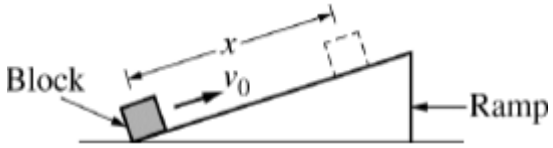
chapter2partb

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

4. (7 points, suggested time 13 minutes)



A student strikes a block at the bottom of a ramp, giving it an initial speed v_0 up the ramp, as shown at right. There is friction between the ramp and the block as it slides a distance *x* up the ramp and then slides back down.

(a) On the dots below, which represent the block as it is sliding up the ramp and down the ramp, draw and label the forces (not components) exerted on the block. Represent each force by a distinct arrow starting on, and pointing away from, the dot. The dashed lines are drawn at the same angle as the surface of the ramp.



Up the Ramp Down the Ramp

(b) The block takes time t_{up} to slide up the ramp a distance *x*. The block then takes time t_{down} to slide back down to the bottom of the ramp, where it has speed v_f. Is t_{down} greater than, equal to, or less t_{up}?

____ $t_{\text{down}} > t_{\text{up}}$ ____ $t_{\text{down}} = t_{\text{up}}$ ____ $t_{\text{down}} < t_{\text{up}}$

In a clear, coherent paragraph-length response that may also contain figures and/or equations, explain your reasoning. If you need to draw anything other than what you have shown in part (a) to assist in your response, use the space below. Do NOT add anything to the figures in part (a).

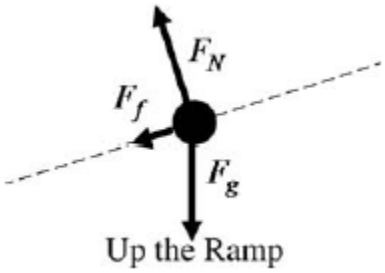
Part A

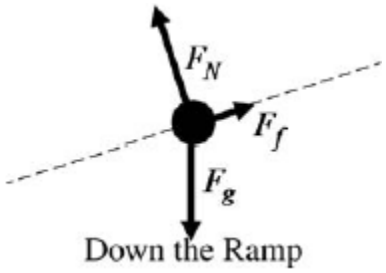
1 point is earned: For a labeled friction force vector in the correct direction in both diagrams

1 point is earned: For labeled gravitational and normal forces in the correct directions in both diagrams, with no extraneous forces

Example:

chapter2partb





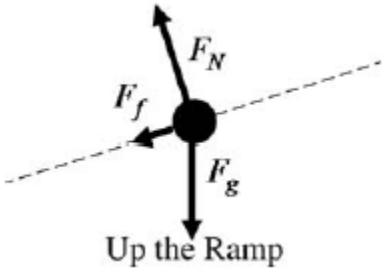
0	1	2

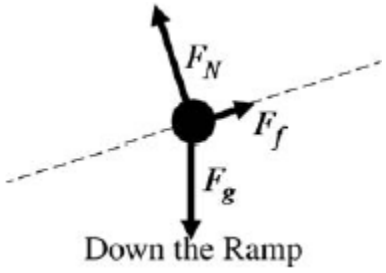
Student response earns 2 of the following 2 point(s)

1 point is earned: For a labeled friction force vector in the correct direction in both diagrams

1 point is earned: For labeled gravitational and normal forces in the correct directions in both diagrams, with no extraneous forces

Example:





Part B

Correct Answer: $t_{\text{down}} > t_{\text{up}}$

Note: The response is graded even if an incorrect selection is made.

1 point is earned: For stating that the magnitude of the net force on the block is greater when it is sliding up the ramp than when it is sliding down the ramp because the direction of the frictional force changes while the direction of the component of the gravitational force along the ramp does not (this can be implied) OR a description of the net force consistent with the free-body diagrams (FBDs) in part (a)

1 point is earned: For stating that the magnitude of acceleration of the block while sliding up the ramp is greater than that when sliding down, OR a description of acceleration consistent with the FBDs in part (a)

1 point is earned: For a justification that v_f is less than v_0, OR average *v* up is greater than average *v* down (e.g., speed changes more on way up than on way down because acceleration is greater on the way up and the same distance covered and final/initial speed on way up/down is zero), OR a description of final and initial speeds consistent with the FBDs in part (a)

1 point is earned: For a correct *argument* that, if v_f is less than v_0 or the average speed up is greater than the average

chapter2partb

speed down, then t_{down} is greater than t_{up}. (This argument could include a kinematic equation.)

Note: Student cannot earn this point even if justification is consistent with an incorrect FBD in part (a)

1 point is earned: For a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response

Note: A maximum of 4 of 5 points (first 3 points plus 5th point) can be earned if the FBDs in part (a) are incorrect (e.g., friction force is in the same direction in both FBDs)

Alternate solution using work/energy reasoning for 1st two points of part (b)

1 point is earned: *For correctly applying work-energy to up/down ramp (or, indicating block-Earth system has the same potential energy at the beginning and end)*

1 point is earned: *For correct treatment of energy loss to friction*

0	1	2	3	4	5 ✓

Student response earns 5 of the following 5 point(s)

Correct Answer: $t_{\text{down}} > t_{\text{up}}$

Note: The response is graded even if an incorrect selection is made.

