is again displaced from the vertical such that the string makes a small angle θ with the vertical. Block A is not held in place, and block B is released from rest.

(c) In the original scenario in which block B hung at rest, block A remained at rest. In this new scenario in which block A is not held in place, block A begins accelerating to the right across the tabletop at the instant block B passes through the bottom of its swing. In a clear, coherent paragraph-length response, explain in terms of the net force on block A why block A remained at rest in the original scenario but accelerates in this new scenario.

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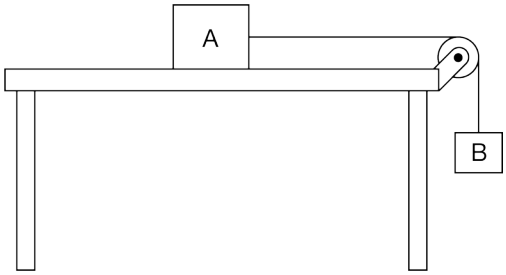
14. This question is a short free-response question. Show your work for each part of the question. (10 points, suggested time 15 minutes)



Block A with mass m_A rests on a horizontal tabletop, while block B with mass m_B hangs from a string of negligible mass that passes over a pulley and attaches to block A, as shown above. The pulley has negligible mass and rotates with negligible friction about its axle. The blocks are at rest due to friction between block A and the tabletop. The coefficient of static friction between block A and the tabletop is μ (mu), where $\mu < 1$.

(a) Determine the magnitude of the tension in the string. Briefly explain your reasoning.

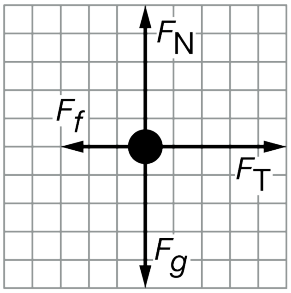


Figure 1

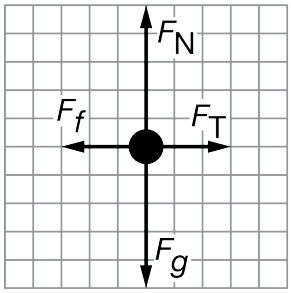


Figure 2

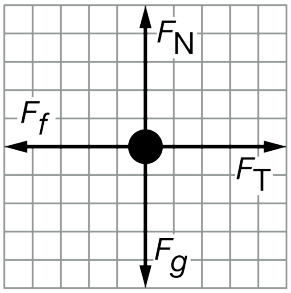


Figure 3

(b) Three students draw the free-body diagrams shown above to represent the forces acting on block A while the two-block system is at rest. Which figure correctly depicts the forces and their relative magnitudes? Explain your reasoning.

(c) A student slowly adds mass to the top of block B. When a total mass m_0 has been added to the top of block B, block A begins to accelerate across the tabletop. In a clear, coherent, paragraph-length response, explain in terms of the net force on block A why block A remained at rest even as mass was added to block B, but block A accelerates once a total mass m_0 was added to block B.

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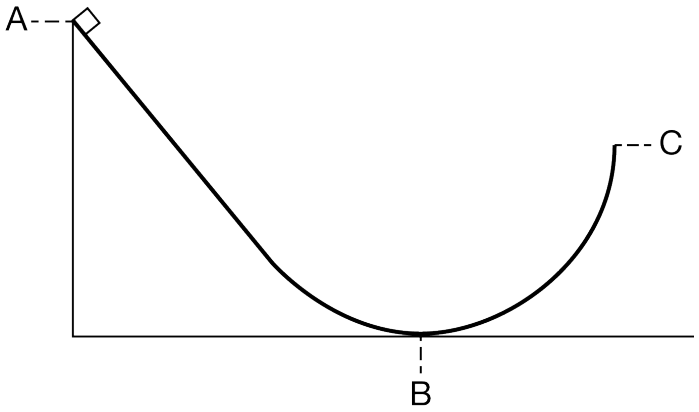
15. This question is a short free-response question. Show your work for each part of the question. (10 points, suggested time 15 minutes)



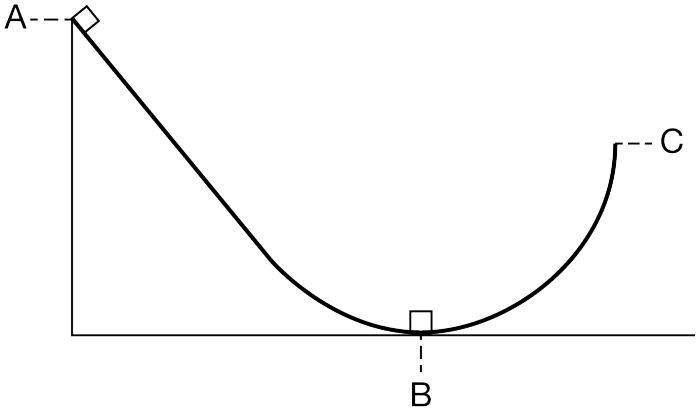
The figure above shows a track consisting of a straight section that connects to a circular section. The bottommost point of the track is at location B, and the track ends at location C, where the track is vertical. A block is released from rest at location A. There is negligible friction between the track and the box.

(a) Is the magnitude of the normal force exerted on the block by the track when the block is at location B greater than, less than, or equal to the normal force immediately before the block reaches location C? Justify your answer.

(b) In a coherent, paragraph-length response, describe the relative angle between the direction of the normal force exerted on the block by the track and the direction of the block's acceleration at the following times.

Immediately after the block is released at location A
When the block is at location B
Immediately before the block reaches location C

Specifically, indicate whether the normal force is parallel to the acceleration, perpendicular to the acceleration, or neither, at each location. Use physical principles to justify your responses.



(c) The scenario is repeated, but an identical block is at rest at location B, as shown above. When the block at location A is released from rest, it slides down the track and collides with and sticks to the identical block. The

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two blocks then continue sliding up the ramp. Is the maximum height reached by the two blocks greater than, less than, or equal to the maximum height reached by the block in the original scenario? Briefly explain your answer.

