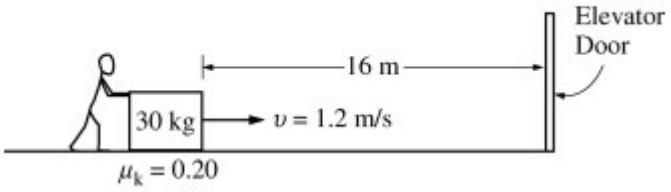
frq3

1.



Beginning at time $t = 0$, a student exerts a horizontal force on a box of mass 30 kg, causing it to move at 1.2 m/s toward an elevator door located 16 m away, as shown above. The coefficient of kinetic friction u_k between the box and the floor is 0.20.

(a) On the dot below that represents the box, draw and label the forces (not components) that act on the box as it moves at constant speed.

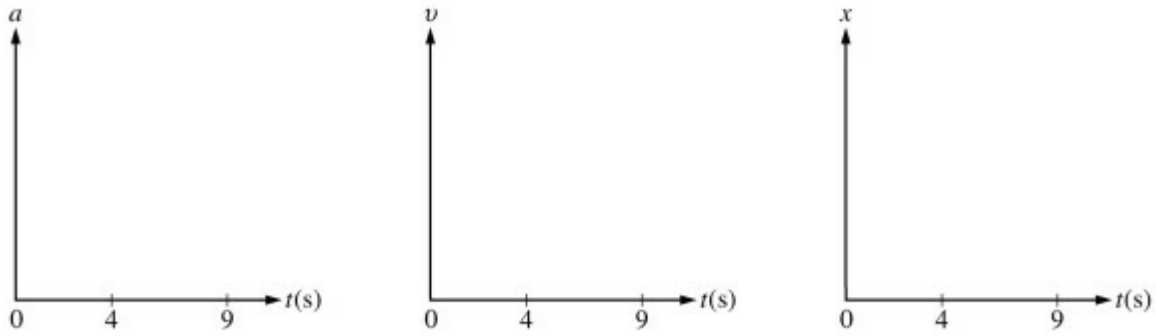
(b) Calculate the magnitude of the horizontal force the student must exert on the box in order to keep it moving at 1.2 m/s. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

At $t = 4.0$ s, the elevator door opens and remains open for 5.0 s. The student immediately exerts a larger constant force on the box and the front of the box reaches the elevator door just as it starts to close.

(c) Calculate the magnitude of the new force that the student exerts.

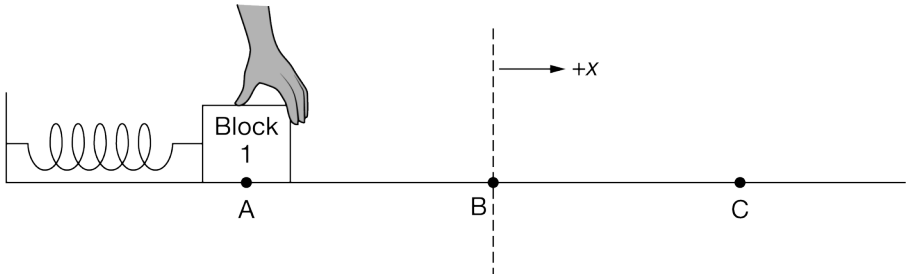
(d) On the axes below, sketch graphs of the acceleration a, velocity v, and position x of the box versus time t between $t = 0$ and the time the front of the box reaches the elevator.

frq3



frq3

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



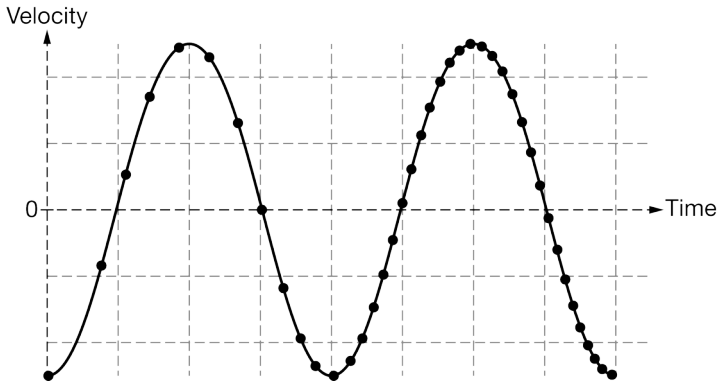
(7 points, suggested time 13 minutes)

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

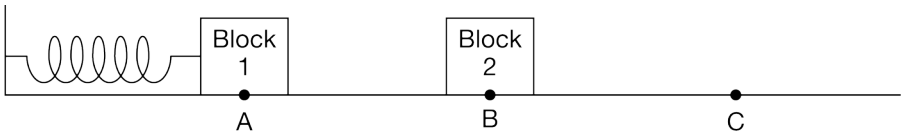


After the block has been oscillating on the table, a motion detector is turned on and the velocity of block 1 as a function of time is measured and plotted in a graph. The students correctly draw a best-fit curve that represents the

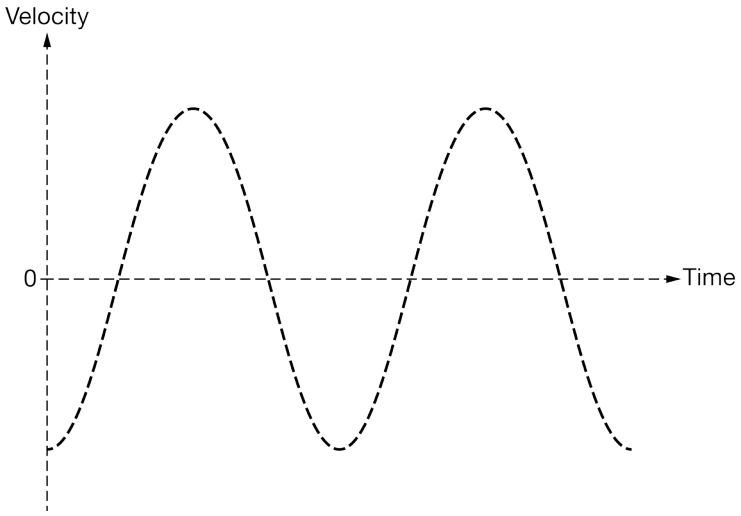
collected data, as shown above.

(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.

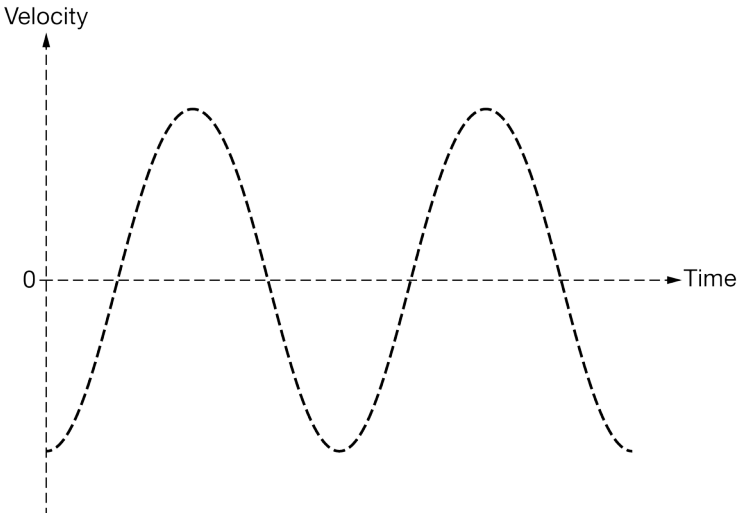


(c) Block 1 is stopped, and again block 1 is held at rest at point A. A second identical block, block 2, is placed at point B. Block 1 is released from rest, and then collides with and sticks to Block 2. After the collision, the two blocks oscillate together on the spring. On the graph below, sketch 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.

frq3



frq3

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

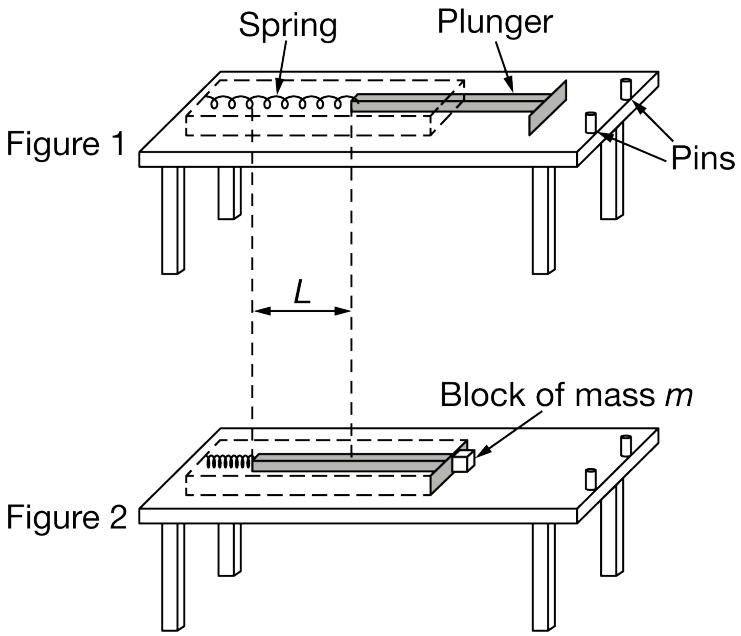
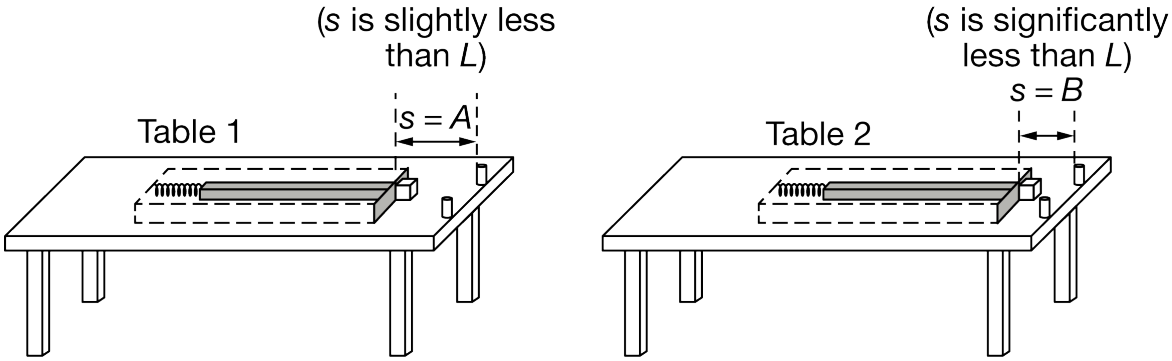


Figure 1

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.



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.

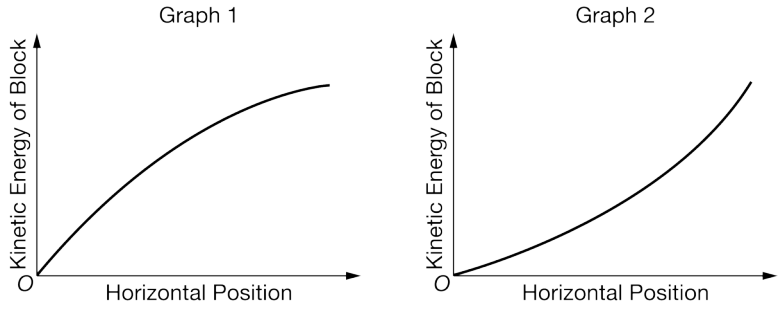
The students correctly derive an equation for the horizontal distance D from the edge of the tabletop that the block lands, in terms of s (the distance between the launcher and the edge of the tabletop):

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

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.

frq3

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

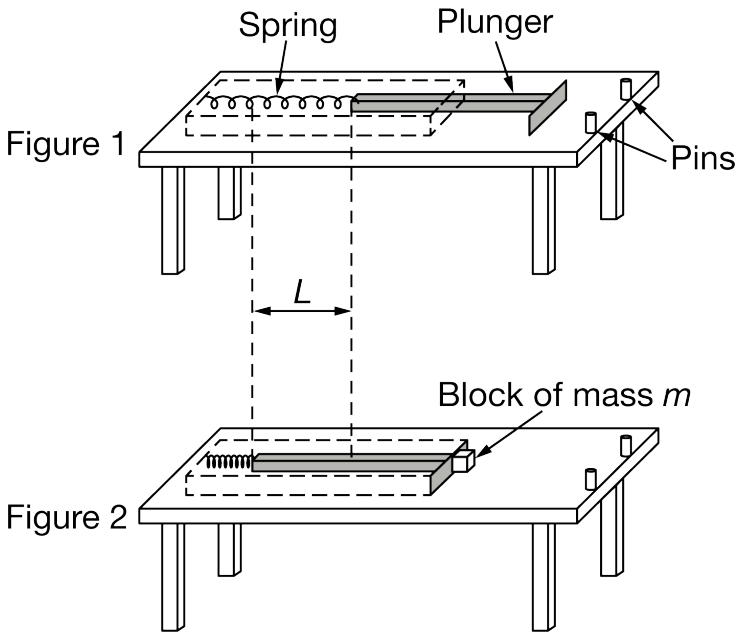
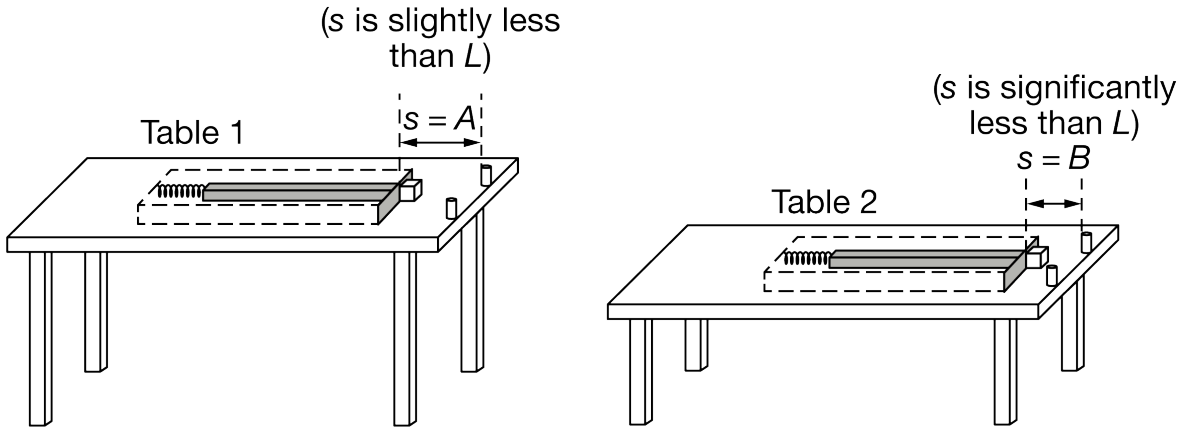


Figure 1

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

frq3

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.