1 point is earned: For stating that the magnitude of the net force on the block is greater when it is sliding up the ramp than when it is sliding down the ramp because the direction of the frictional force changes while the direction of the component of the gravitational force along the ramp does not (this can be implied) OR a description of the net force consistent with the free-body diagrams (FBDs) in part (a)

1 point is earned: For stating that the magnitude of acceleration of the block while sliding up the ramp is greater than that when sliding down, OR a description of acceleration consistent with the FBDs in part (a)

1 point is earned: For a justification that v_f is less than v_0, OR average *v* up is greater than average *v* down (e.g., speed changes more on way up than on way down because acceleration is greater on the way up and the same distance covered and final/initial speed on way up/down is zero), OR a description of final and initial speeds consistent with the FBDs in part (a)

1 point is earned: For a correct *argument* that, if v_f is less than v_0 or the average speed up is greater than the average speed down, then t_{down} is greater than t_{up}. (This argument could include a kinematic equation.)

Note: Student cannot earn this point even if justification is consistent with an incorrect FBD in part (a)

1 point is earned: For a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response

Note: A maximum of 4 of 5 points (first 3 points plus 5th point) can be earned if the FBDs in part (a) are incorrect (e.g., friction force is in the same direction in both FBDs)

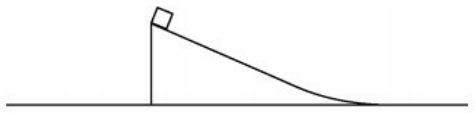
chapter2partb

Alternate solution using work/energy reasoning for 1st two points of part (b)

1 point is earned: *For correctly applying work-energy to up/down ramp (or, indicating block-Earth system has the same potential energy at the beginning and end)*

1 point is earned: *For correct treatment of energy loss to friction*

2.



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.

Part 1

1 point is earned for any mention of energy conversion

1 point is earned f or indicating that the same amount of potential energy is converted to kinetic energy in each trial

1 point is earned for indicating that the kinetic energy is shared between the block and plane in trial 1

1 point is earned for indicating that the block has all the kinetic energy in trial 2

1 point is earned for a description of the motion of the plane in each trial

1 point is earned for using momentum or forces to explain the motion in each trial

1 point is earned for a coherent argument that leads to a correct conclusion

For example: The speed of the block is greater in trial 2. Since gravity is the only force doing work in both trials, energy is conserved. The potential energy of the block at the top of the plane is converted into kinetic energy. In trial 1 the plane is free to move, so if the block ends up going to the right, the plane has to move to the left to conserve momentum.

0	1	2	3	4	5	6	7 ✓

The student response earns all of the following points:

1 point is earned for any mention of energy conversion

chapter2partb

1 point is earned f or indicating that the same amount of potential energy is converted to kinetic energy in each trial

1 point is earned for indicating that the kinetic energy is shared between the block and plane in trial 1

1 point is earned for indicating that the block has all the kinetic energy in trial 2

1 point is earned for a description of the motion of the plane in each trial

1 point is earned for using momentum or forces to explain the motion in each trial

1 point is earned for a coherent argument that leads to a correct conclusion

For example: The speed of the block is greater in trial 2. Since gravity is the only force doing work in both trials, energy is conserved. The potential energy of the block at the top of the plane is converted into kinetic energy. In trial 1 the plane is free to move, so if the block ends up going to the right, the plane has to move to the left to conserve momentum.

chapter2partb

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

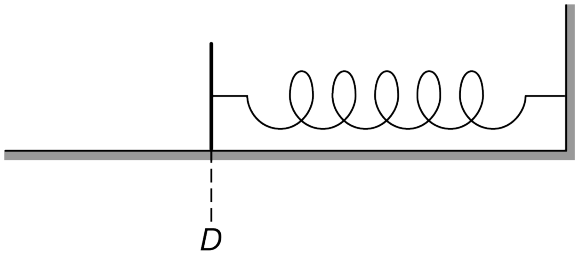


Figure 1. Spring at Relaxed Length

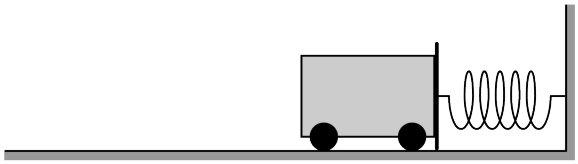


Figure 2. Cart Held Against Plate

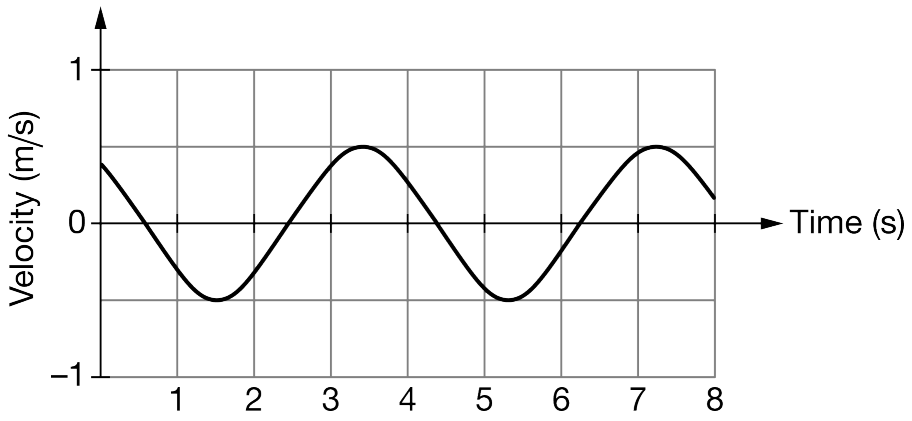
Students intend to use a cart-spring system to study motion. A vertical plate with negligible mass is attached to a horizontal spring of spring constant k. When the spring is at its relaxed length, the plate is at position D as indicated in Figure 1 above. A cart is glued to the plate. The cart is initially 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."