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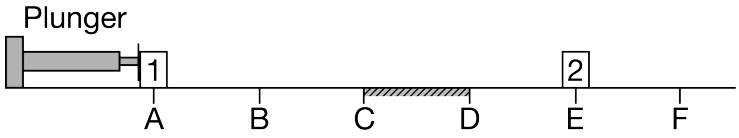
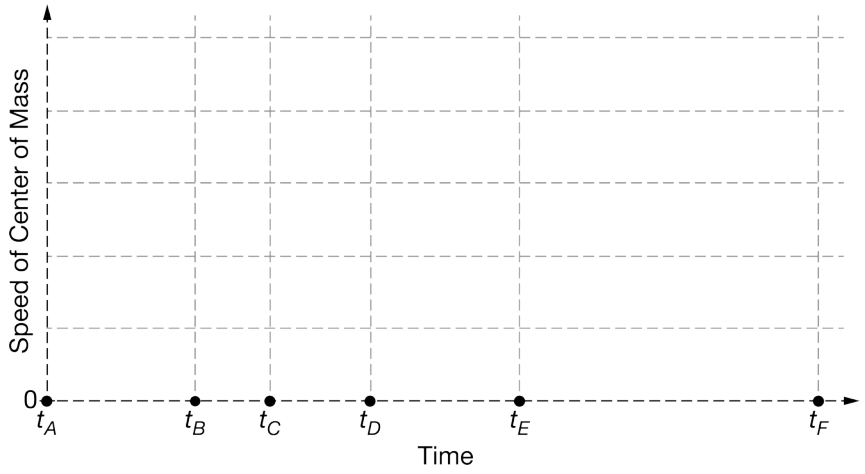
16. This question is a short free-response question. Show your work for each part of the question.

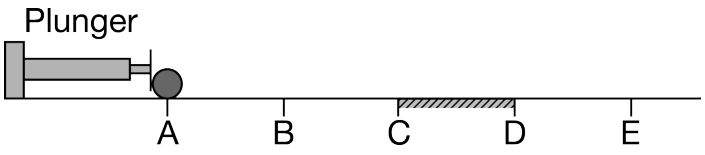


(7 points, suggested time 13 minutes)

Identical blocks 1 and 2 are placed on a horizontal surface at points A and E, respectively, as shown. The surface is frictionless except for the region between points C and D, where the surface is rough. Beginning at time t_A, block 1 is pushed with a constant horizontal force from point A to point B by a mechanical plunger. Upon reaching point B, block 1 loses contact with the plunger and continues moving to the right along the horizontal surface toward block 2. Block 1 collides with and sticks to block 2 at point E, after which the two-block system continues moving across the surface, eventually passing point F.

(a) On the axes below, sketch the speed of the center of mass of the two-block system as a function of time, from time t_A until the blocks pass point F at time t_F. The times at which block 1 reaches points A through F are indicated on the time axis.





(b) The plunger is returned to its original position, and both blocks are removed. A uniform solid sphere is placed at point A, as shown. The sphere is pushed by the plunger from point A to point B with a constant horizontal force that is directed toward the sphere's center of mass. The sphere loses contact with the plunger at point B and continues moving across the horizontal surface toward point E. In which interval(s), if any, does the sphere's angular momentum about its center of mass change? Check all that apply.

_____ A to B _____ B to C _____ C to D _____ D to E

_____ None

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Briefly explain your reasoning.

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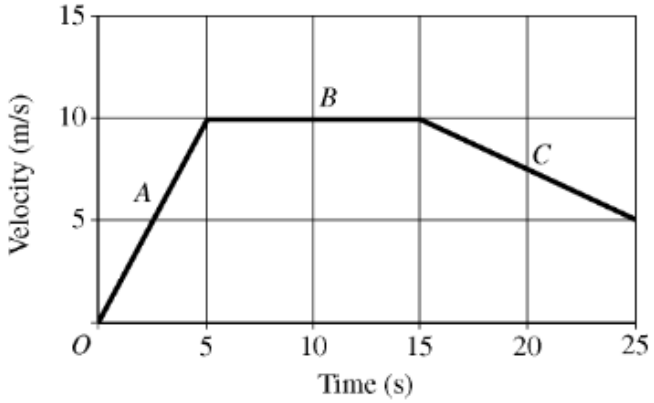
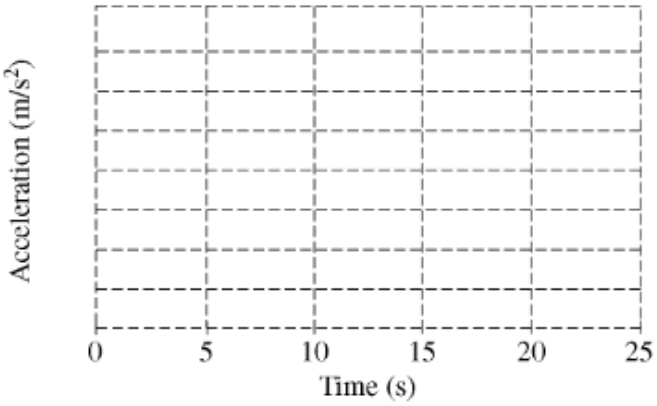
17.



A 0.40 kg object moves in a straight line under the action of a net force. The graph above shows the velocity as a function of time for the object during a 25 s interval. At time $t = 0$, the object is at the position $x = 0$.

(a) On the grid below, sketch a graph of the acceleration as a function of time for the object. Label the scale for the acceleration.



(b) Calculate the position of the object at t = 5.0 s.

(c) On which segment of the graph is the net force acting on the object zero?

____ A ____ B ____ C

Justify your answer.

(d) Calculate the net force on the object during the first 3.0 s of the motion.

(e) Calculate the amount of work done on the object by the net force during the first 15 s of the motion.