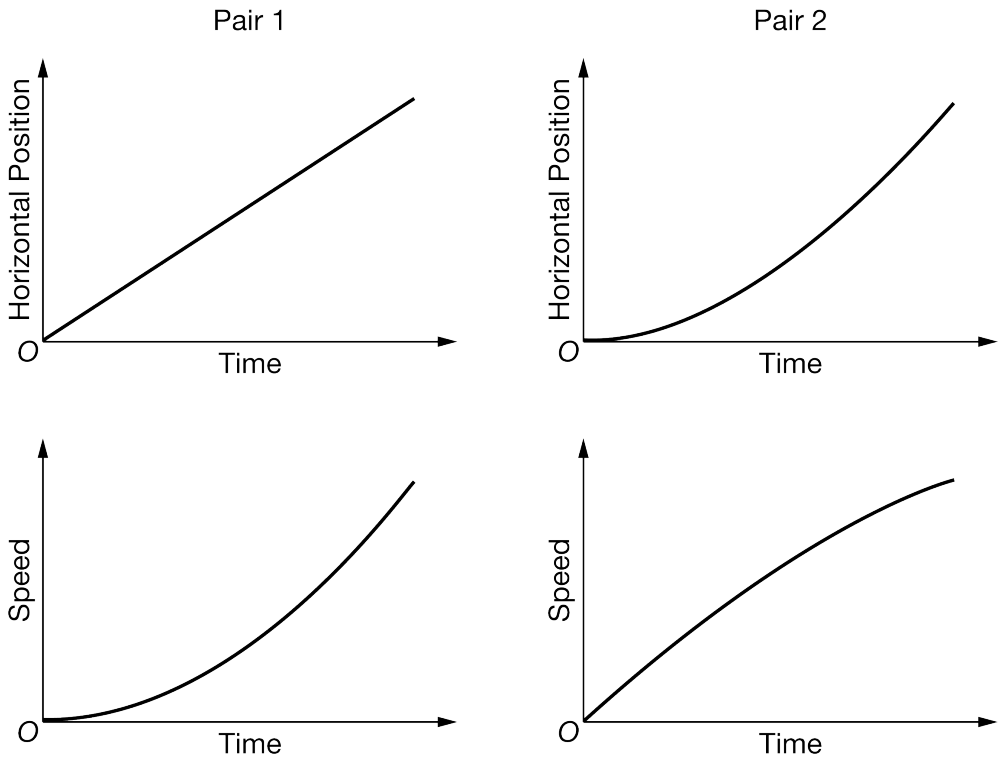
The students correctly derive an equation for the speed v of the block when it is at the edge of the tabletop, in terms of s (the distance between the launcher and the edge of the tabletop):

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

(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.

frq3



(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.

5.

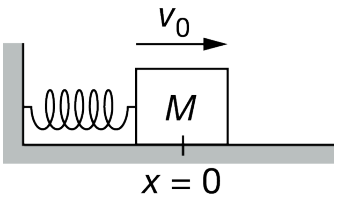


The figure above shows part of a system consisting of a block at the top of an inclined plane that rests on a table, which is located on Earth. The block and plane are at rest when the block is released. In trial 1 there is no friction between the block and the plane or between the plane and the table. In trial 2 the plane is fixed to the table so it cannot move, but there is still no friction between the block and the plane.

Indicate whether the speed of the block relative to the table when the block reaches the bottom of the plane is greater in trial 1 or trial 2. Justify your answer in a clear, coherent, paragraph-length explanation.

frq3

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

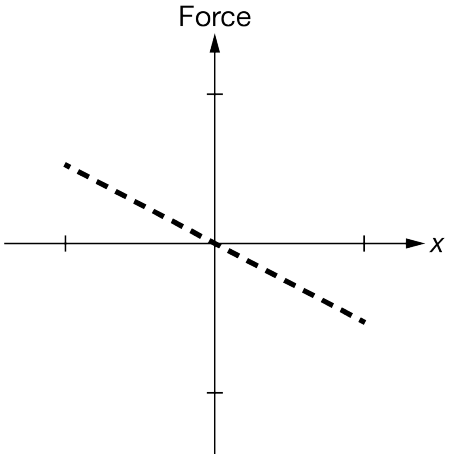


A block of mass M is attached to a spring of negligible mass and can slide on a horizontal surface along the x -direction, as shown above. There is friction present between the block and the surface. The spring exerts no force on the block when the center of the block is located at $x = 0$. At the instant shown above, the block is located at $x = 0$ and moving toward the right with speed $v = v_0$.

(a) For the instant shown above, with the block located at $x = 0$ and moving to the right, predict the direction of the net force on the block. If the net force is zero, select "The net force is zero."

____ To the left ____ The net force is zero ____ To the right

Briefly justify your prediction.



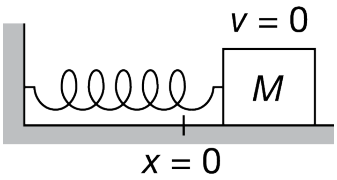
(b) The above graph indicates the force exerted on the block by the spring as a function of position x, with the positive direction toward the right. On the same graph, draw a graph of the net force on the block, as a function of position x, for situations where the block is moving toward the right.

(c) Is the graph you drew in part (b) consistent with your prediction in part (a) ?

____ Yes ____ No

Provide claims for why the answers to parts (a) and (b) are or are not consistent.

frq3



(d) In the figure above, the block of mass M has come to rest at a location to the right of the spring's equilibrium position. The spring has a spring constant k, and the coefficients of kinetic and static friction between the block and the surface are μ_k and μ_s, respectively.

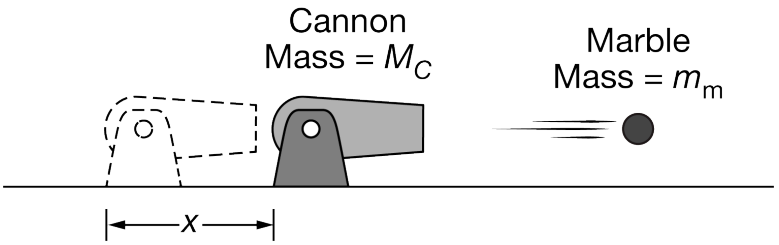
i. On the dot below, which represents the block at rest and to the right of $x = 0$, draw and label the forces (not components) that act on the block. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



ii. Derive an expression for the maximum displacement possible for the block that will allow the block to still remain at rest. Express your answer in terms of M, k, μ_k, μ_s, and physical constants, as appropriate.

frq3

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



Note: Figure not drawn to scale.

Students launch marbles of mass m_{m} horizontally from a toy cannon of mass M_C, where M_C is always greater than m_{m}, as shown above. Each time a marble is launched, the cannon slides backward before coming to rest. The coefficient of kinetic friction between the cannon and the ground is μ (mu). For each launch, the students use a new marble with a different mass launched at the same speed v relative to the ground. The students record the distance x the cannon slides backward for each launch.

(a) Without manipulating equations, briefly describe what happens to the distance x that the cannon slides backward as students increase the mass of the marble. Explain your reasoning.

(b) Students find the following equation on the Internet to describe the distance x that the cannon slides backward: $x = \frac{m_{\mathrm{m}}^2 v^2}{2g\mu M_C^2}$. Whether or not the equation is correct, is it consistent with your prediction in part (a)? Briefly justify your answer.

(c) Without manipulating or stating equations, briefly describe whether it would take more work to stop the marble or to stop the cannon after the marble has been launched. Justify your answer.

(d) Students correctly derive the following equation relating the work W done on an object initially at rest, the momentum p of the object, and the mass m of the object: $W = \frac{p^2}{2m}$. Is this equation consistent with your description in part (c)? Justify your answer.

Students then discuss the mechanical energy of the marble-cannon system during the short time interval in which the marble is accelerated inside the cannon and make the following claims:

Student 1: The cannon is pushing the marble forward, and the marble is pushing back with equal and opposite force. Since the work done by the cannon cancels out the work done by the marble, the mechanical energy of the system is constant.

Student 2: The mechanical energy of the system increases while the marble is being accelerated. The marble gains kinetic energy to the right, and the cannon gains an equal amount of kinetic energy to the left.

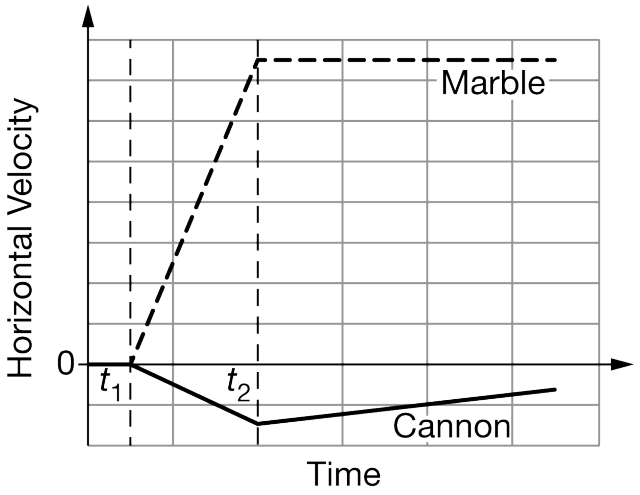
(e) Which underlined phrase or phrases in student 1's statement are ***correct***, if either? If neither phrase is ***correct***, write "none."

(f) Which underlined phrase or phrases in student 1's statement are ***incorrect***, if either? If neither phrase is

incorrect, write "none."

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

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

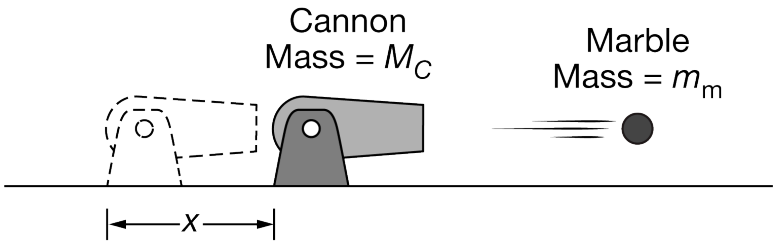


The graph above shows the horizontal component of the velocity of the marble (dashed line) and the cannon (solid line) relative to the ground. Before time t_1 the marble-cannon system is at rest. At time t_1 the marble begins accelerating within the cannon, and at time t_2 the marble leaves the cannon.

(i) Provide three pieces of evidence that together explain why the magnitude of the rate of change of the cannon's velocity is less than the magnitude of the rate of change of the marble's velocity during the time interval from t_1 to t_2.

frq3

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



Note: Figure not drawn to scale.

Students launch identical marbles of mass m_{m} horizontally from a toy cannon of varying mass M_C, where M_C is always greater than m_{m}, as shown above. The students can attach weights to the cannon to change M_C. Each time a marble is launched, the cannon slides backward before coming to rest. The coefficient of kinetic friction between the cannon and the ground is μ (mu). For each launch, the students vary the mass of the cannon and launch a marble with the same speed v relative to the ground. The students record the distance x that the cannon slides backward.

(a) Without manipulating equations, explain how the distance x that the cannon slides backward changes, if at all, when marbles are launched from more massive cannons.

(b) Students find the following equation on the Internet to describe the distance x that the cannon slides backward: $x = \frac{m_{\mathrm{m}}^2 v^2}{2g\mu M_C^2}$. Whether or not the equation is correct, is it consistent with your prediction in part (a)? Briefly justify your answer.

(c) If constant horizontal forces were exerted over the same distance on the cannon and on the marble after the launch, which object would require a force with a greater magnitude to completely stop it? Without manipulating or referencing equations, briefly explain your reasoning.

(d) Students correctly derive the following equation relating the force F exerted on an object initially at rest over a distance d, the mass m of the object, and the final momentum p of the object: $F = \frac{p^2}{2md}$. Is this equation consistent with your description in part (c)? Justify your answer.

Students then discuss the mechanical energy of the marble after it has been launched by the cannon but before it reaches the ground. Both students agree that air resistance is negligible and make the following claims.

Student 1: The mechanical energy of the marble is constant. There are no external forces exerted on the marble, so its energy does not change.

Student 2: The mechanical energy decreases as the marble falls. This happens because the gravitational force is doing work on the marble.

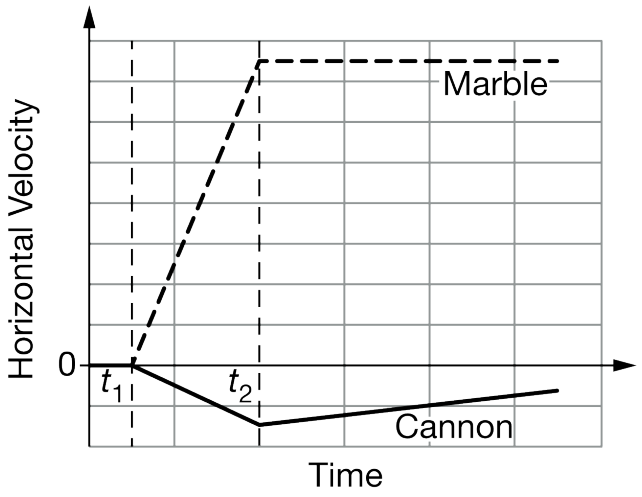
(e) Which underlined phrase or phrases in student 1's statement are ***correct***, if either? If neither phrase is ***correct***, write "none."

frq3

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

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

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

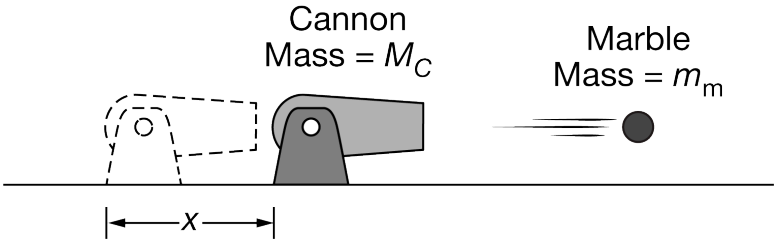


The graph above shows the horizontal component of the velocity of the marble (dashed line) and the cannon (solid line) relative to the ground. Before time t_1 the marble-cannon system is at rest. At time t_1 the marble begins accelerating within the cannon, and at time t_2 the marble leaves the cannon.

(i) Describe the motion of the center of mass of the marble-cannon system during the time interval from t_1 to t_2. Explain your reasoning.

frq3

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



Note: Figure not drawn to scale.

Students launch identical marbles of mass m_{m} horizontally from a toy cannon of mass M_C, where $M_C > m_{\text{m}}$, as shown above. The cannon can be adjusted to change the launch speed v of the marble relative to the ground. Each time a marble is launched, the cannon slides backward before coming to rest. The coefficient of kinetic friction between the cannon and the ground is μ (mu). For each launch, the students vary the launch speed v and record the distance x the cannon slides backward for each launch speed.

(a) Without manipulating equations, briefly describe what happens to the distance x that the cannon slides backward as students increase the launch speed. Explain your reasoning.

(b) Students find the following equation on the Internet to describe the distance x that the cannon slides backward: $x = \frac{m_{\text{m}}^2 v^2}{2g\mu M_C^2}$. Whether or not the equation is correct, is it consistent with your prediction in part (a)? Briefly justify your answer.

(c) Without manipulating or stating equations, briefly describe whether the cannon or the marble has more kinetic energy immediately after the marble leaves the cannon. Justify your answer.

(d) Students correctly derive an equation relating the kinetic energy K, the momentum p, and the mass m of an object: $K = \frac{p^2}{2m}$. Is this equation consistent with your description in part (c)? Justify your answer.

Students then discuss the mechanical energy of the marble after it has been launched by the cannon but before it reaches the ground. Both students agree that air resistance is negligible and make the following claims.

Student 1: There are two external forces exerted on the marble while it is in the air, the gravitational force and the force exerted by the cannon. Therefore, the mechanical energy of the marble changes while it is in the air.