chapter2partb

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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

The response accurately includes

- ☐ 1 point is earned for a correct statement and no incorrect statements.

Example Responses:

The student is correct in saying that if the spring is stiffer, the force exerted by the spring will be greater for the same compression.

OR

The first statement

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

The response accurately includes

- ☐ 1 point is earned for an incorrect statement and no correct statements.

Example Response:

chapter2partb

The student is incorrect in saying that the cart could come loose as the spring expands, before it reaches D.

OR

The second statement

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for indicating that the difference in the two velocities from the graph is needed
  OR
  indicating that the force multiplied by the change in time would give the impulse.
- ☐ 1 point is earned for indicating that multiplying the difference in velocity by the mass will give the impulse or change in momentum
  OR
  providing a correct way to solve for acceleration and stating that the acceleration multiplied by the mass would yield the average force.

Example Responses:

Subtract the velocity at 4 seconds from the velocity at 6 seconds, as read from the graph. Multiplying the velocity difference by the cart mass gives the change in momentum, or impulse.

OR

Impulse is equal to force multiplied by change in time. Use the graph to find the change in velocities from 4 seconds to 6 seconds. Divide this difference by the time (2 seconds) to determine the average acceleration. Multiply the acceleration by the cart's mass to determine the average force applied to the cart. Multiply the average force by the difference in time to determine impulse.

Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5	6 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for indicating that the period would be different (not necessarily shorter).

chapter2partb

- 1 point is earned for indicating that the period would be shorter because less mass is oscillating.
- 1 point is earned for indicating that the amplitude of the velocity graph would not change
  OR
  stating that that no other factors change.
- 1 point is earned for a correct justification that the amplitude of the velocity graph will not change.
- 1 point is earned for an additional correct statement about a change in the oscillation of the spring-cart system, even if it is not related to the velocity graph. Examples include:
  · The frequency would be larger
  · The energy of the system will be smaller
  · The amplitude of the position vs time graph would be smaller (the spring would compress less)
  · The acceleration of the cart would change
- 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

With a less massive cart, the period shown in the graph would be shorter, since period increases with mass. The amplitude of the velocity graph would stay the same because the maximum velocity would be the same as the velocity of the cart at impact, and that has not changed. Changing the mass of the cart would affect the period. If the mass decreases, the period would also decrease. The spring would compress less with a lighter car.

chapter2partb

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

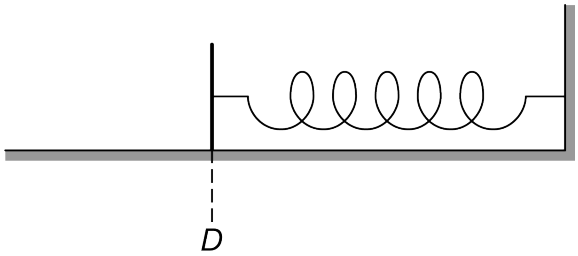


Figure 1. Spring at Relaxed Length

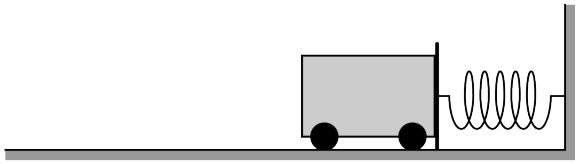


Figure 2. Cart Held Against Plate

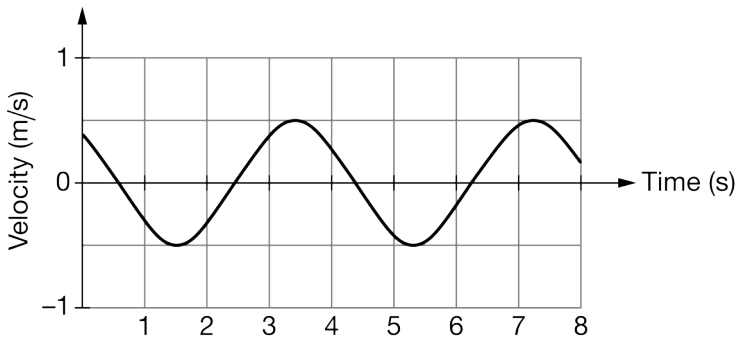
Students intend to use a cart-spring system to study motion. A vertical plate with negligible mass is attached to a horizontal spring of spring constant k. When the spring is at its relaxed length, the plate is at position D as indicated in Figure 1 above. A cart is glued to the plate. The cart is initially 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."



chapter2partb

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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

The response accurately includes

- ☐ 1 point is earned for a correct statement and no incorrect statements.