(f) For the interval $t = 15$ s to $t = 25$ s, is the work done on the object by the net force positive, negative, or zero?

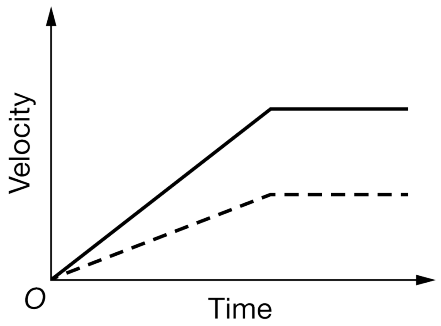
____ Positive ____ Negative ____ Zero

Justify your answer.

18. This question is a short free-response question. Show your work for each part of the question. (10 points, suggested time 15 minutes)



Two disks, A and B, are initially at rest at the left end of a track, as shown above. Disk A is more massive than disk B. The track has a horizontal section and then curves upward at the right end. The disks are simultaneously pushed to the right by identical, constant, horizontal forces of magnitude F for the same amount of time. The forces are removed before the disks reach the curved section of the track, and there is negligible friction between the track and the disks.



(a) The graph above shows the velocity of each disk as a function of time while the disks are moving on the horizontal section. Identify which disk's motion is represented by the solid line. Explain your reasoning.

(b) When the horizontal forces are removed, which disk, if either, has a greater momentum? If the disks have equal momentum, state this explicitly. Briefly justify your answer in terms of the impulse acting on each disk.

(c) After sliding across the horizontal section of the track, both disks slide partway up the curved section of the track. Identify which disk, if either, reaches a greater maximum height. If both disks reach the same maximum height, state this explicitly.

(d) In a clear, coherent, paragraph-length response, justify your answer to part (c).

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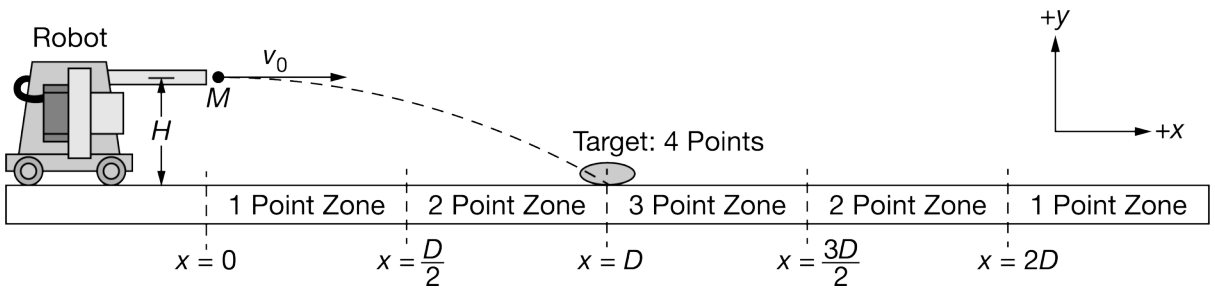
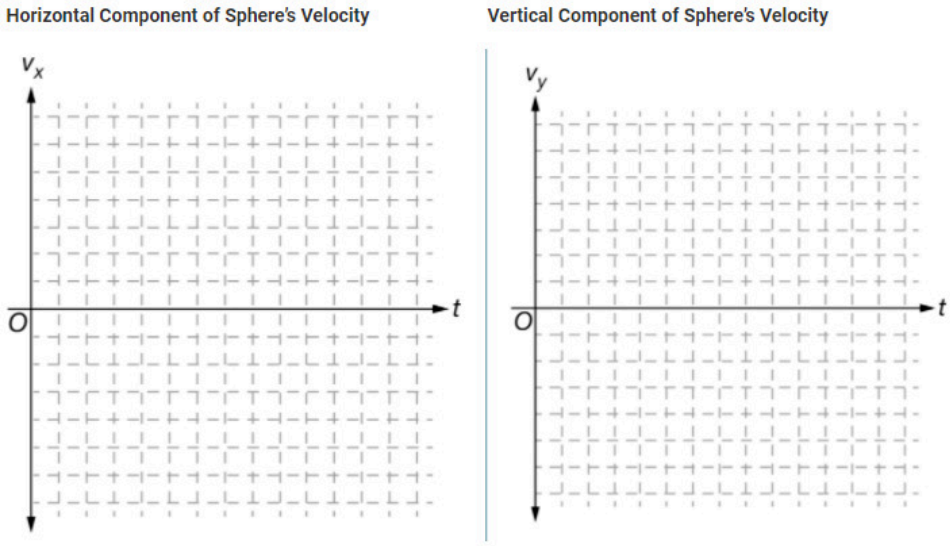
19. This question is a short free-response question. Show your work for each part of the question.



A group of students prepare for a robotic competition and build a robot that can launch large spheres of mass M in the horizontal direction with a variable speed and from a variable vertical position and a fixed horizontal position $x = 0$. The robot is calibrated by adjusting the speed at which the sphere is launched and the height of the robot's sphere launcher. Depending on where the spheres land on the ground, students earn points based on the accuracy of the robot. The robot is calibrated so that when the spheres are launched from a vertical position $y = H$ and speed v_0, they consistently land on the ground on a target that is at a position $x = D$. Positive directions for vector quantities are indicated in the figure.

(a) On the axes below, sketch the graphs of the horizontal and vertical components of the sphere's velocity v as a function of time t between $t = 0$, when the sphere is launched and $t = T$, when the sphere hits the target. Label $t = T$ for the horizontal component of the sphere's velocity and the vertical component of the sphere's velocity.



When the students arrive at the competition, it is determined that the height of the sphere launcher can no longer be adjusted due to a mechanical malfunction. Therefore, the spheres must be launched at a vertical position of $y = \frac{H}{2}$. However, the spheres may be launched at speed v_0 or $2v_0$.

(b) In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, describe the speed at which a sphere should be launched so that the students earn the maximum number of points in the competition.