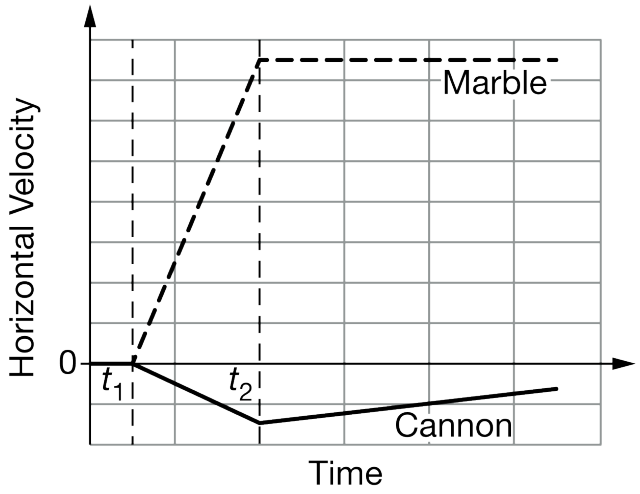
Student 2: The cannon does not exert a force on the marble after the launch. Therefore, the mechanical energy of the marble is constant.

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

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

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

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



The graph above shows the horizontal component of the velocity for the marble (dashed line) and the cannon (solid line) relative to the ground. Before time t_1 the marble-cannon system is at rest. At time t_1 the marble begins accelerating within the cannon, and at time t_2 the marble leaves the cannon.

(i) Describe how to find the change in the distance between the center of mass of the cannon and the center of mass of the marble from time t_1 to time t_2. Assume that before time t_1 the center of mass of the marble is at the same position as the center of mass of the cannon.

frq3

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

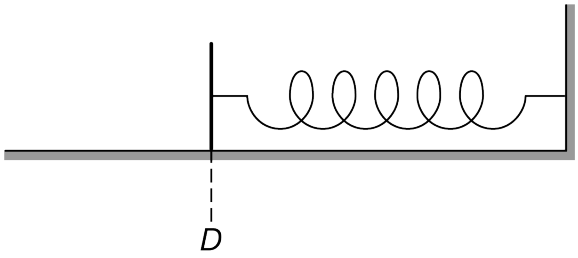


Figure 1. Spring at Relaxed Length

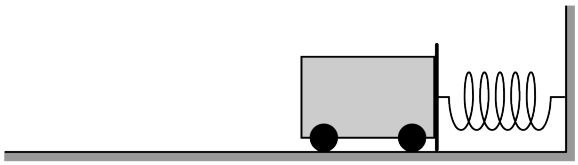


Figure 2. Cart Held Against Plate

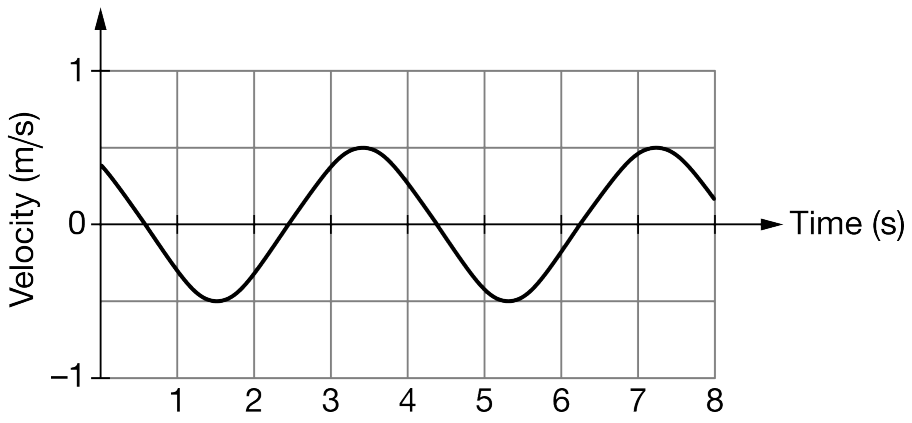
Students intend to use a cart-spring system to study motion. A vertical plate with negligible mass is attached to a horizontal spring of spring constant k. When the spring is at its relaxed length, the plate is at position D as indicated in Figure 1 above. A cart is glued to the plate. The cart is initially held so that the spring is compressed as shown in Figure 2 above. The maximum force the glue can exert is $F_{\max}$. Assume friction is negligible.

The students plan to release the cart from rest so that the cart oscillates. They discuss whether the cart could detach from the plate during the cart's motion if the glue is not strong enough. One student makes the following claim:

"If the spring is stiffer, the force exerted by the spring will be greater for the same compression. This means that the cart could come loose as the spring expands, before it reaches D."

(a) Which underlined phrase or phrases are ***correct***, if either? If neither phrase is ***correct***, write "none."

(b) Which underlined phrase or phrases are ***incorrect***, if either? If neither phrase is ***incorrect***, write "none."



frq3

The cart is removed, and the plate is coated with very strong glue. The cart rolls to the right with positive velocity v_{cart}, collides with and sticks to the plate, and then oscillates back and forth at the end of the spring. The graph above shows the velocity of the cart as a function of time after it has completed several oscillations.

(c) Explain how this graph could be used along with the known mass of the cart to find the impulse exerted on the cart by the spring during the time interval between 4 seconds and 6 seconds.

(d) The collision is repeated with a lighter cart. Again, the cart moves with velocity v_{cart}, collides with and sticks to the plate, and oscillates back and forth. In a clear, coherent paragraph-length response, explain how a graph of the cart's velocity as a function of time would differ from the one shown above if the cart were lighter. Provide a physical reason why each difference would occur.

frq3

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

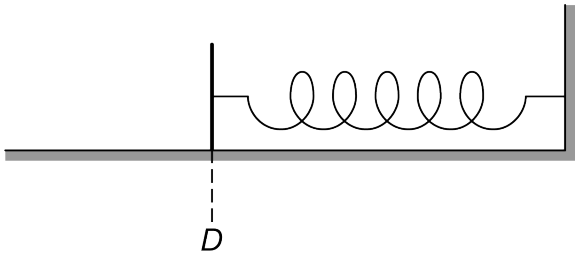


Figure 1. Spring at Relaxed Length

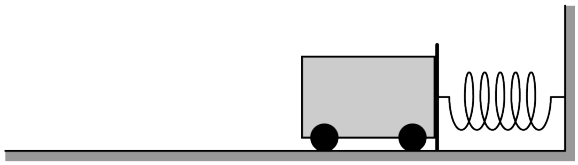


Figure 2. Cart Held Against Plate

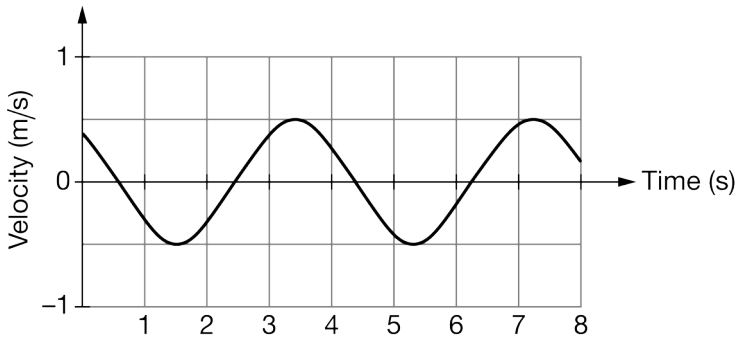
Students intend to use a cart-spring system to study motion. A vertical plate with negligible mass is attached to a horizontal spring of spring constant k. When the spring is at its relaxed length, the plate is at position D as indicated in Figure 1 above. A cart is glued to the plate. The cart is initially held so that the spring is compressed as shown in Figure 2 above. The maximum force the glue can exert is $F_{\max}$. Assume friction is negligible.

The students plan to release the cart from rest so that the cart oscillates. They discuss whether the cart could detach from the plate during the cart's motion if the glue is not strong enough. One student makes the following claim:

"The cart could never detach from the plate because the cart and the plate exert equal and opposite forces on each other, so the forces on the cart add to zero."

(a) Which underlined phrase or phrases are ***correct***, if either? If neither phrase is ***correct***, write "none."

(b) Which underlined phrase or phrases are ***incorrect***, if either? If neither phrase is ***incorrect***, write "none."



The cart is removed, and the plate is coated with very strong glue. The cart rolls to the right with positive velocity

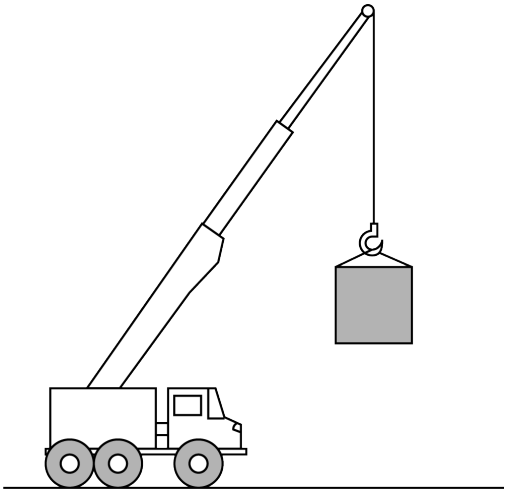
v_{cart}, collides with and sticks to the plate, and then oscillates back and forth at the end of the spring. The graph above shows the velocity of the cart as a function of time after it has completed several oscillations.

(c) Explain how this graph could be used to find the maximum compression of the spring as it oscillates.

(d) The plate of negligible mass is replaced with a plate with mass similar to the cart's mass, and the collision is repeated. Again, the cart moves with velocity v_{cart}, collides with and sticks to the plate, and oscillates back and forth. In a clear, coherent paragraph-length response, explain how a graph of the cart's velocity as a function of time would differ from the one shown above if the plate's mass were not negligible. Provide a physical reason why each difference would occur.

frq3

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

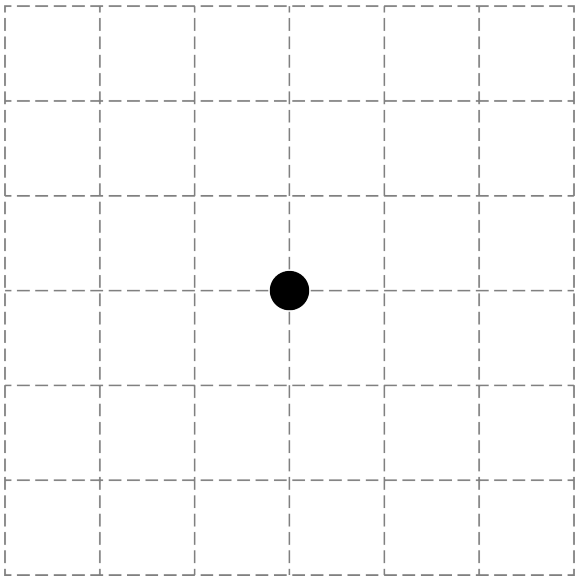


(12 points, suggested time 25 minutes)

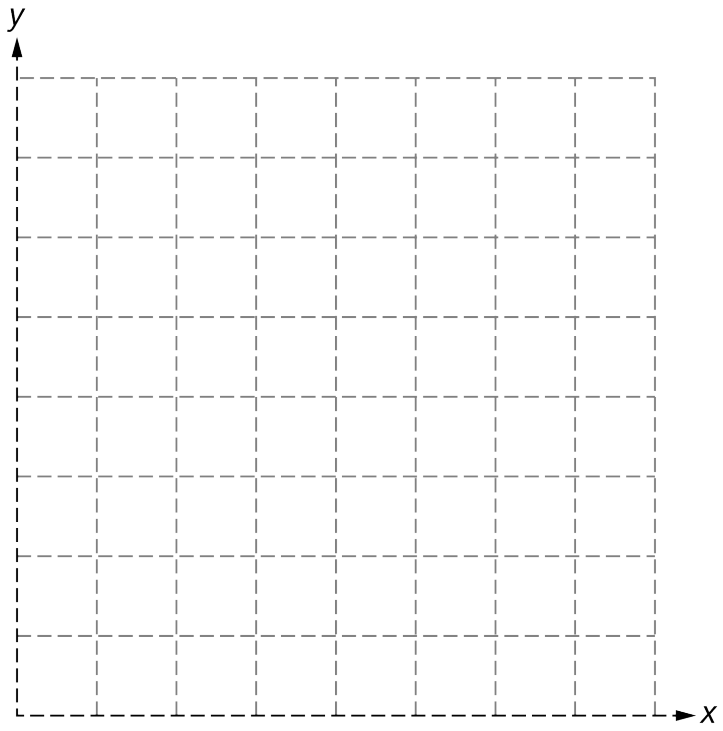
A crane and box are both initially at rest. At time $t = 0$ s, the crane begins to drive forward at a constant speed of $0.5\ \frac{\text{m}}{\text{s}}$, while also lifting the box with an upward acceleration of $1\ \frac{\text{m}}{\text{s}^2}$. The box does not swing while being lifted by the crane.

(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.



(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.

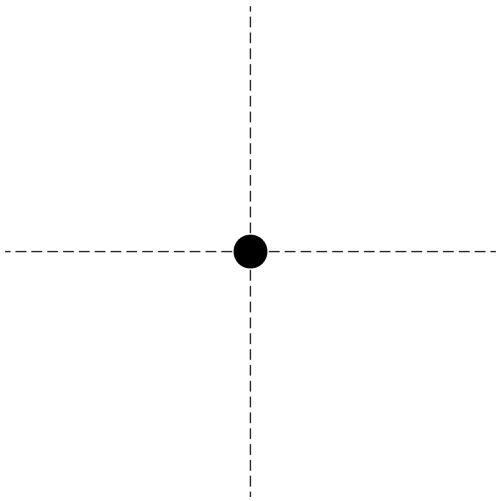
(c) Assume that, at $t = 0$ s, the horizontal position of the box is $x = 0$ and it has a vertical position of $y = 0$. Derive an equation that describes the vertical position y of the box as a function of the horizontal position x of the box.

(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 $t_1 < t < t_2$.

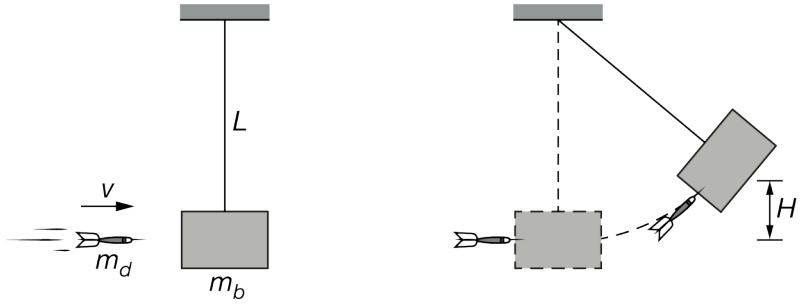
(e) The dot below represents the box during the time interval $t_1 < t < t_2$. On the dot, draw an arrow indicating the direction of the net force exerted on the block during this interval. The arrow should start on, and point away from, the dot.

frq3



frq3

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



A dart with mass m_d is launched toward a block of mass m_b that is suspended from a string of length *L*, as shown at left above. The dart is moving horizontally with speed *v* immediately before it strikes the block and remains embedded. The dart-block system then swings up to a point at which its center of mass reaches a maximum height *H* above its starting position, as shown at right above. The block's mass m_b is greater than the dart's mass m_d.

(a) Indicate which object, if either, experiences a net horizontal force of larger magnitude during the collision. If the net horizontal force is the same magnitude for both objects, state this explicitly. Briefly explain your reasoning.