Example Responses:

The student is correct in saying that the cart and the plate exert equal and opposite forces on each other.

OR

The first statement

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

The response accurately includes

- ☐ 1 point is earned for an incorrect statement and no correct statements.

Example Responses:

The student is incorrect in saying that the forces on the cart add to zero.

chapter2partb

OR

The second statement

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for indicating that finding the area somewhere under the curve is needed
  OR
  indicating that energy is conserved during oscillation.
- ☐ 1 point is earned for indicating that the area for one quarter of a cycle is needed
  OR
  using $v_{\max}$ from the graph to solve for $x_{\max}$ by setting maximum kinetic energy equal to maximum spring potential energy.

Example Responses:

Take the area under the curve for a quarter of a period.

OR

Energy is conserved during the oscillation, therefore Kinetic Energy at equilibrium = Spring Potential energy at the extremes. By setting those 2 values equal to each other, and using the max velocity from the graph, we can solve for the maximum distance (x) and determine the maximum distance the spring is compressed.

Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5	6 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for recognizing that the period would be different (not necessarily longer).
- ☐ 1 point is earned for indicating that the period would be longer because there is more mass.
- ☐ 1 point is earned for recognizing that kinetic energy is lost in an inelastic collision.
- ☐ 1 point is earned for a claim that the amplitude of the graph will different (not necessarily less).

chapter2partb

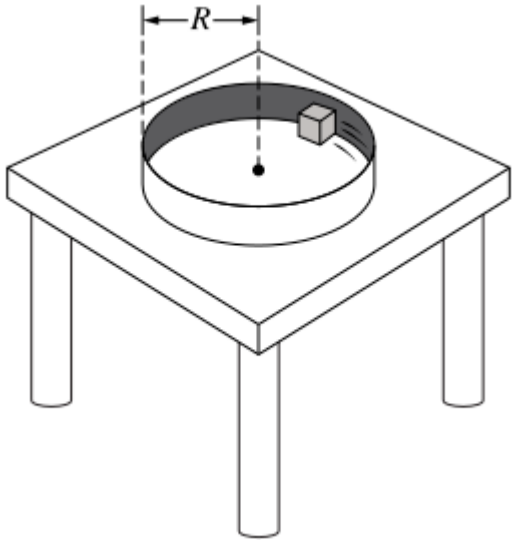
- 1 point is earned for indicating that the amplitude will be less because the total energy of the cart-plate-spring system is less
  OR
  indicating that the amplitude will be less because a greater mass means a smaller velocity because of conservation of momentum.
- 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

With an additional mass due to the plate, the period would be longer since period increases with mass. Some of the initial kinetic energy of the cart will be dissipated in the completely inelastic collision with the plate if the plate has nonzero mass, so there will be less kinetic energy immediately after the collision. With less kinetic energy at zero spring displacement, there is less total mechanical energy that can be converted to spring potential energy. So, the maximum spring potential energy will be less and therefore the amplitude will be less as well.

chapter2partb

5.



(7 points, suggested time 13 minutes)

A small block is sliding on a smooth horizontal surface as it travels in a circular path against the inside of a cylinder with a rough inner wall, as shown. Friction between the block and the horizontal surface is negligible, but friction between the block and the wall is nonnegligible.

m_0 is the mass of the block.
v_0 is the initial speed of the block.
R is the radius of the cylinder.
μ_k is the coefficient of kinetic friction between the block and the wall.

(a) Determine expressions for the following in terms of m_0, v_0, R, μ_k, and physical constants, as appropriate.

i. The normal force F_N exerted on the block by the cylinder when the speed of the block is v_0

ii. The frictional force F_f exerted on the block by the vertical wall when the speed of the block is v_0

(b) In a clear, coherent paragraph-length response that may also contain equations and drawings, describe the changes, if any, to both the centripetal and tangential accelerations as the block slides on the horizontal surface against the inside of the cylinder.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both** of the following criteria.

chapter2partb

- [ ] 1 point is earned for equating the normal force to the centripetal force.
- [ ] 1 point is earned for multiplying the normal force by the coefficient of friction, μ_k.
  Scoring Note: Writing the equation for friction, $F_f = \mu F_N$, earns this point only if F_N is determined in previous step.

Example Response

$F_N = \frac{m_0 {v_0}^2}{R}$
$F_f = \mu_k F_N$
$F_f = \frac{\mu_k m_0 {v_0}^2}{R}$

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5 ✓

The response accurately includes **all** the following criteria.

- [ ] 1 point is earned for stating one of the following:
  - The speed decreases due to friction between the block and the wall
  - The direction of the tangential acceleration is opposite of the direction of the tangential velocity
- [ ] 1 point is earned for relating the change in speed to the change in the magnitude of the centripetal acceleration, *e.g.* since the speed decreases, the centripetal acceleration also decreases.
- [ ] 1 point is earned for **one** of the following:
  - Correctly relating the change in centripetal acceleration to the change in friction force between the wall and block, *e.g.* since the centripetal acceleration decreases/increases, the friction force also decrease/increases
  - Using the equation from part (a) to explicitly relate speed to frictional force
- [ ] 1 point is earned for correctly relating change in frictional force to the tangential acceleration, *e.g.* when the frictional force decreases, the tangential acceleration decreases.
- [ ] 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response