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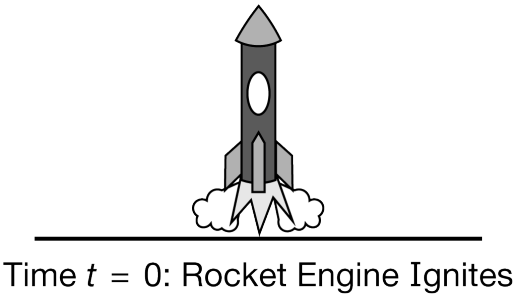
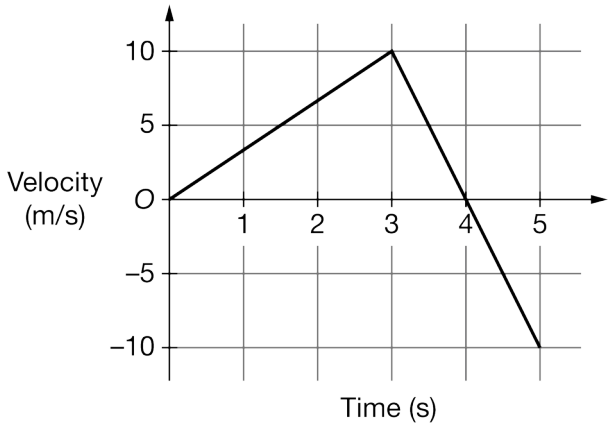
20. This question is a short free-response question. Show your work for each part of the question.



(7 points, suggested time 13 minutes)

A model rocket of constant mass 0.5 kg is launched vertically at time $t = 0$. The rocket's engine provides a constant force of magnitude F_0 for three seconds and then stops firing. The vertical velocity of the rocket as a function of time for the first 5 seconds of the flight is shown in the graph below.



(a) Calculate F_0.

(b) Calculate the time at which the rocket hits Earth after being launched.

(c) On the axes below, sketch a graph of the vertical position of the rocket as a function of time for the first 5 seconds of the flight.

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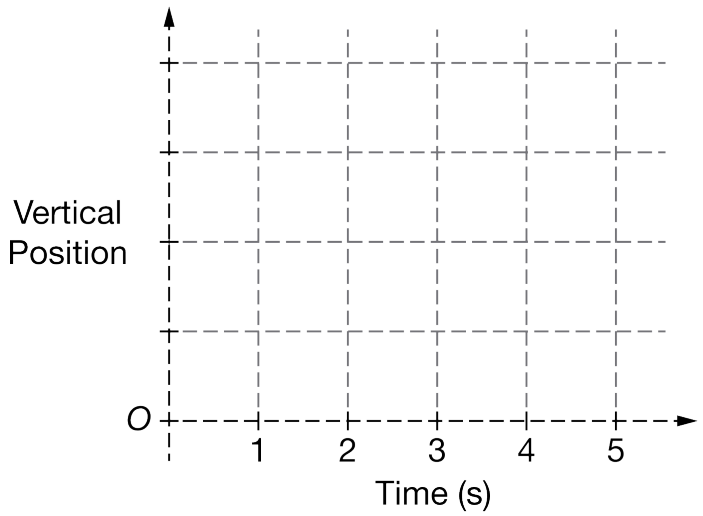

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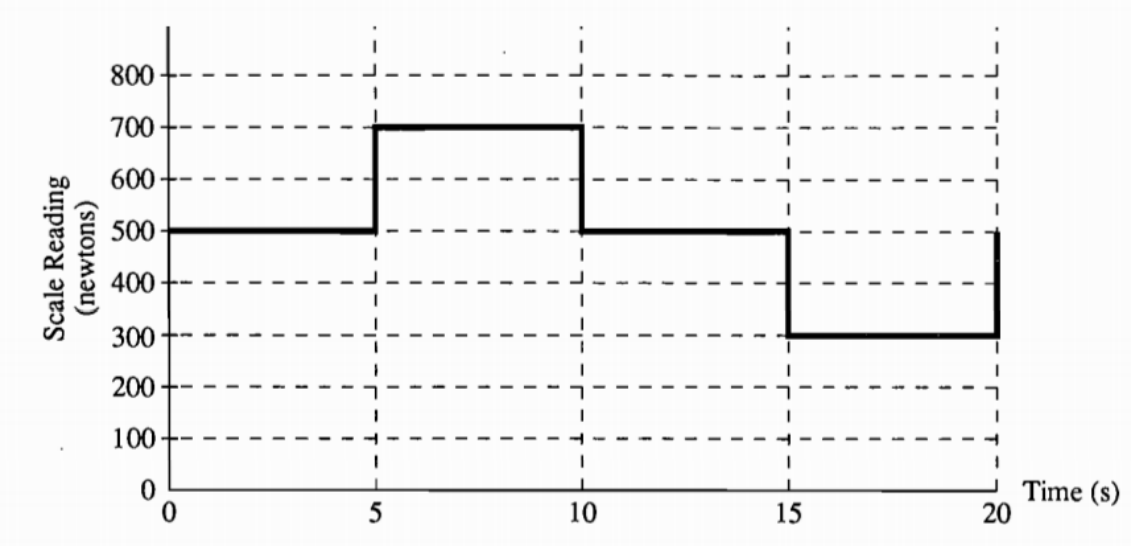


A student whose normal weight is 500 newtons stands on a scale in an elevator and records the scale reading as a function of time. The data are shown in the graph above. At time t = 0, the elevator is at displacement x = 0 with velocity v = 0. Assume that the positive directions for displacement, velocity, and acceleration are upward.

(a) On the diagram to the right,draw and label of the forces on the student at t = 8 seconds.