(b) If the experiment was repeated with a dart with the same horizontal speed but with mass smaller than m_d, how would the maximum height reached by the center of mass of the dart-block system compare to *H* ? Explain your response without deriving or manipulating equations.

Two students are discussing the motion of the dart-block system at the instant it first reaches a height of $H/2$, and they make the following statements:

Student 1: When the dart-block system is at a height of $H/2$, the kinetic energy of the system is half of its maximum value, and therefore the speed of the system is half of its maximum speed.

Student 2: When the dart-block system reaches a height of $H/2$, the centripetal force is equal to the tension in the string. Therefore, the acceleration of the system must point toward the fixed end of the string.

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

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

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

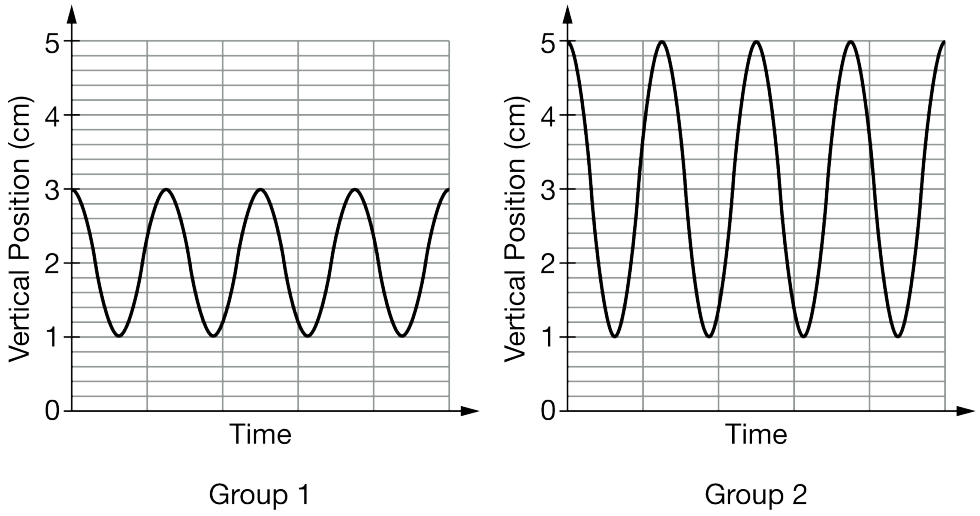
(f) Which underlined phrase or phrases, if either, are ***incorrect*** about student 2's statement? If neither phrase is ***incorrect***, write "none."

(g) The students correctly derive an equation for the maximum height: $H = \frac{1}{2g}\left(\frac{v}{1+\frac{m_b}{m_d}}\right)^2$. Explain how this

equation supports your claim in part (b).

(h) Could the masses of the dart and block both be changed so that the maximum height *H* reached by the dart-block system would remain the same as in the original setup? Justify your answer by referring to the equation in part (g).

After the collision, the dart-block system is then allowed to swing freely, and the students produce the graph shown below at left, labeled Group 1, of the vertical position of the center of mass of the dart-block system as a function of time. A second group of students makes a single change to the setup and then repeats the experiment. Their graph, labeled Group 2, of the vertical position of the center of mass of the dart-block system as a function of time is shown below at right.

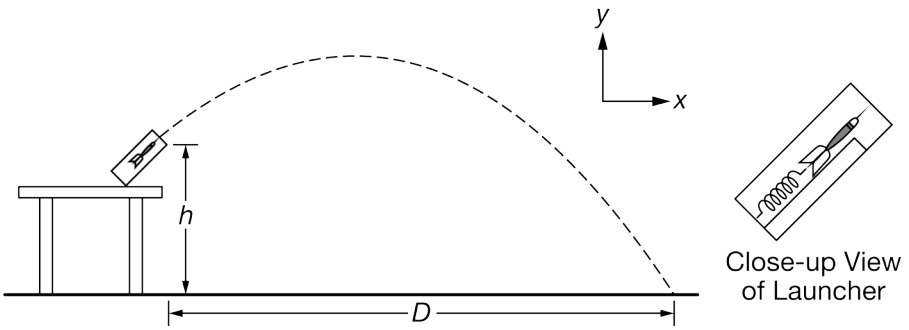


Note: The time scale is the same for both graphs.

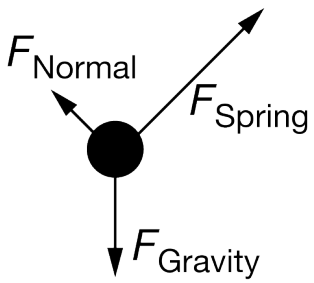
(i) Indicate the single difference in either the dart mass or the string length between group 1's setup and group 2's setup that could lead to the difference between the two graphs. Justify your answer.

frq3

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

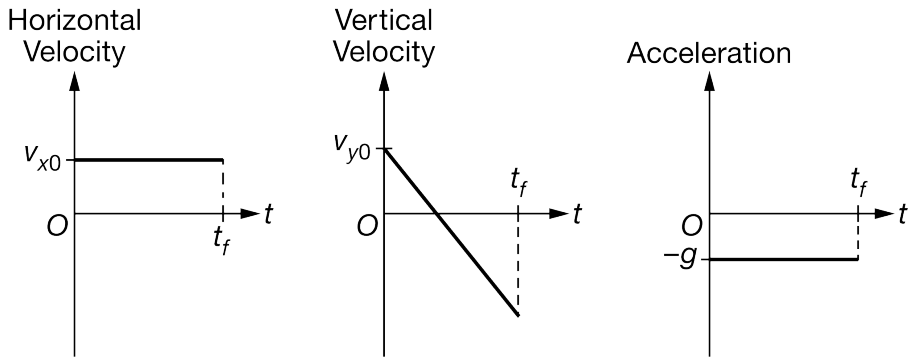


A launcher is used to launch a dart with initial speed v from a table at an angle, as shown above. The dart exits the end of the launcher at a height h above the floor and lands a horizontal distance D from the end of the launcher. A close-up view is included that shows the dart in the launcher immediately before being launched. Inside the launcher, the dart rests on a platform with negligible friction, and a compressed spring is released to push the dart out of the launcher. Assume air resistance is negligible.



(a) A diagram of the forces exerted on the dart while it is being launched is shown above. Describe what changes would need to be made to the diagram to make it a correct diagram for the dart when it is in the air (after it has left the launcher but before it has reached the ground). Assume air resistance is negligible.

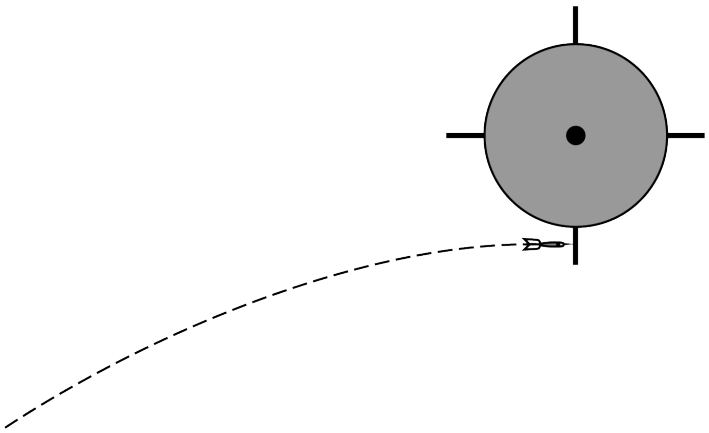
The three graphs shown below represent properties of the motion of the dart from the instant it is launched at time $t = 0$ until immediately before it hits the floor at time t_f.



(b) Assuming the values of v_{x0}, v_{y0}, t_f, and g are known, which of the above graphs could lead to a determination of the distance D, and how could a student use the chosen graph to determine D ?

(c) After the dart passes the highest point of its trajectory, the angle between the velocity vector of the dart and the horizontal (the x-axis) continues to increase until the dart strikes the ground. In a clear, coherent, paragraph-length response, explain the following:

- why the angle between the dart's velocity and the horizontal continues to increase and
- why, no matter how large the height h of the end of the launcher is, the angle between the dart's velocity and the horizontal can never be 90 degrees.

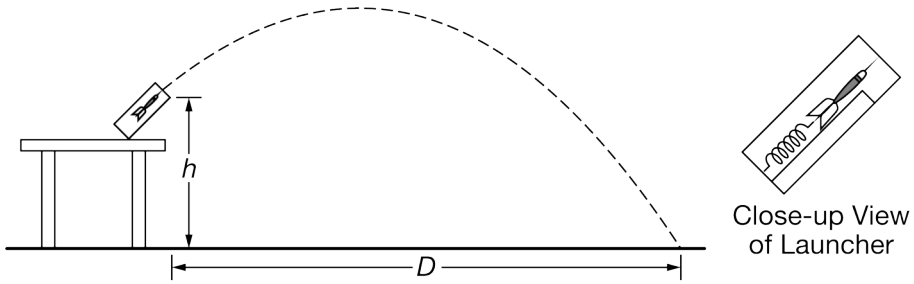


The dart is now launched so that it collides and sticks to a wheel at the instant its velocity is completely horizontal, as shown above. The wheel is free to rotate about a pivot at its center that has negligible friction.

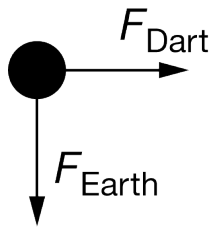
(d) Indicate whether the linear momentum of the dart-wheel system will be constant during the collision. Justify your answer.

frq3

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

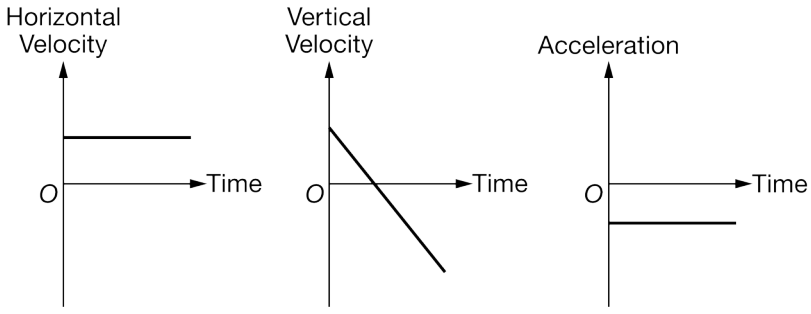


A launcher is used to launch a dart with initial speed v from a table at an angle, as shown above. The dart exits the end of the launcher at a height h above the floor and lands a horizontal distance D from the end of the launcher. A close-up view is included that shows the dart in the launcher immediately before being launched. Inside the launcher, the dart rests on a platform with negligible friction, and a compressed spring is released to push the dart out of the launcher. Assume air resistance is negligible.



(a) A student creates the incorrect diagram shown above of the forces exerted on the dart at an instant in time after it has been launched but before it reaches the floor. Indicate what aspect of the diagram is incorrect. Assume air resistance is negligible.

A student produces the three possibly incorrect graphs shown below representing properties of the motion of the dart after it is launched.

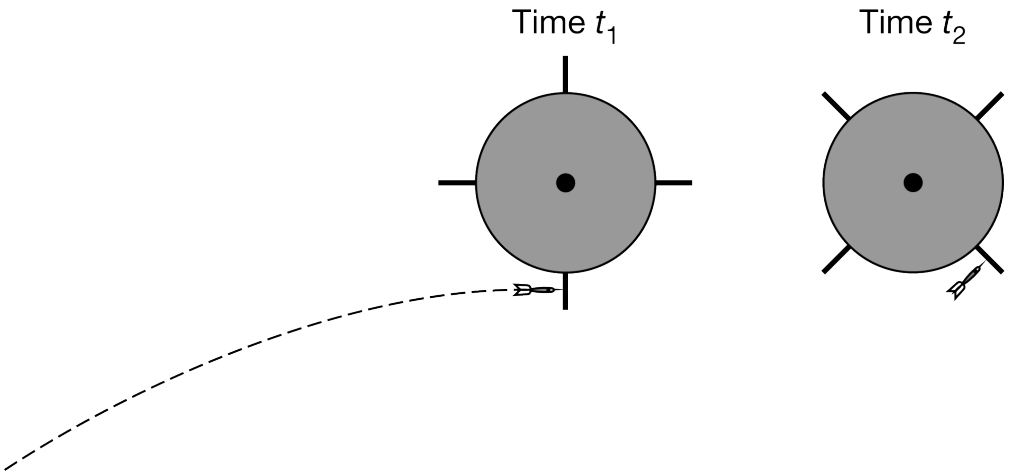


(b) Another student claims that the horizontal velocity graph is not correct because the dart is accelerating, and therefore the horizontal velocity is not constant. Is the student's claim valid? Justify your answer.

(c) From the instant the dart is launched until it reaches the highest point in its trajectory, the magnitude of the dart's velocity decreases. In a clear, coherent, paragraph-length response, explain the following:

frq3

why the magnitude of the dart's velocity decreases until the dart reaches its highest point and why the magnitude of the dart's velocity does not decrease to zero.

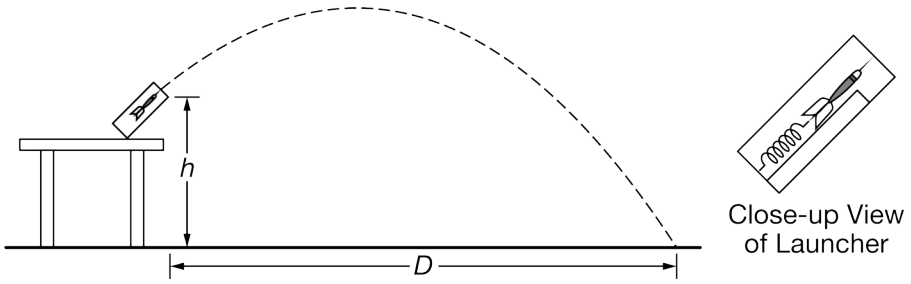


The dart is now launched so that it collides with and sticks to a wheel at time t_1, which is the instant the dart's velocity is completely horizontal, as shown above at left. The wheel is initially at rest and is free to rotate about a pivot at its center that has negligible friction. A short time later, at time t_2, the dart-wheel system is still rotating in a counterclockwise direction, as shown above at right.

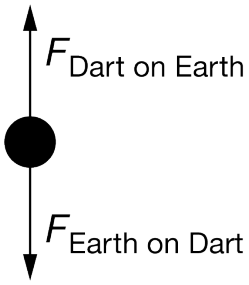
(d) At time t_2, is the angular speed of the dart-wheel system about the pivot increasing, decreasing, or constant? Justify your answer.

frq3

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

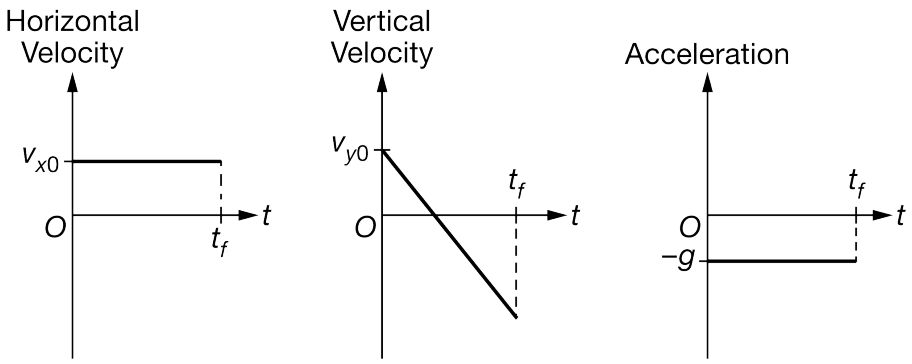


A launcher is used to launch a dart with initial speed v from a table at an angle, as shown above. The dart exits the end of the launcher at a height h above the floor and lands a horizontal distance D from the end of the launcher. A close-up view is included that shows the dart in the launcher immediately before being launched. Inside the launcher, the dart rests on a platform with negligible friction, and a compressed spring is released to push the dart out of the launcher. Assume air resistance is negligible.