The block slows because friction acts on the block from the wall against the direction of the block's motion. Since the block slows, the centripetal acceleration $\frac{v^2}{R}$ decreases as R remains constant. The centripetal acceleration (which is

chapter2partb

decreasing) is provided by the normal force and since the normal force is decreasing, the force of friction also decreases. Since the decreasing force of friction is the tangential force, then the tangential acceleration also decreases.

chapter2partb

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

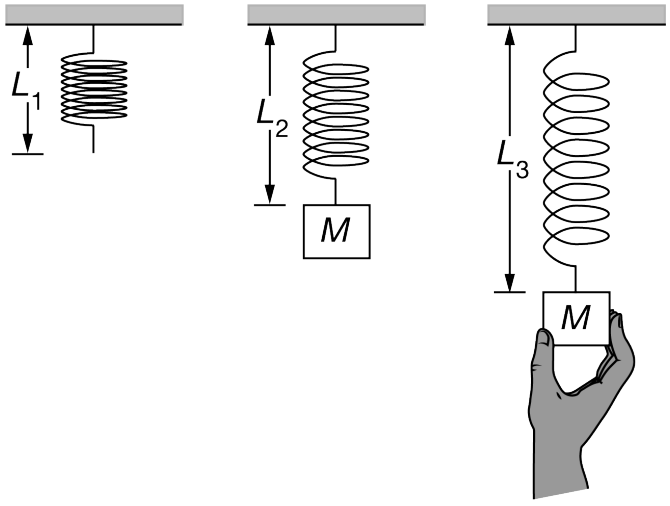


Figure 1 Figure 2 Figure 3

(7 points, suggested time 13 minutes)

A spring with unstretched length L_1 is hung vertically, with the top end fixed in place, as shown in Figure 1 above. A block of mass M is attached to the bottom of the spring, as shown in Figure 2, and the spring has length $L_2 > L_1$ when the block hangs at rest. The block is then pulled downward and held in place so that the spring is stretched to a length $L_3 > L_2$, as shown in Figure 3.

(a) On the dot below, which represents the block in Figure 3, draw and label the forces (not components) exerted on the block. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



(b) The student releases the block. Consider the time during which the block is moving upward toward its equilibrium position and the spring length is still longer than L_2.

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, indicate why the total mechanical energy is increasing, decreasing, or constant for each of the systems listed below.

chapter2partb

System 1: The block
System 2: The block and the spring
System 3: The block, the spring, and Earth

Use E_1, E_2, and E_3 to denote the total mechanical energy of systems 1, 2, and 3, respectively.

Part A

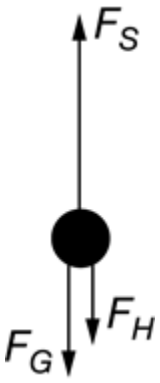
Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes both of the following criteria:

- ☐ Including all three forces exerted on the block: the upward spring force, the downward gravitational force, and the downward force of the hand holding the block.
- ☐ Including at least one of the three forces exerted on the block, with no extraneous forces.

Example Response:



Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Responses that do not explicitly refer to the forms of energy in one or more of the systems can still earn the point for the first of the five criteria.

The correct forms of energy in each system are the following.

System 1: Kinetic energy K_{block} of the block (There is no potential energy for system 1.)

System 2: K_{block} and the potential energy U_{spring} of the spring

System 3: K_{block}, U_{spring}, and the gravitational potential energy U_{grav} of the block-Earth system

chapter2partb

0	1	2	3	4	5 ✓

The response accurately includes all five of the following criteria:

- ☐ A response with no incorrect claims about which forms of energy are present in each system.
- ☐ Correctly demonstrating that total mechanical energy is increasing for the block.
- ☐ Correct reasoning demonstrating that total mechanical energy is decreasing for the block-spring system.
- ☐ Correctly claiming that total mechanical energy is constant for a closed system such as the block-spring-Earth system.
- ☐ A logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Acceptable Full Response:

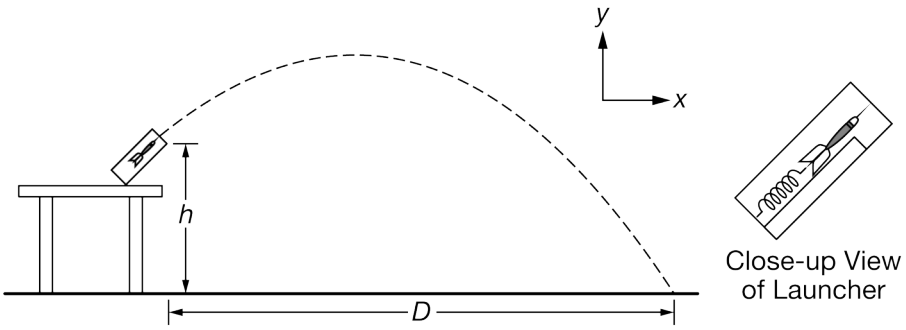
For system 1 of just the block: When the force holding the block is removed, the block's acceleration and the net force on the block are upward since the spring force is greater than the gravitational force. The net force is in the direction of the block's motion, so its speed and kinetic energy are both increasing. The total mechanical energy is the kinetic energy for a single-object system, so E_1 is increasing.