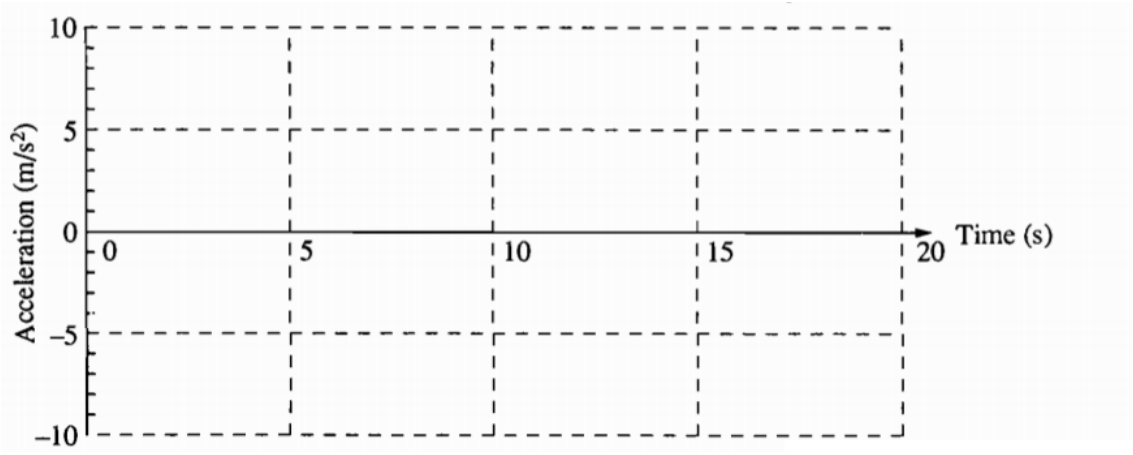
(b) Calculate the acceleration a of the elevator for each 5-second interval.

i. Indicate your results by completing the following table.

Time interval(s)	0-5	5-10	10-15	15-20
a(m/s^2)	____	____	____	____

ii. Plot the acceleration as a function of time on the following graph

1frq

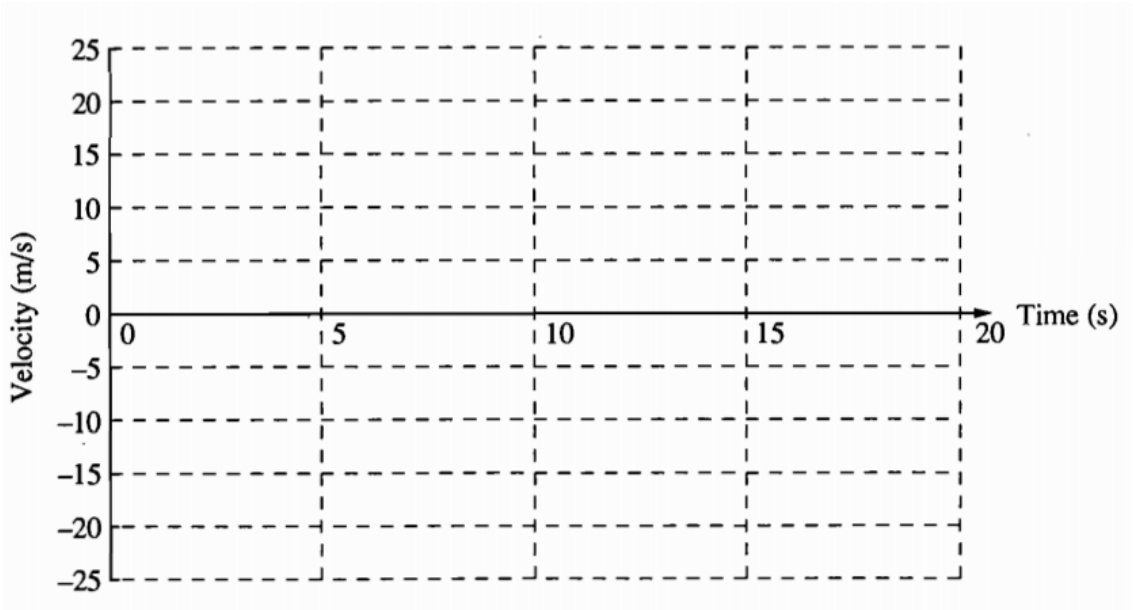


(c) Determine the velocity v of the elevator at the end of each 5-second interval.

i. Indicate your results by completing the following table

Time interval(s)	5	10	15	20
v(m/s)	____	____	____	____

ii. Plot the velocity as a function of time on the following graph.



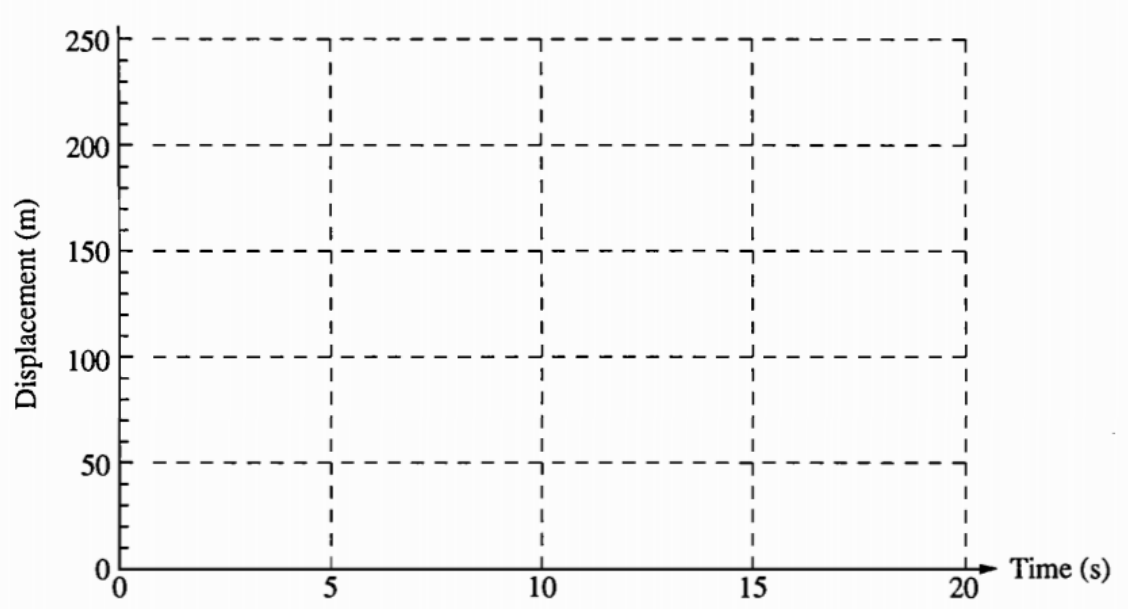
(d) Determine the displacement x of the elevator above the starting point at the end of each 5-second interval.