(a) A student creates the incorrect diagram shown above of the forces exerted on the dart at an instant in time after it has been launched but before it reaches the floor. Indicate what aspect of the diagram is incorrect. Assume air resistance is negligible.

The three graphs shown below represent properties of the motion of the dart from the instant it is launched at time $t = 0$ until immediately before it hits the floor at time t_f.



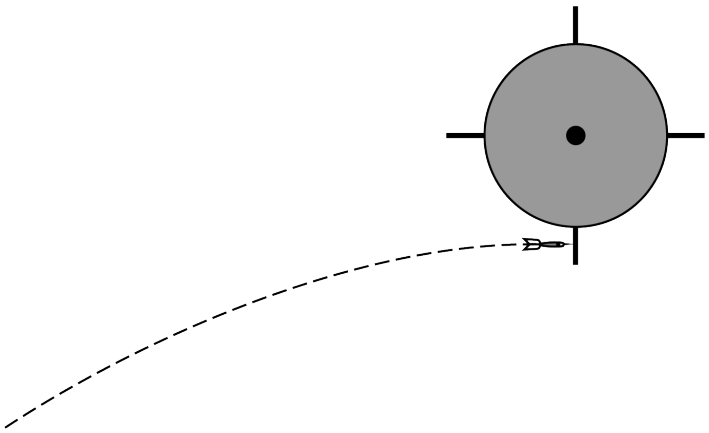
(b) Assuming the values of v_{x0}, v_{y0}, t_f, and g are known, which of the above graphs could lead to a

frq3

determination of the height h, and how could a student use the chosen graph to determine h ?

(c) After the dart passes the highest point of its trajectory, the angle between the velocity vector of the dart and the acceleration vector of the dart decreases until the dart strikes the ground. In a clear, coherent, paragraph-length response, explain the following:

- why the angle between the dart's velocity and acceleration continues to decrease and
- why, no matter how large the height h of the end of the launcher is, the angle between the dart's velocity and acceleration can never reach zero degrees.

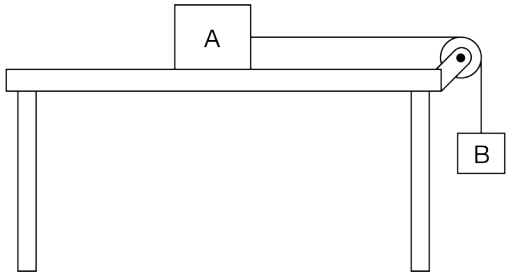


The dart is now launched so that it collides and sticks to a wheel at the instant its velocity is completely horizontal, as shown above. The wheel is free to rotate about a pivot at its center that has negligible friction.

(d) Indicate whether the angular momentum of the dart-wheel system about the pivot will be constant during the collision. Justify your answer.

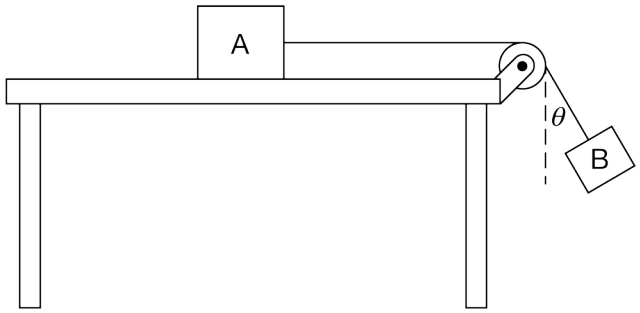
frq3

17. 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).

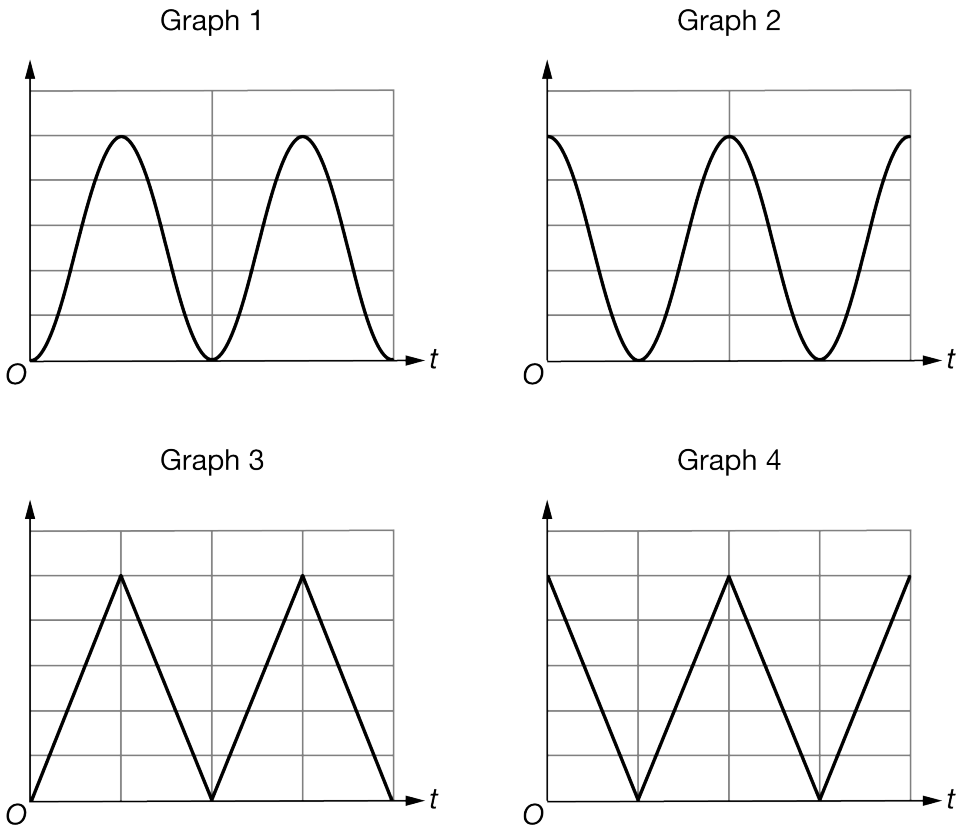
(a) What is the magnitude of the frictional force acting on block A? Justify your answer.



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.

frq3



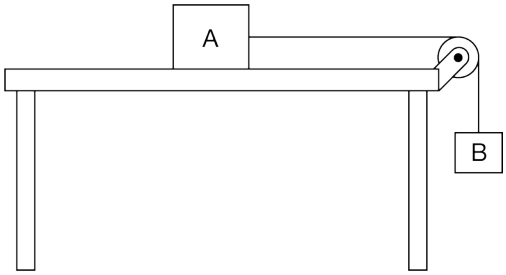
(b) Block A is held at rest while block B swings back and forth. Which of the graphs shown above best represents the kinetic energy of block B as a function of time *t* after it is released from rest at time $t = 0$? Explain your reasoning.

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.

frq3

18. 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.

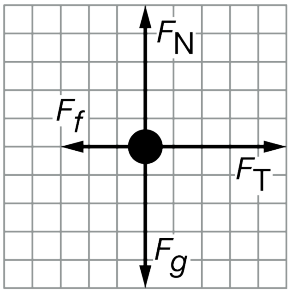


Figure 1

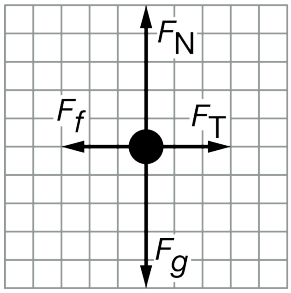


Figure 2

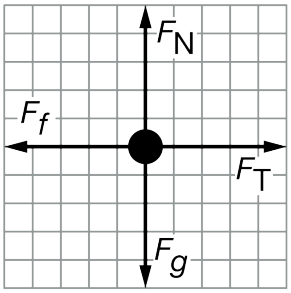


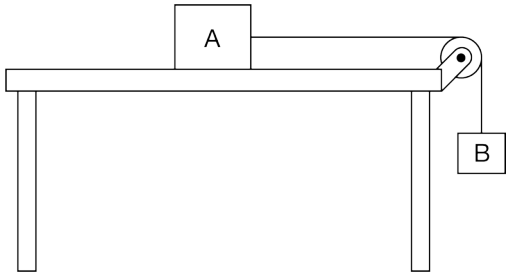
Figure 3

(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.

frq3

19. 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).

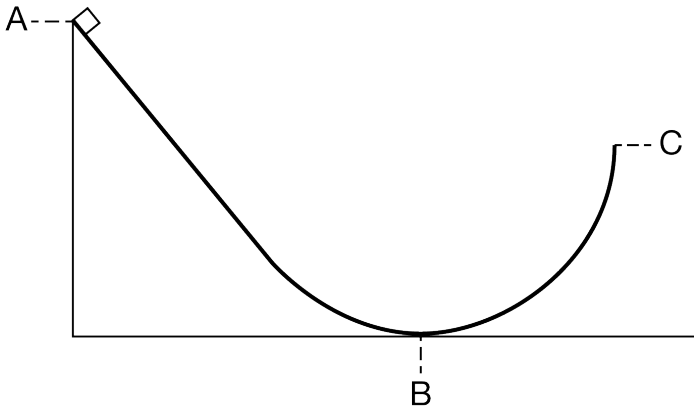
(a) A student claims the magnitude of the frictional force acting on block A must be equal to $\mu m_{\mathrm{A}} g$. Briefly explain why the student's claim is incorrect.

(b) Block B is given a quick downward push so that block A begins accelerating across the tabletop and block B accelerates toward the floor. The tension in the string while the two-block system accelerates is T_2. How does T_2 compare to T_1 ? Explain your reasoning.

(c) After block B falls a distance , the blocks have speed v_1. In a second trial, the pulley of negligible mass is replaced with a different pulley whose mass is not negligible, and the process described in part (b) is repeated. After block B again falls a distance d, the blocks have speed v_2. In a clear, coherent, paragraph-length response, explain how v_1 and v_2 compare.

frq3

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



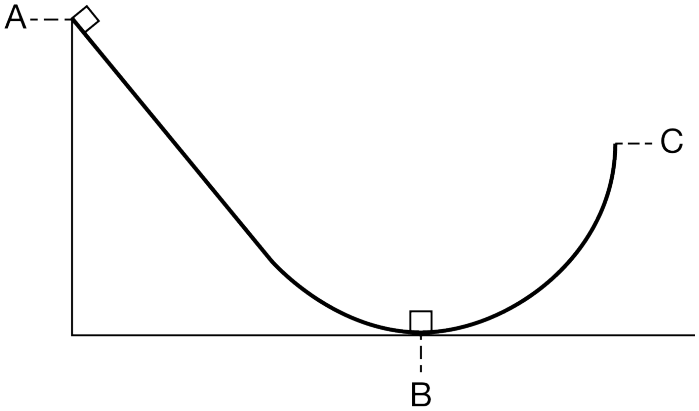
The figure above shows a track consisting of a straight section that connects to a circular section. The bottommost point of the track is at location B, and the track ends at location C, where the track is vertical. A block is released from rest at location A. There is negligible friction between the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



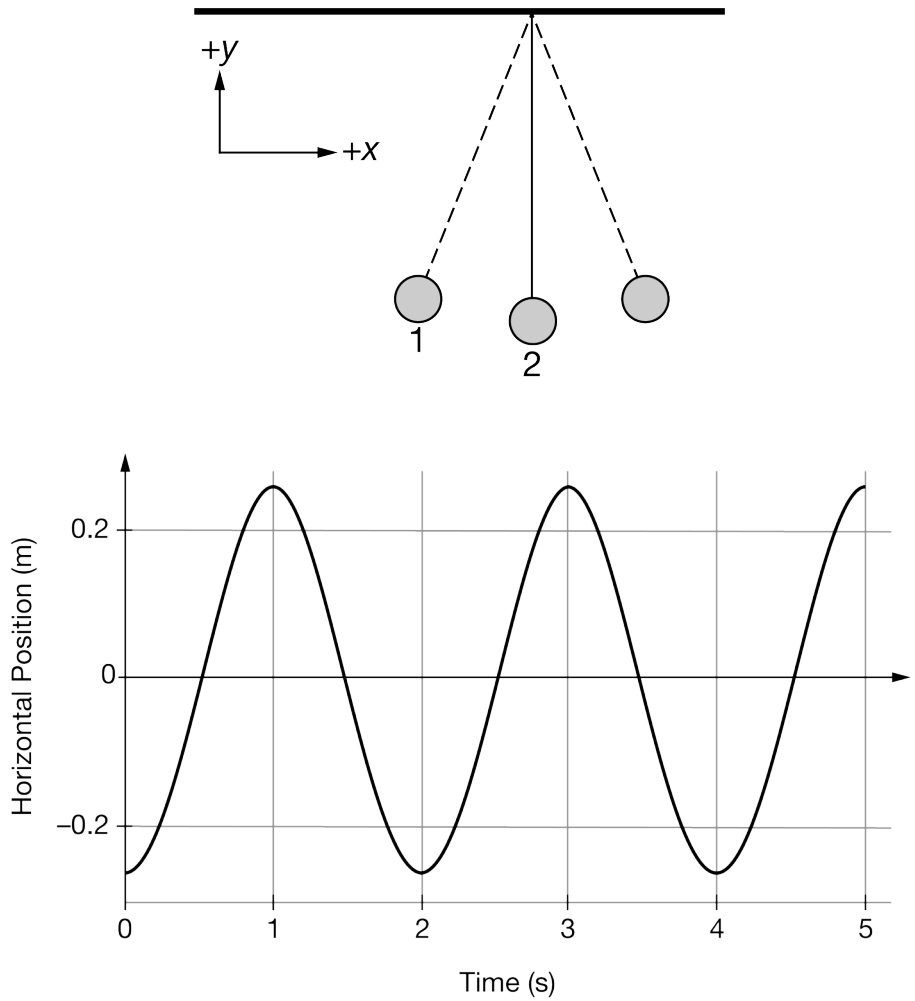
(c) The scenario is repeated, but an identical block is at rest at location B, as shown above. When the block at location A is released from rest, it slides down the track and collides with and sticks to the identical block. The

frq3

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.

frq3

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

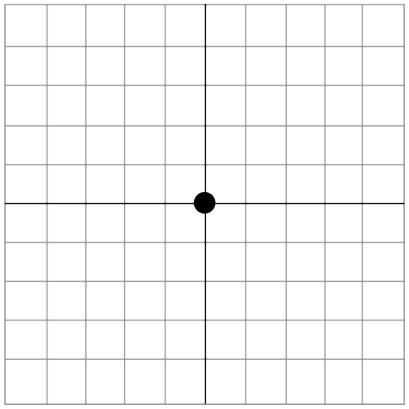


One end of a string is secured to the ceiling of a classroom, and the other end of the string is attached to a sphere of mass $0.2\ \text{kg}$ so that a pendulum is established. The sphere is raised at an angle of 15° above the sphere's equilibrium position and then released from rest so that the pendulum oscillates, as shown in the figure. Location 1 is shown in the figure. A graph of the pendulum's horizontal position as a function of time is shown in the graph.