System 3 can be considered a closed system with no external forces exerted on it, so E_3 is constant. Note that $E_3 = K_{\text{block}} + U_{\text{spring}} + U_{\text{grav}}$, where K_{block} is the block's kinetic energy, U_{spring} is the spring's potential energy, and U_{grav} is the gravitational potential energy of the block-Earth system.

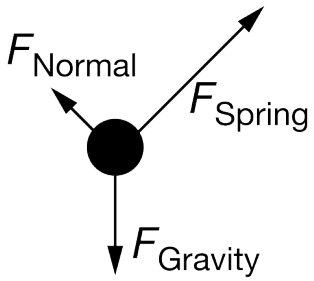
System 2 has total mechanical energy $E_2 = K_{\text{block}} + U_{\text{spring}}$, which equals $E_3 - U_{\text{grav}}$. E_3 is constant, while U_{grav} is increasing because the block is moving upward. So $E_2 = E_3 - U_{\text{grav}}$ must be decreasing.

chapter2partb

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

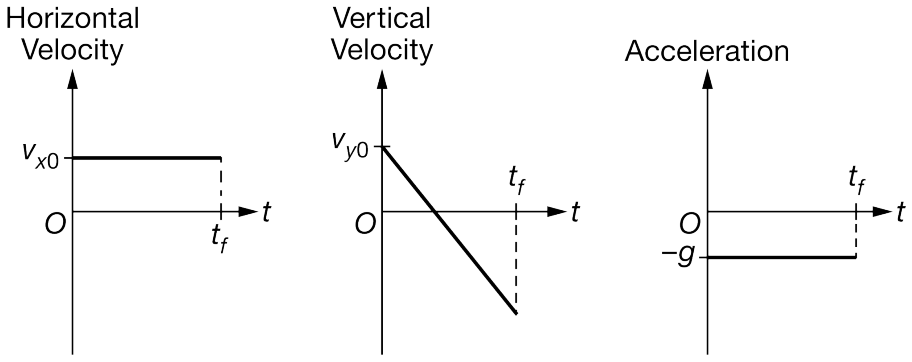


A launcher is used to launch a dart with initial speed v from a table at an angle, as shown above. The dart exits the end of the launcher at a height h above the floor and lands a horizontal distance D from the end of the launcher. A close-up view is included that shows the dart in the launcher immediately 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.

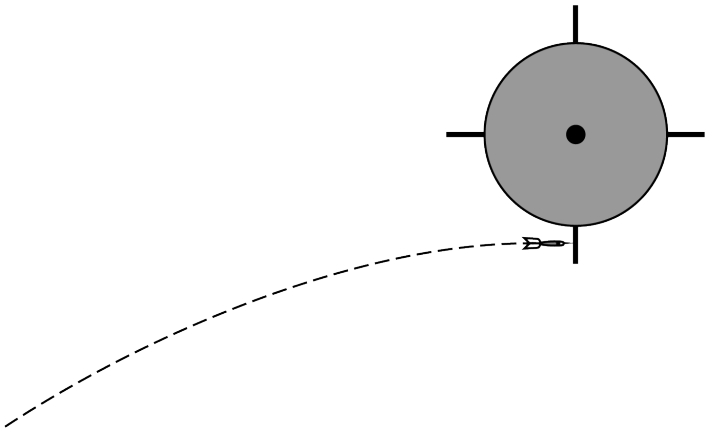


chapter2partb

(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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

The response accurately includes

- ☐ 1 point is earned for indicating that the normal force and spring force would be removed.

Example Response:

When the dart is in the air, the normal force and the spring force should be removed from the diagram.

Part B

chapter2partb

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for selecting the horizontal velocity graph.
- ☐ 1 point is earned for indicating area under the velocity graph can be used to find distance.

Example Response:

The students can determine the distance the dart travels horizontally by looking at the area under the horizontal velocity graph. This will be the horizontal displacement of the dart.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for indicating that the horizontal velocity component remains constant.
- ☐ 1 point is earned for indicating that the vertical velocity component increases.
- ☐ 1 point is earned for indicating that the resultant velocity is the vector sum of the two components (this point is for mentioning/evaluating the resultant, rather than the two individual components).
- ☐ 1 point is earned for explaining that the angle can never be 90 degrees because there is always a horizontal component (or for indicating that the velocity vector can never be totally vertical).
- ☐ 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

The horizontal component of the velocity remains constant because there is no acceleration in the horizontal direction. The vertical component of the velocity will increase. The total velocity is the vector sum of the two velocity components. Since there is always a horizontal component, the angle can never be 90 degrees, so the total velocity cannot ever be totally vertical.

Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

chapter2partb

0	1	2 ✓

The response accurately includes **both** of the following criteria.