i. Indicate your results by completing the following table

Time interval(s)	5	10	15	20
x(m)	____	____	____	____

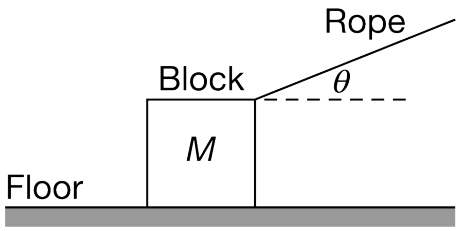
1frq

ii. Plot the displacement as a function of time on the following graph.



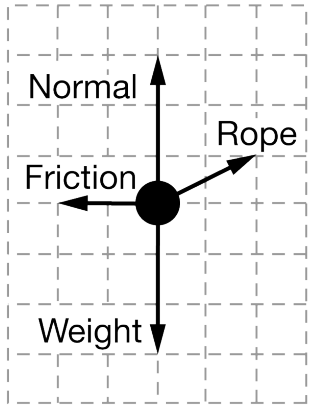
1frq

22. This question is a long free-response question. Show your work for each part of the question. (15 points, suggested time 25 minutes)

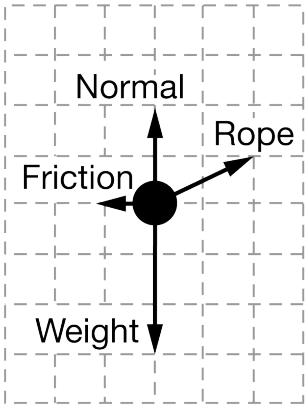


A block of mass M is pulled by a rope that makes an angle θ (theta) above the horizontal, as shown above. The coefficient of kinetic friction between the block and floor is μ (mu).

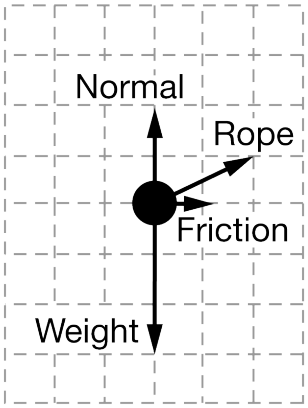
The block is initially at rest and starts accelerating to the right along the floor. Three students each draw a diagram to indicate all of the forces that are exerted on the block as it moves. In the students' diagrams, which are shown below, the lengths of the arrows indicate the relative magnitudes of the forces.



Student 1's Diagram



Student 2's Diagram



Student 3's Diagram

Only one of the students has drawn a diagram that could correctly represent the forces. The other two students' diagrams are incorrect.

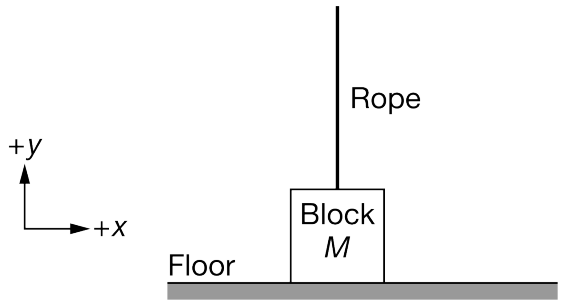
(a) Which student has drawn a diagram that could correctly represent the forces exerted on the block?

(b) For the incorrect student diagrams, explain why the diagram could not represent the forces exerted on the block. If there is more than one specific reason a diagram is incorrect, identify each of the reasons.

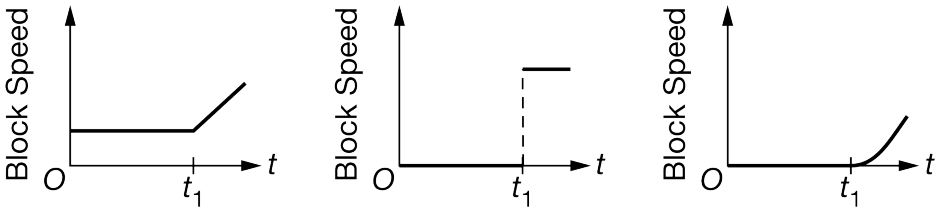
(c) Briefly explain why slightly increasing the force F exerted by the rope on the block (without changing the angle θ) would cause a decrease in the friction force.

(d) The friction force f is $f = \mu(W - F\sin\theta)$, where W is the weight of the block and F is the force exerted by the rope. Explain why this equation is consistent with the claim that an increase in F would cause a decrease in the friction force.