(a) The dot below represents the sphere at location 2. Draw a free-body diagram that shows and labels the forces (not components) exerted on the sphere at the location. Draw the relative lengths of all vectors to reflect the relative magnitudes of all forces.

frq3

Location 2



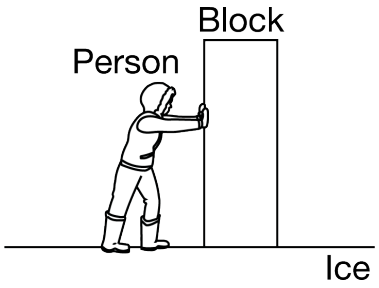
(b) Calculate the maximum kinetic energy of the sphere as it oscillates.

The sphere is raised to a new angle above the sphere's equilibrium position that is less than the angle described for part (a). The sphere is released from rest so that the pendulum oscillates.

(c) Explain how the motion of the sphere changes, if at all, based on the appropriate evidence.

frq3

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



A person pushes a large block on a horizontal ice surface in a straight line to the right with constant speed, as shown above. The mass of the block is $10\ \text{kg}$ and frictional forces between the block and the ice are negligible. However, the block has a wide cross-sectional area such that air resistance acting on the block cannot be neglected. The opposite is true for the person: air resistance on the person is negligible, but the person's shoes do not slip on the ice. The table shows the force exerted by the person on the block for several values of constant speed.

Force of person's push (N)	**Constant speed of block** $(\text{m/s}) \pm 0.05$
20	1.25
40	2.51
60	3.73
80	5.00

(a) A student claims that the data show that the magnitude of the force of air resistance is proportional to the speed of the object, within experimental uncertainty. Use physics principles to explain whether the claim is correct.

(b) As the person pushes the block, the person moves with the same constant speed as the block. Consider the scenario in which the person's speed is $5.00\ \text{m/s}$.

i. On the dot below, which represents the person, draw and label the forces (not components) exerted on the person. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

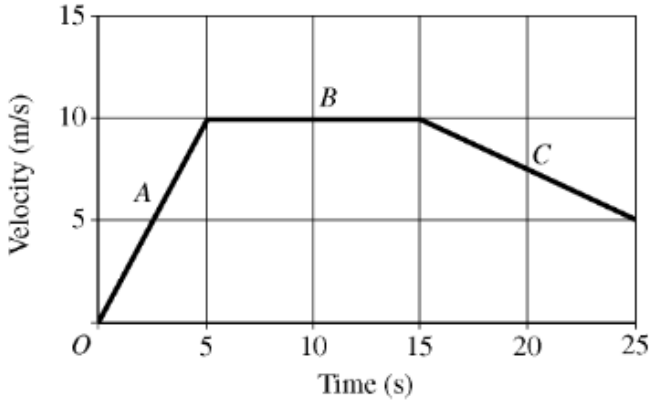


frq3

ii. The person now stops and releases the block. Determine the magnitude and direction of the block's acceleration at the instant the block is released.

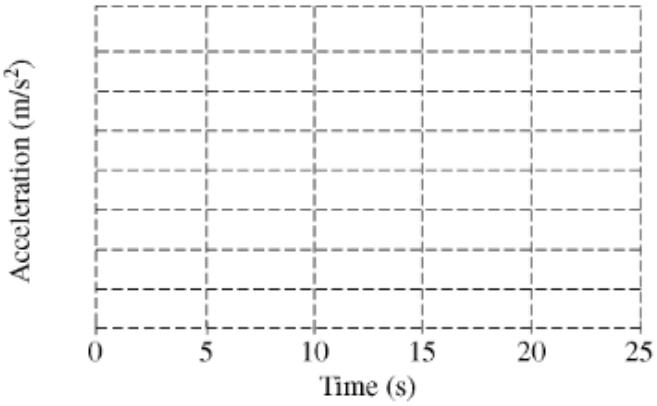
frq3

23.



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.

frq3

(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.

frq3

24.



The Sojourner rover vehicle shown in the sketch above was used to explore the surface of Mars as part of the Pathfinder mission in 1997. Use the data in the tables below to answer the questions that follow.

Mars Data	Sojourner Data
Radius: 0.53 x Earth's radius Mass: 0.11 x Earth's mass	Mass of Sojourner vehicle: 11.5 kg Wheel diameter: 0.13 m Stored energy available: 5.4 x 10^5J Power required for driving under average conditions: 10W Land speed: 6.7 x 10^{-3} m/s

1. Determine the acceleration due to gravity at the surface of Mars in terms of *g*, the acceleration due to gravity at the surface of Earth.

2. Calculate Sojournerís weight on the surface of Mars.

3. Assume that when leaving the Pathfinder spacecraft Sojourner rolls down a ramp inclined at 20° to the horizontal. The ramp must be lightweight but strong enough to support Sojourner. Calculate the minimum normal force that must be supplied by the ramp.

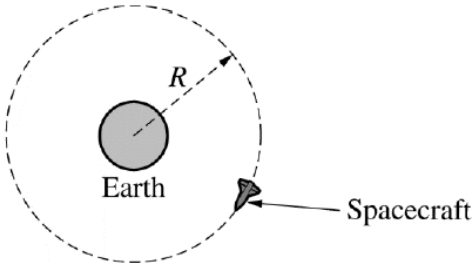
4. What is the net force on Sojourner as it travels across the Martian surface at constant velocity? Justify your answer.

5. Determine the maximum distance that Sojourner can travel on a horizontal Martian surface using its stored energy.

6. Suppose that 0.010% of the power for driving is expended against atmospheric drag as Sojourner travels on the Martian surface. Calculate the magnitude of the drag force.

frq3

25.

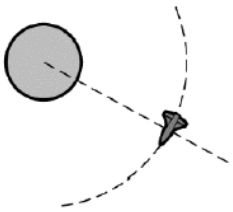


Note: Figure not drawn to scale.

A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above.

The mass of Earth is M_E.

a. In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.



Note: Figure not drawn to scale.

b. i. Derive an equation for the orbital period T of the spacecraft in terms of m, M_E, R, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

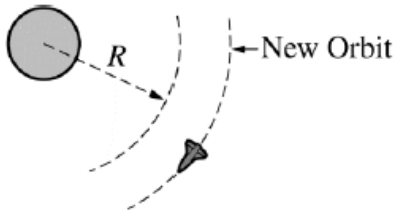
ii. A second spacecraft of mass $2m$ is placed in a circular orbit with the same radius R. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

____Greater than ____Less than ____Equal to

Briefly explain your reasoning.

c. The first spacecraft is moved into a new circular orbit that has a radius greater than R, as shown in the figure below.

frq3



Note: Figure not drawn to scale.

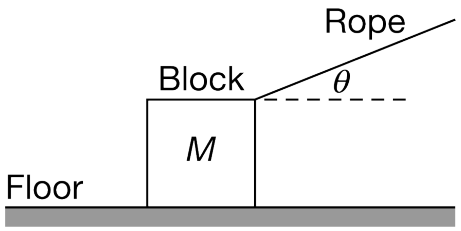
Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

____Greater than ____Less than ____Equal to

Briefly explain your reasoning.

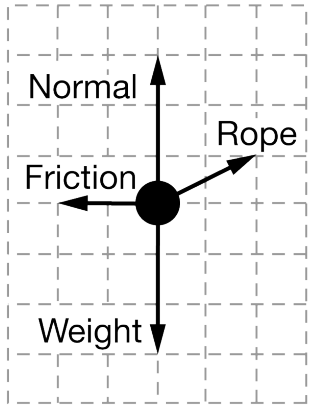
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26. This question is a long free-response question. Show your work for each part of the question. (15 points, suggested time 25 minutes)

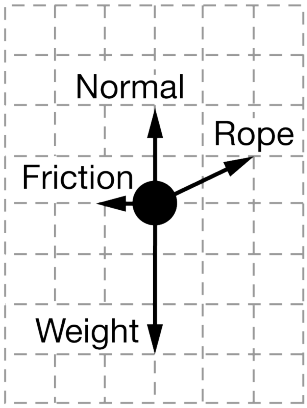


A block of mass M is pulled by a rope that makes an angle θ (theta) above the horizontal, as shown above. The coefficient of kinetic friction between the block and floor is μ (mu).

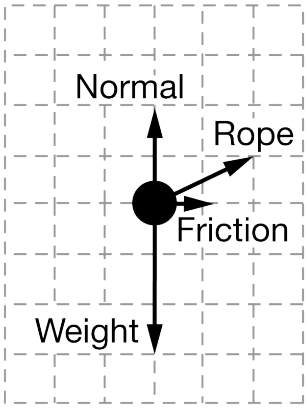
The block is initially at rest and starts accelerating to the right along the floor. Three students each draw a diagram to indicate all of the forces that are exerted on the block as it moves. In the students' diagrams, which are shown below, the lengths of the arrows indicate the relative magnitudes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

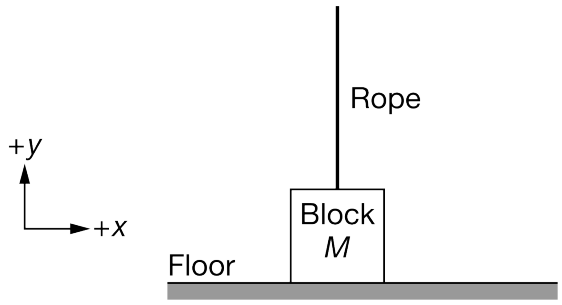
(a) Which student has drawn a diagram that could correctly represent the forces exerted on the block?

(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.

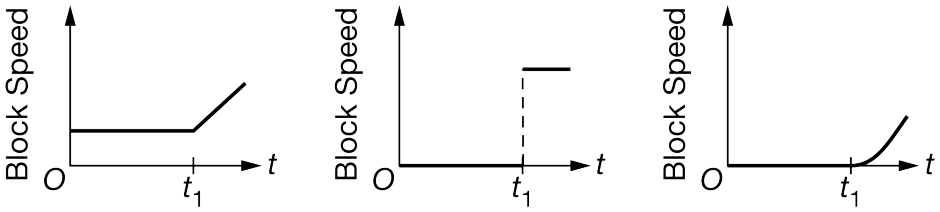
(c) Briefly explain why slightly increasing the force F exerted by the rope on the block (without changing the angle θ) would cause a decrease in the friction force.

(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.

frq3



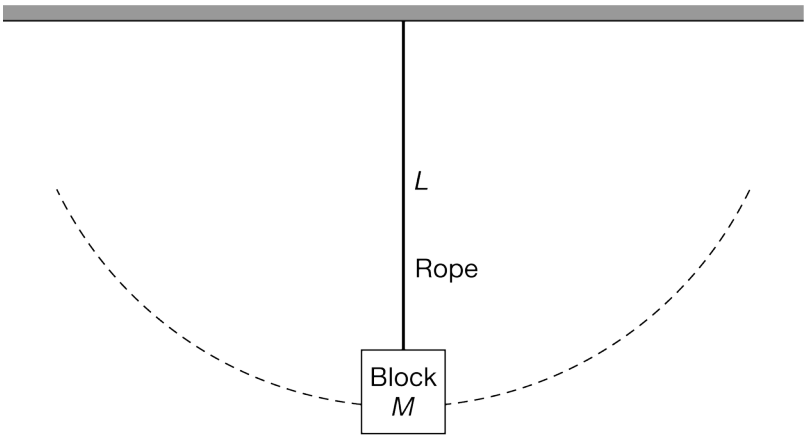
The rope is now attached to the center of the top of the block, as shown above. The force exerted by the rope is initially zero newtons at time $t = 0$. The force steadily increases, becomes equal to the block's weight W at time t_1, and continues to increase further. Three students sketch the graphs 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.

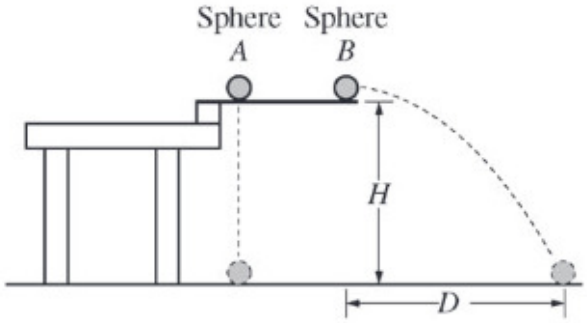
With one end of the rope still attached to the block, the other end of the rope is attached to a ceiling to create a

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.

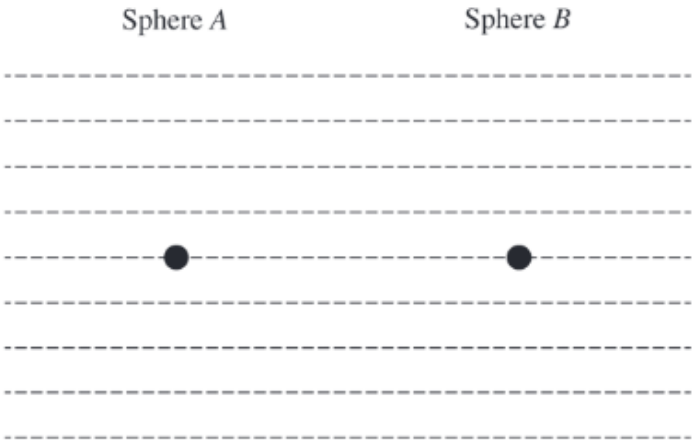
frq3

27.



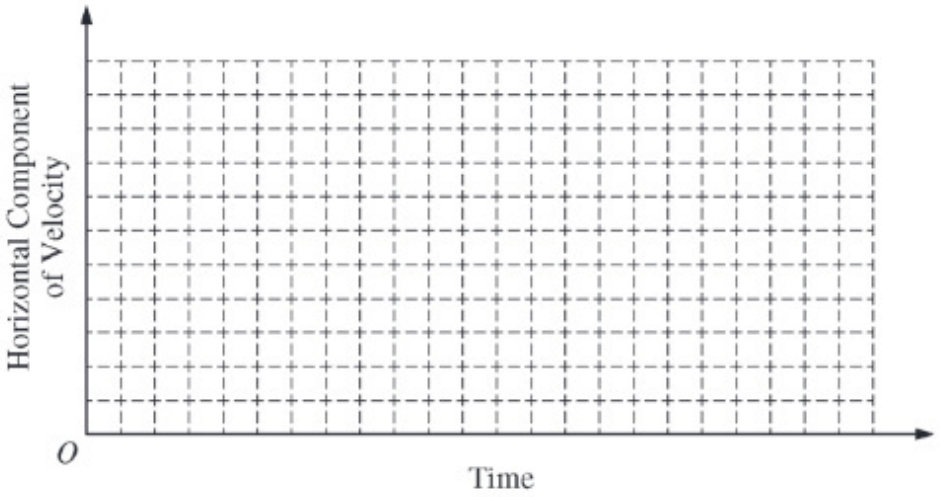
Two identical spheres are released from a device at time t = 0 from the same height H, as shown above. Sphere A has no initial velocity and falls straight down. Sphere B is given an initial horizontal velocity of magnitude v_0 and travels a horizontal distance D before it reaches the ground. The spheres reach the ground at the same time t_f, even though sphere B has more distance to cover before landing. Air resistance is negligible.