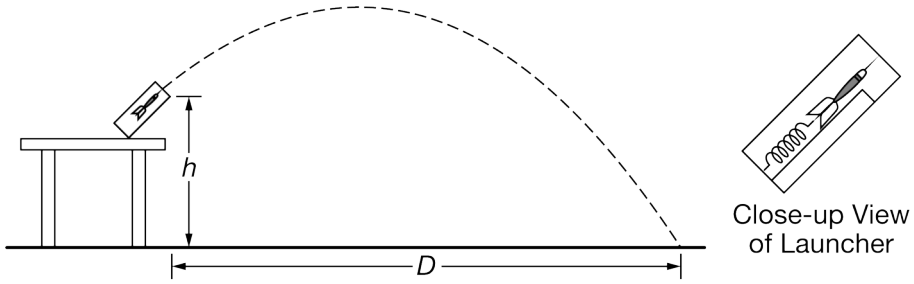
- ☐ 1 point is earned for indicating the linear momentum will not be constant, with an attempt at justification.
- ☐ 1 point is earned for indicating that there is an external force on the wheel (or that the dart will slow down and the wheel will have no net linear momentum).

Example Response:

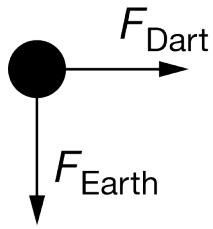
The linear momentum of the system will not be constant because there is an external force on the wheel, exerted at the wheel axle.

chapter2partb

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

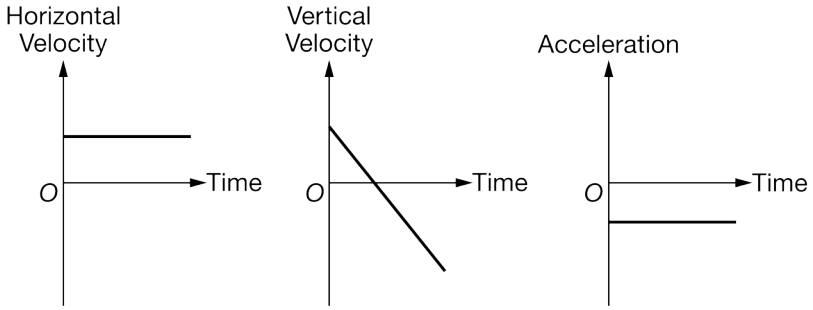


A launcher is used to launch a dart with initial speed v from a table at an angle, as shown above. The dart exits the end of the launcher at a height h above the floor and lands a horizontal distance D from the end of the launcher. A close-up view is included that shows the dart in the launcher immediately 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.

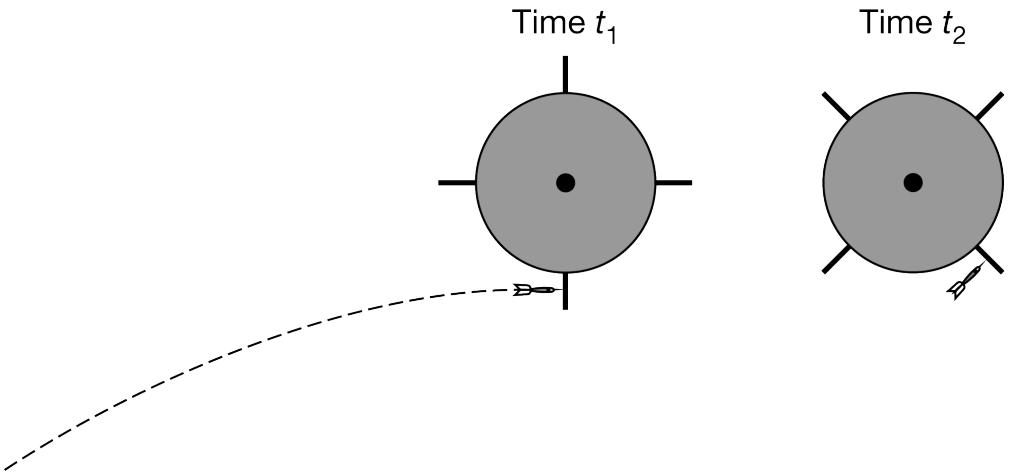


(b) Another student claims that the horizontal velocity graph is not correct because the dart is accelerating, and therefore the horizontal velocity is not constant. Is the student's claim valid? Justify your answer.

chapter2partb

(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:

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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

The response accurately includes

- ☐ 1 point is earned for indicating the horizontal force should not be included.

Example Response:

There shouldn't be a horizontal force exerted on the dart.

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

chapter2partb

0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for indicating the claim is not valid, with an attempt at an explanation.
- ☐ 1 point is earned for indicating the acceleration or force is vertical, so the horizontal velocity does not change.
  OR
  For indicating that the acceleration or force is not horizontal, so the horizontal velocity does not change.

Example Response:

The claim is not valid. The acceleration is vertical only, so the horizontal velocity does not change.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for indicating that velocity has two components.
- ☐ 1 point is earned for indicating that the horizontal velocity component remains constant while vertical velocity component decreases.
- ☐ 1 point is earned for indicating that the resultant velocity decreases because it is the vector sum of the horizontal and vertical components (point is for mentioning/evaluating the resultant, rather than the two individual components).
- ☐ 1 point is earned for indicating that the magnitude cannot be zero because there is always a nonzero horizontal component.
- ☐ 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

The velocity includes both the horizontal and vertical components. The horizontal component stays constant while the vertical component decreases. So, the resultant velocity decreases because it is the resultant of the vertical and horizontal components. But the total velocity can never be zero since there is always a horizontal component that is nonzero.

Part D

chapter2partb

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both** of the following criteria.