1frq



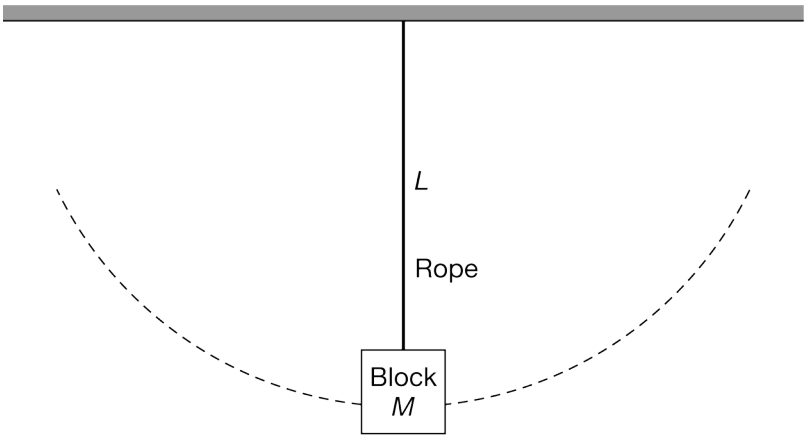
The rope is now attached to the center of the top of the block, as shown above. The force exerted by the rope is initially zero newtons at time $t = 0$. The force steadily increases, becomes equal to the block's weight W at time t_1, and continues to increase further. Three students sketch the graphs shown below to represent the speed of the block as a function of time t. One of the graphs is consistent with this scenario, while the other graphs are not consistent with this scenario.



Graph 1 Graph 2 Graph 3

(e) Which graph is consistent with the scenario in which the force exerted by the rope on the block steadily increases?

(f) Identify all features of the other two graphs that make them inconsistent with this scenario. Explain your reasoning.



Note: Figure not drawn to scale.

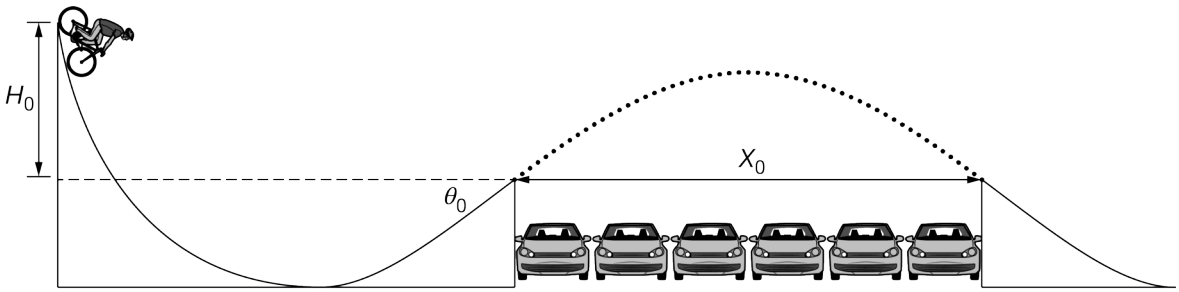
With one end of the rope still attached to the block, the other end of the rope is attached to a ceiling to create a

pendulum with length L, where L is much greater than the dimensions of the block. A second identical pendulum is located on the Moon, where the acceleration due to gravity is less than that on Earth. Both pendulums are displaced by the same small angle and released from rest.

(g) Does the pendulum on Earth or the pendulum on the Moon have a greater period of oscillation? Briefly explain your choice without reference to equations, but by describing the restoring forces exerted on and motion of each block.

1frq

23. This question is a short free-response question. Show your work for each part of the question.



Note: Figure not drawn to scale.

(7 points, suggested time 13 minutes)

A stunt cyclist builds a ramp that will allow the cyclist to coast down the ramp and jump over several parked cars, as shown above. To test the ramp, the cyclist starts from rest at the top of the ramp, then leaves the ramp, jumps over six cars, and lands on a second ramp.

H_0 is the vertical distance between the top of the first ramp and the launch point.
θ_0 is the angle of the ramp at the launch point from the horizontal.
X_0 is the horizontal distance traveled while the cyclist and bicycle are in the air.
m_0 is the combined mass of the stunt cyclist and bicycle.

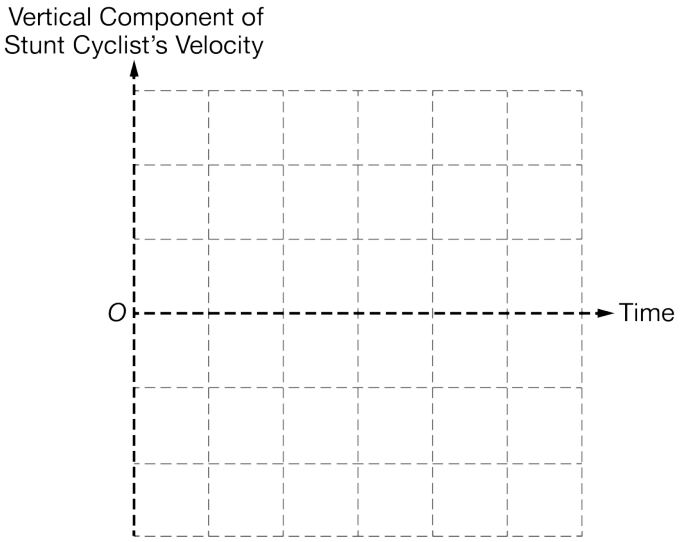
(a) Derive an expression for the distance X_0 in terms of H_0, θ_0, m_0, and physical constants, as appropriate.

(b) If the vertical distance between the top of the first ramp and the launch point were $2H_0$ instead of H_0, with no other changes to the first ramp, what is the maximum number of cars that the stunt cyclist could jump over?

Justify your answer, using the expression you derived in part (a).

(c) On the axes below, sketch a graph of the vertical component of the stunt cyclist's velocity as a function of time from immediately after the cyclist leaves the ramp to immediately before the cyclist lands on the second ramp. On the vertical axis, clearly indicate the initial and final vertical velocity components in terms of H_0, θ_0, m_0, and physical constants, as appropriate. Take the positive direction to be upward.

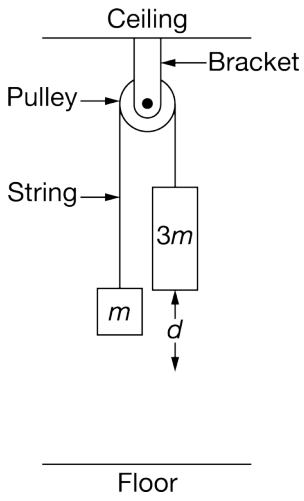
1frq



1frq

24. This question is a short free-response question. Show your work for each part of the question.

(7 points, suggested time 13 minutes)



Two blocks, with masses m and $3m$, are attached to the ends of a string with negligible mass that passes over a pulley, as shown above. The pulley has negligible mass and friction and is attached to the ceiling by a bracket. The blocks are simultaneously released from rest.