(a) The dots below represent spheres A and B. Draw a free-body diagram showing and labeling the forces (not components) exerted on each sphere at time $\frac{t_f}{2}$.



(b) On the axes below, sketch and label a graph of the horizontal component of the velocity of sphere A and of sphere B as a function of time.

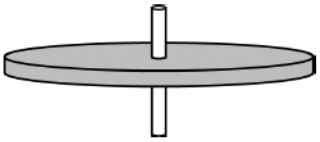
frq3



(c) In a clear, coherent, paragraph-length response, explain why the spheres reach the ground at the same time even though they travel different distances. Include references to your answers to parts (a) and (b).

frq3

28.

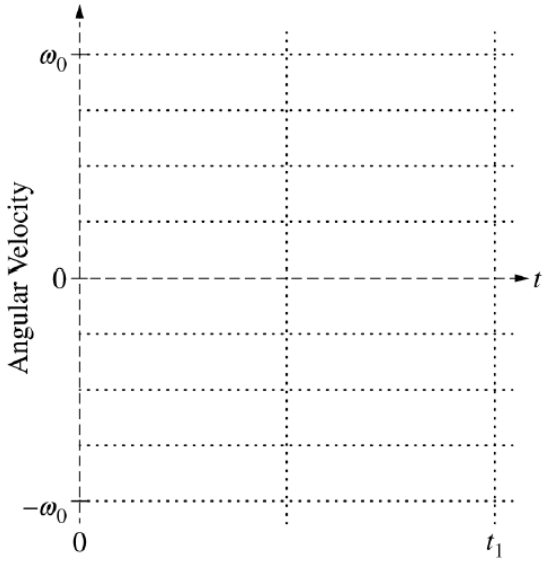


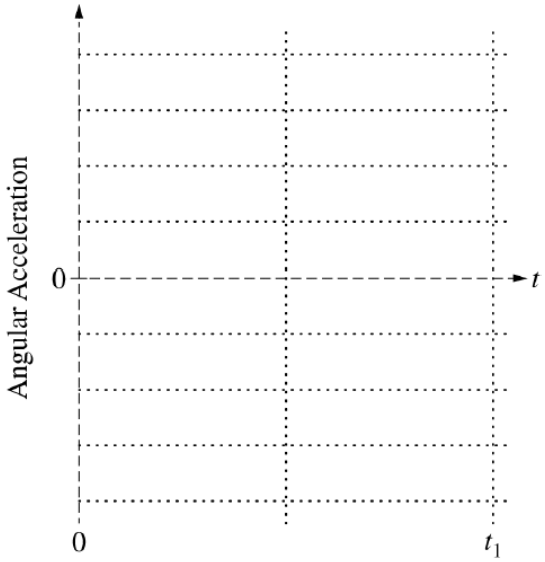
The disk shown above spins about the axle at its center. A student's experiments reveal that, while the disk is spinning, friction between the axle and the disk exerts a constant torque on the disk.

a. At time $t = 0$ the disk has an initial counterclockwise (positive) angular velocity ω_0.The disk later comes to rest at time $t = t_1$.

   i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.

   ii. On the grid at right below, sketch the disk's angular acceleration as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.



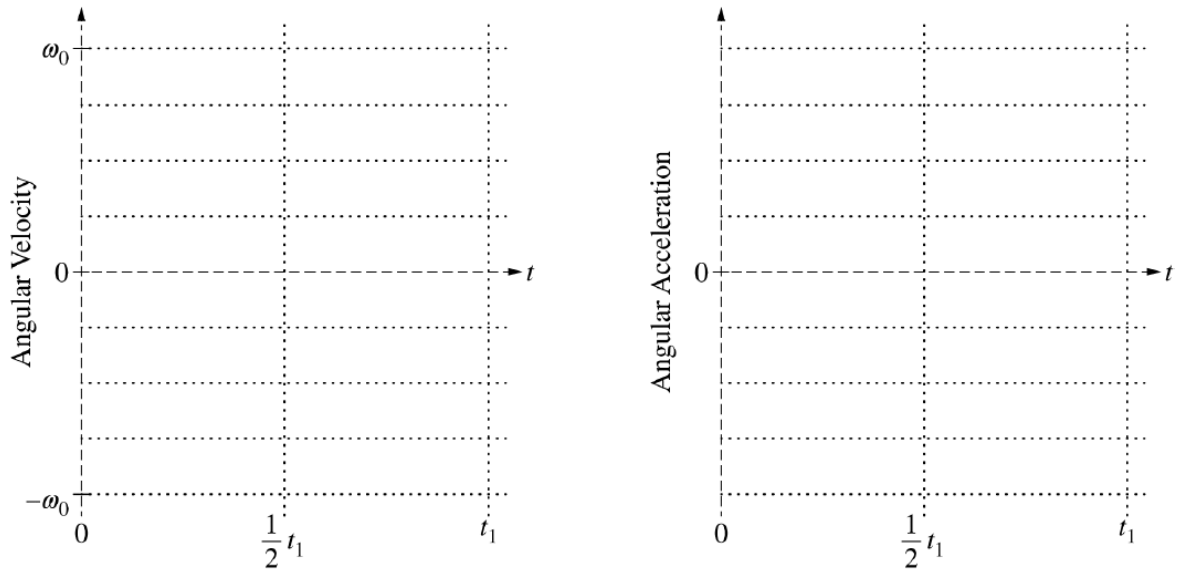


b. The magnitude of the frictional torque exerted on the disk is τ_0. Derive an equation for the rotational inertia I of the disk in terms of τ_0, ω_0, t_1, and physical constants, as appropriate.

c. In another experiment, the disk again has an initial positive angular velocity ω_0 at time $t = 0$. At time $t = \frac{1}{2}t_1$, the student starts dripping oil on the contact surface between the axle and the disk to reduce the friction. As time passes, more and more oil reaches that contact surface, reducing the friction even further.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time from $t = 0$ to $t = t_1$, which is the time at which the disk came to rest in part (a).

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time from $t = 0$ to $t = t_1$.



d. The student is trying to mathematically model the magnitude τ of the torque exerted by the axle on the disk when the oil is present at times $t > \frac{1}{2}t_1$. The student writes down the following two equations, each of which includes a positive constant (C_1 or C_2) with appropriate units.

$$(1)\ \tau = C_1\left(t - \tfrac{1}{2}t_1\right) \text{ (for } t > \tfrac{1}{2}t_1\text{)}$$
$$(2)\ \tau = \frac{C_2}{\left(t + \frac{1}{2}t_1\right)} \text{ (for } t > \tfrac{1}{2}t_1\text{)}$$

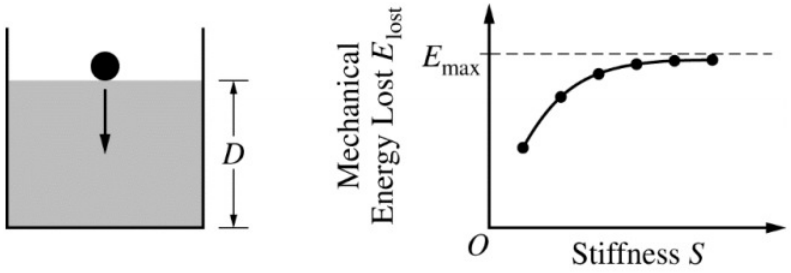
Which equation better mathematically models this experiment?

____Equation (1) ____Equation (2)

Briefly explain why the equation you selected is plausible and why the other equation is not plausible.

frq3

29.



Food scientists have created a new oil. At room temperature, the oil is a liquid. As the oil gets colder, however, it stiffens (thickens) into a sticky gel. To explore the properties of the oil, the scientists fill a container with the oil to a height D, as shown in the figure above on the left. They drop a small steel ball of mass M from rest at the top of the oil. Using video to capture the ball's motion, the scientists calculate E_{lost} , the mechanical energy lost by the ball-Earth system from the time the ball enters the oil to the time just before the ball strikes the bottom of the container. The scientists also define the "stiffness" S of the oil as a quantity proportional to the force required to move a rod through the oil at a standard constant speed. The scientists calculate E_{lost} and S at several different temperatures, ranging from room temperature to the lowest temperature at which the ball still falls through the oil. The graph above on the right shows E_{lost} as a function of S for the calculated data points and a best-fit curve.

a. Give a physical reason why the curve in the graph would not reach the vertical (E_{lost}) axis even if the scientists had taken data over a broader range of temperatures.

b. As S increases, E_{lost} approaches a maximum value labeled E_{max} on the graph above. Write an equation for E_{max} in terms of *M, D*, and physical constants, as appropriate.

   Justify your answer.

c. One of the scientists, in trying to represent the relationship between the oil stiffness and the mechanical energy lost, writes down the equation $2\ E_{lost} = CS^2$, where *C* is a constant with appropriate units. Another scientist points out that this equation cannot be correct. Give two reasons why the equation cannot be correct.

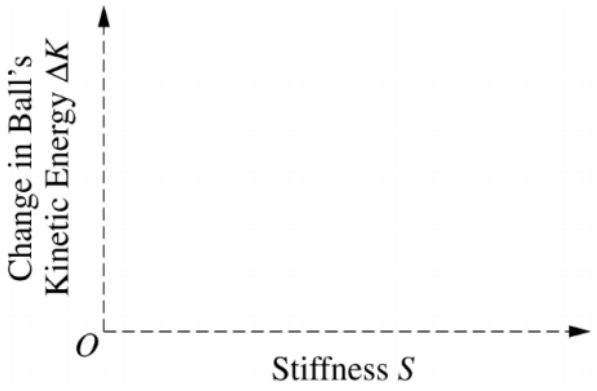
d. Further attempting to model the ball's motion, the scientists write the following equation for the time t the ball takes to fall through the oil: $t = Z/S$, where Z is a constant with appropriate units. Is this equation plausible—in other words, does it make physical sense?

   ____ Plausible ____ Not plausible

   Briefly explain your reasoning.

e. ΔK is the change in kinetic energy of the ball between the time it is released from rest and the time just before the ball strikes the bottom of the container. On the axes below, sketch ΔK as a function of S, the oil stiffness.

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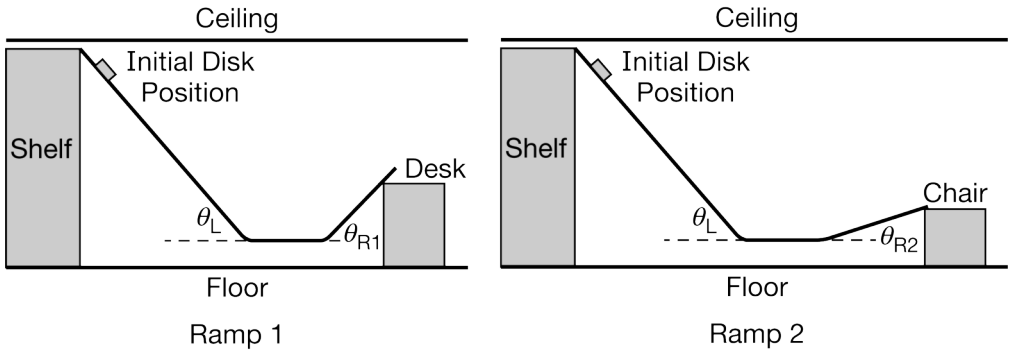


frq3

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

A class of physics students is investigating projectile motion using a variety of equipment. Assume air resistance can be ignored in all cases.

One group constructs a long ramp as shown in Ramp 1 below. In their experiment, they release a disk from the left side of the ramp and allow the disk to launch off the right side. The ramp is smooth enough that friction can be ignored. The left side of the ramp is supported by the top of a shelf, and the other side is supported by the top of a desk. The left and right sides of the ramp are at angles θ_{L} and θ_{R1} with the horizontal respectively.

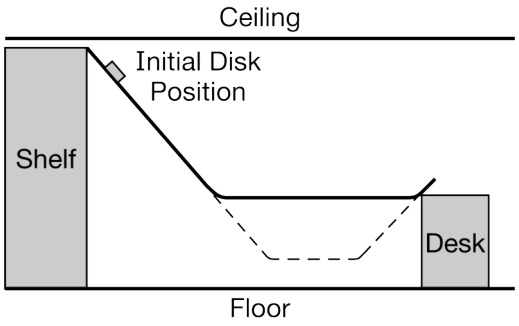


Note: Figures not drawn to scale.

The students release a disk and measure the maximum height it reaches after leaving the right side of the ramp. The students then adjust the ramp so that $\theta_{\mathrm{R2}} < \theta_{\mathrm{R1}}$ and the height of the right side of the ramp is lower as shown in the Ramp 2 configuration above. Assume the length of the right section of the ramp is the same in both cases.

(a) Will the disk launched from Ramp 2 reach a maximum height that is greater than, less than, or equal to the maximum height reached by the disk launched from Ramp 1? Justify your answer.

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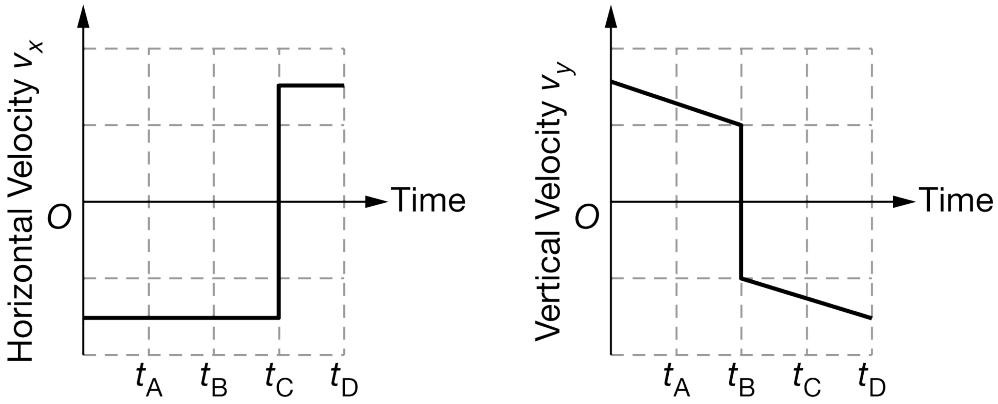


Ramp 3

Note: Figure not drawn to scale.

Finally, the students adjust the ramp into the configuration labeled Ramp 3 above in which the horizontal section of the ramp is at a greater height than in Ramp 1, which is represented by the dotted line. The students release the disk on Ramp 3.

(b) On which ramp, Ramp 1 or Ramp 3, if either, does the disk spend more time on the horizontal section of the ramp before launching off the right side? Explain your answer.



One group uses a device that can launch a steel ball. The group launches the ball and it bounces off the ceiling, floor, and wall several times though not necessarily in that order. Each collision can be modeled as elastic, and friction between the ball and the surfaces is negligible. The graphs above show the horizontal and vertical components of the velocity of the ball during some time interval in the ball's motion. The positive direction is taken to be upward.