(a) Derive an equation for the speed v of the block of mass $3m$ after it falls a distance d in terms of m, d, and physical constants, as appropriate.

(b) Determine the work done by the string on the two-block system as each block moves a distance d.

(c) The acceleration of the center of mass of the blocks-string-pulley system has magnitude a_{COM}. Briefly explain, in terms of any external forces acting on the system, why a_{COM} is less than g.

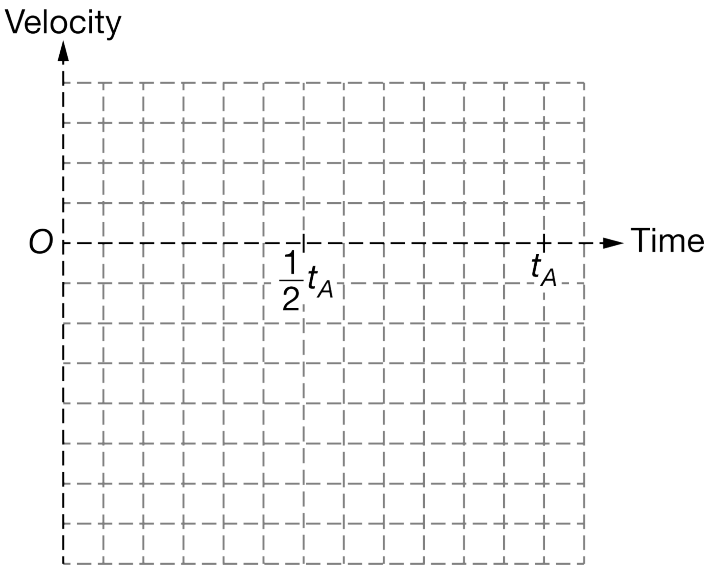
1frq

25. This question is a short free-response question. Show your work for each part of the question.

(7 points, suggested time 13 minutes)

In an experiment two identical rocks are simultaneously thrown from the edge of a cliff a distance h_0 above the ground. Rock A is thrown vertically upward with speed v_0 and rock B is thrown vertically downward with speed v_0. Rock A and rock B strike the ground at times t_{A} and t_{B}, respectively. Consider the positive vertical direction to be upward.

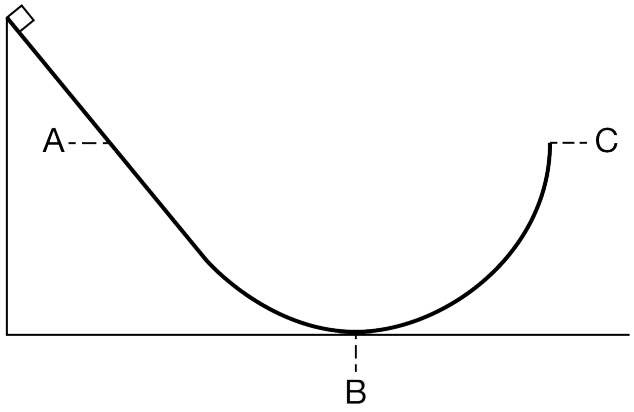
(a) On the axes given below, sketch and label graphs of the velocity as a function of time for rock A and rock B. Label the time t_{B}. Times t_{A} and $\frac{1}{2}t_{\mathrm{A}}$ are given on the graph.



(b) Rock B hits the ground at time t_{B}. Derive an equation for the time t_{A} it takes rock A to hit the ground in terms of v_0, t_{B}, and physical constants, as appropriate.

1frq

26. This question is a short free-response question. Show your work for each part of the question. (10 points, suggested time 15 minutes)



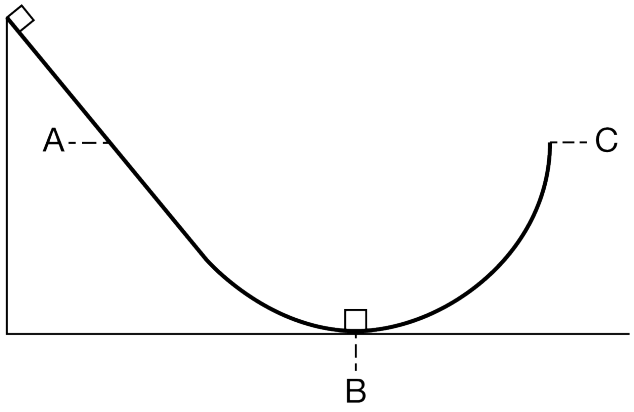
The figure above shows a track consisting of a straight section that connects to a circular section. Three locations are indicated: location A on the straight section of the track, location B at the bottommost point of the track, and location C at the point where the track is vertical. Locations A and C are at the same height. A block is released from rest at the top of the straight section of the track. There is negligible friction between the track and the block.

(a) Is the magnitude of the normal force exerted on the block by the track at location A greater than, less than, or equal to the normal force at location B? Justify your answer.

(b) In a coherent, paragraph-length response, describe the relative angle between the direction of the block's velocity and the direction of the block's acceleration at the following times.

When the block is at location A
When the block is at location B
Immediately before the block reaches location C

Specifically, indicate whether the velocity is parallel to the acceleration, perpendicular to the acceleration, or neither, at each location. Use physical principles to justify your responses.



(c) The scenario is repeated, but an identical block is at rest at location B, as shown above. When the block at the

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top of the straight section of the track is released from rest, it slides down the track and collides elastically with the identical block and comes to rest. The identical block then begins sliding up the ramp. Is the maximum height reached by the identical block greater than, less than, or equal to the maximum height reached by the block in the original scenario? Briefly explain your answer.