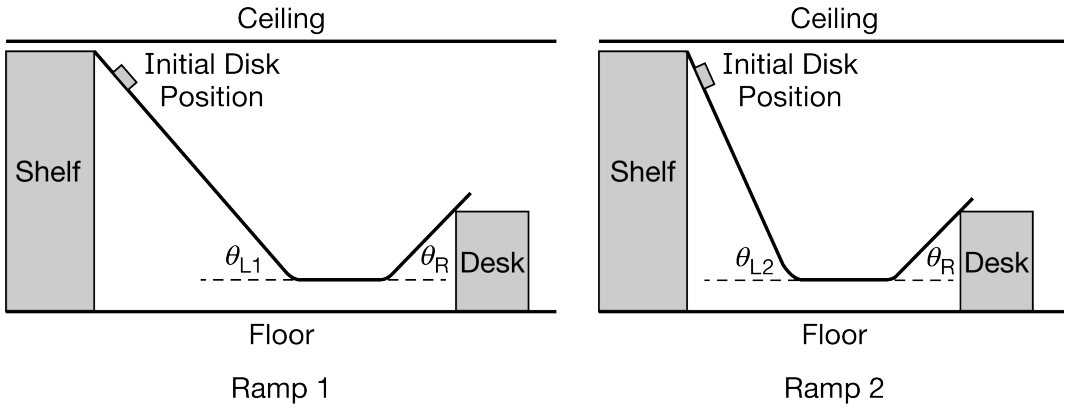
(c) During the time interval shown in the graphs, the ball has two collisions. In a clear, coherent, paragraph-length response, identify the times when these collisions occur using the times indicated on the graph, and explain how you know whether each collision is with the wall, the ceiling, or the floor.

frq3

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

A class of physics students is investigating projectile motion using a variety of equipment. Assume air resistance can be ignored in all cases.

One group constructs a long ramp as shown in Ramp 1 below. In their experiment, they release a disk from the left side of the ramp and allow the disk to launch off the right side. The ramp is smooth enough that friction can be ignored. The left side of the ramp is supported by the top of a shelf, and the other side is supported by the top of a desk. The left and right sides of the ramp are at angles θ_{L1} and θ_{R} with the horizontal respectively.

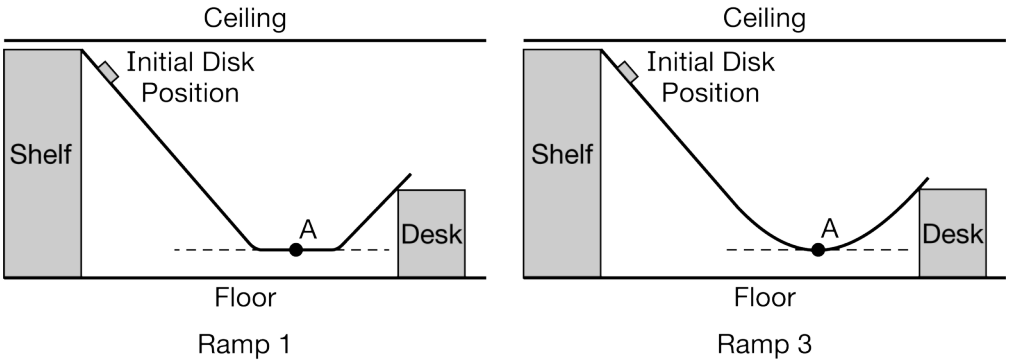


Note: Figures not drawn to scale.

The students release a disk from Ramp 1 and measure the maximum height it reaches after leaving the right side of the ramp. The students then increase the angle of the left ramp so that $\theta_{\mathrm{L1}} < \theta_{\mathrm{L2}}$, and they keep the top of the ramp against the shelf as shown in the Ramp 2 configuration above so that the disk is released at the same height.

(a) Will the disk launched from Ramp 2 reach a maximum height that is greater than, less than, or equal to the maximum height reached by the disk launched from Ramp 1? Justify your answer.

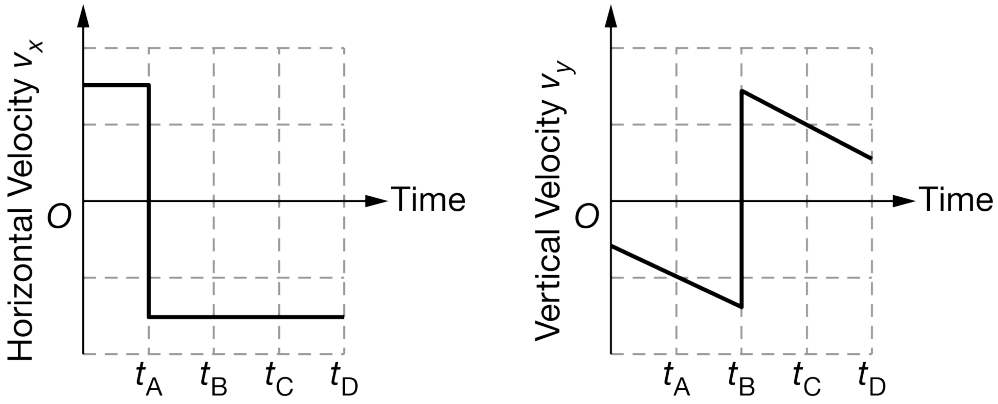
frq3



Note: Figures not drawn to scale.

Next, the students adjust the ramp into the configuration labeled Ramp 3 in which the lowest part of the ramp has been shaped into a circular curve. The lowest point of Ramp 3 is at the same height as the lowest section of Ramp 1. Both ramps are shown above.

(b) On which ramp, Ramp 1 or Ramp 3, is the force exerted by the ramp on the disk at point A greater? Explain your answer.

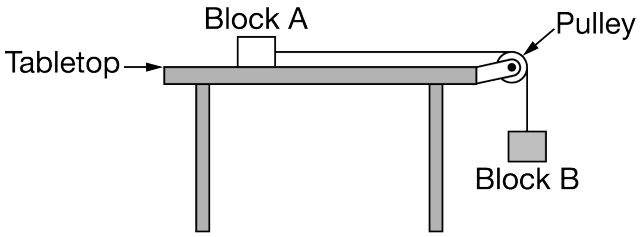


Another group uses a device that can launch a steel ball. The group launches the ball and it bounces off the ceiling, floor, and wall several times though not necessarily in that order. Each collision can be modeled as elastic, and friction between the ball and the surfaces is negligible. The graphs above show the horizontal and vertical components of the velocity of the ball during some time interval in the ball's motion. The positive direction is taken to be upward.

(c) During the time interval shown in the graphs, the ball has two collisions. In a clear, coherent, paragraph-length response, identify the times when each of these collisions occur using the times indicated on the graph, and explain how you know whether each collision is with the wall, the ceiling, or the floor.

frq3

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



(12 points, suggested time 25 minutes)

This problem explores how the relative masses of two blocks affect the acceleration of the blocks. Block A, of mass m_A, rests on a horizontal tabletop. There is negligible friction between block A and the tabletop. Block B, of mass m_B, hangs from a light string that runs over a pulley and attaches to block A, as shown above. The pulley has negligible mass and spins with negligible friction about its axle. The blocks are released from rest.

(a)

i. Suppose the mass of block A is much greater than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Briefly explain your reasoning without deriving or using equations.

ii. Now suppose the mass of block A is much less than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Briefly explain your reasoning without deriving or using equations.

(b) Now suppose neither block's mass is much greater than the other, but that they are not necessarily equal. The dots below represent block A and block B, as indicated by the labels. On each dot, draw and label the forces (not components) exerted on that block after release. Represent each force by a distinct arrow starting on, and pointing away from, the dot.



(c) Derive an equation for the acceleration of the blocks after release in terms of m_A, m_B, and physical constants, as appropriate. 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).

(d) Consider the scenario from part (a)(ii), where the mass of block A is much less than the mass of block B. Does your equation for the acceleration of the blocks from part (c) agree with your reasoning in part (a)(ii)?

_____ Yes _____ No

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Briefly explain your reasoning by addressing why, according to your equation, the acceleration becomes (or approaches) a certain value when m_A is much less than m_B.

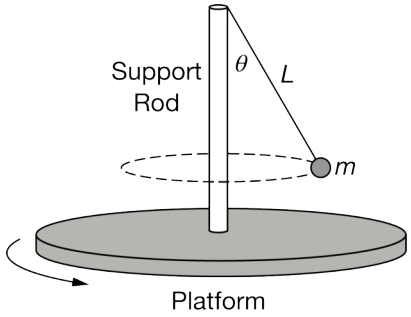
(e) While the blocks are accelerating, the tension in the vertical portion of the string is T_1. Next, the pulley of negligible mass is replaced with a second pulley whose mass is not negligible. When the blocks are accelerating in this scenario, the tension in the vertical portion of the string is T_2. How do the two tensions compare to each other?

_____ $T_2 > T_1$ _____ $T_2 = T_1$ _____ $T_2 < T_1$

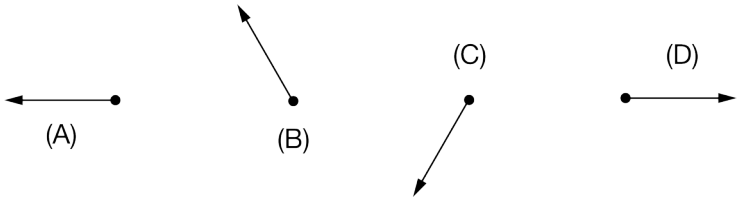
Briefly explain your reasoning.

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



A vertical support rod is fixed at the center of a platform. A light string of length L is attached to the top of the support rod, and the other end of the string is attached to a sphere of mass m, as shown above. The platform rotates with an angular speed that can be varied. When the platform rotates with a constant angular speed ω (omega), the string makes an angle θ (theta) with the rod.



(a) Identify which of the above vectors represents the net force exerted on the sphere at the moment shown above. Briefly justify your answer.

(b) Is the magnitude of the tension in the string greater than, less than, or equal to the weight of the sphere? Explain your reasoning.

(c) The string can never be completely horizontal no matter how fast the platform is rotating. Without writing any equations or formulas, explain why.

One of the following two equations for the square of the tangential speed v of the sphere as a function of θ is consistent with the statement in part (c) that the string can never be horizontal as the platform is rotating.

Equation 1: $v^2 = \frac{gL(\sin^2\theta)}{(\cos\theta)}$ **Equation 2:** $v^2 = \frac{gL(\cos^2\theta)}{(\sin\theta)}$

(d) Indicate which equation is consistent with the statement in part (c), and explain why. Also explain why the other equation is not consistent with the statement in part (c).

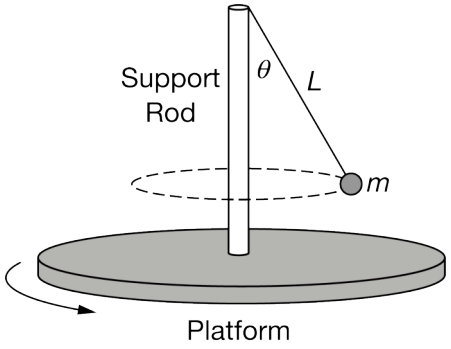
(e) In a series of experimental trials, a group of students changes L and adjusts v to keep θ constant. They record L and v for each trial. Based on the equation in part (d) that you indicated as consistent with the statement in part (c), what quantities could the students graph to yield a straight line whose slope could be used to find the acceleration due to gravity, g ?

(f) Let I be the rotational inertia of the sphere-rod-platform system about a vertical axis through the center of the

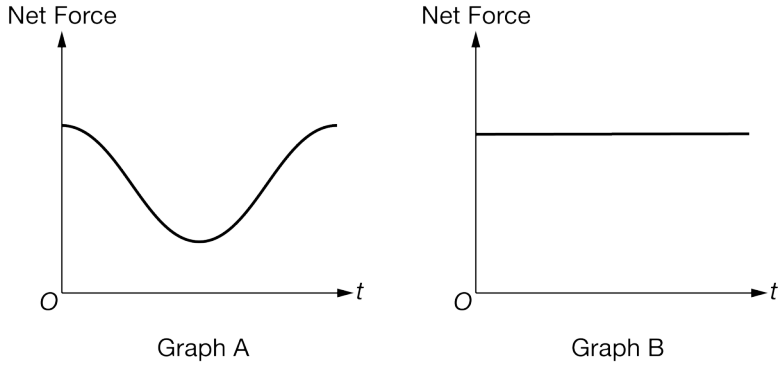
support rod. Does I increase, decrease, or stay the same when L increases (but θ stays constant)? Briefly explain your reasoning.

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



A vertical support rod is fixed at the center of a platform. A light string of length L is attached to the top of the support rod, and the other end of the string is attached to a sphere of mass m, as shown above. The platform rotates with an angular speed that can be varied. When the platform rotates with a constant angular speed ω (omega), the string makes an angle θ (theta) with the rod.



(a) The platform rotates with a constant angular speed. Which of the above graphs correctly shows the magnitude of the net force exerted on the sphere as a function of time t ? Briefly justify your answer.

(b) Is the magnitude of the tension in the string greater than, less than, or equal to the centripetal force exerted on the sphere? Explain your reasoning.

(c) The string is nearly vertical when the sphere's tangential speed is very small. Without writing any equations or formulas, explain why.

(d) A student derives an equation for the square of the tangential speed v of the sphere as a function of θ : $v^2 = gL(\tan\theta)(\sin\theta)$. Indicate whether the equation is consistent with the statement in part (c) and explain why.

(e) In a series of experimental trials, a group of students adjusts v and measures θ while keeping all other variables constant. They record v and θ for each trial. If the students use the equation given in part (d), what quantities could they graph to yield a straight line whose slope could be used to find the acceleration due to gravity, g ?

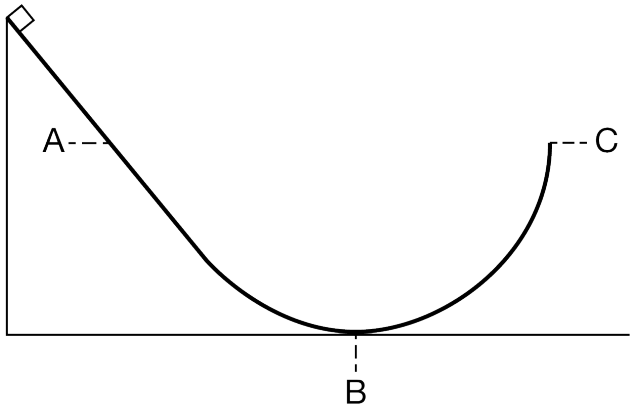
(f) Let I be the rotational inertia of the sphere-rod-platform system about a vertical axis through the center of the

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support rod. Does I increase, decrease, or stay the same when θ decreases? Briefly explain your reasoning.

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



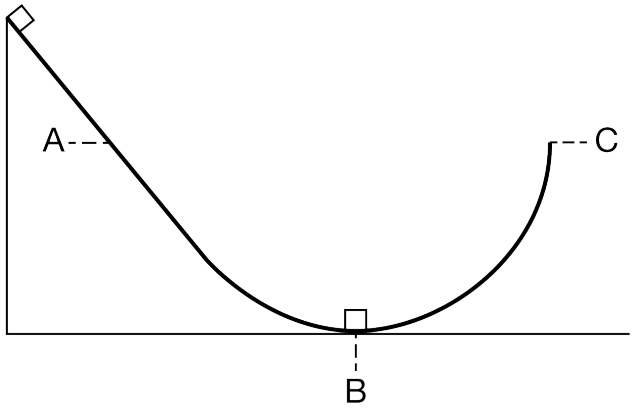
The figure above shows a track consisting of a straight section that connects to a circular section. Three locations are indicated: location A on the straight section of the track, location B at the bottommost point of the track, and location C at the point where the track is vertical. Locations A and 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.