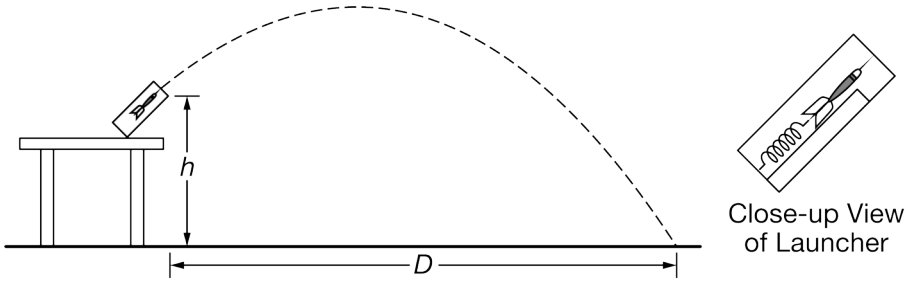
- ☐ 1 point is earned for indicating that the angular speed is decreasing, with an attempt at an explanation.
- ☐ 1 point is earned for indicating that there is a net torque exerted by the gravitational force on the dart, opposite the direction of rotation (or, clockwise).

Example Response:

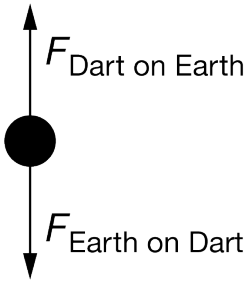
The angular speed is decreasing because there is a net torque exerted by the gravitational force on the dart, opposite to the direction of the rotation.

chapter2partb

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

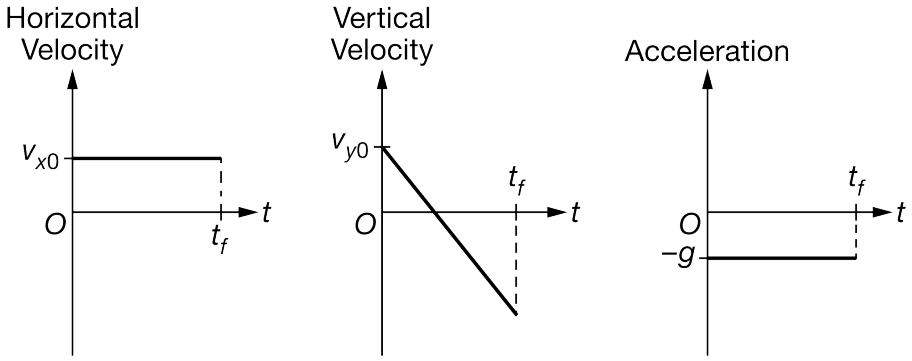


A launcher is used to launch a dart with initial speed v from a table at an angle, as shown above. The dart exits the end of the launcher at a height h above the floor and lands a horizontal distance D from the end of the launcher. A close-up view is included that shows the dart in the launcher immediately 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.

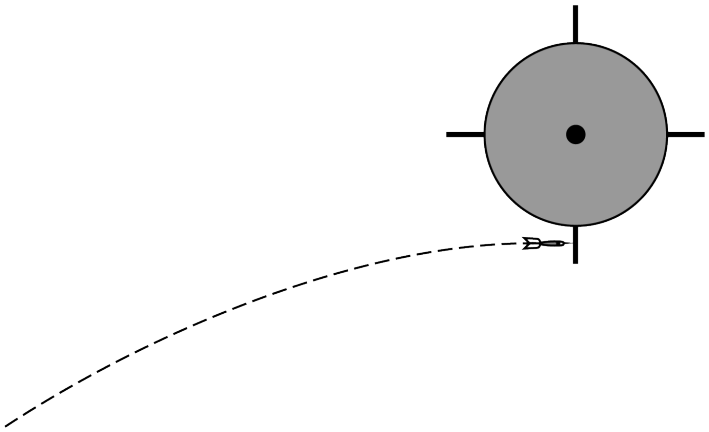


chapter2partb

(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 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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

The response accurately includes

- ☐ 1 point is earned for indicating the force exerted by the dart on Earth should not be included.

Example Response:

The force of the dart on Earth does not belong on a free-body diagram of the dart.

Part B

chapter2partb

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for selecting the vertical velocity graph.
- ☐ 1 point is earned for indicating area under the velocity graph can be used to find *h*.

Example Response:

The vertical velocity graph can be used to find h. The total area under the curve on the vertical velocity graph will be the vertical displacement of the dart. The absolute value of this area is equal to h.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for indicating that the acceleration is downward.
- ☐ 1 point is earned for indicating that the vertical velocity component increases while the horizontal velocity component remains constant.
- ☐ 1 point is earned for a statement that the resultant velocity is the vector sum of the two components (this point is for mentioning/evaluating the resultant, rather than the two individual components).
- ☐ 1 point is earned for explaining that the angle can never be zero degrees since there is always a horizontal component (or for indicating that the velocity vector can never be totally vertical).
- ☐ 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

The acceleration of the dart is downward and constant, equal in magnitude to g. The vertical velocity increases, while the horizontal velocity remains constant because there is no acceleration in the horizontal direction. The total velocity is the vector sum (using the Pythagorean theorem) of the two velocities. Therefore, the angle can never be zero, since there is always a horizontal component.

Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

chapter2partb

0	1	2 ✓

The response accurately includes **both** of the following criteria.

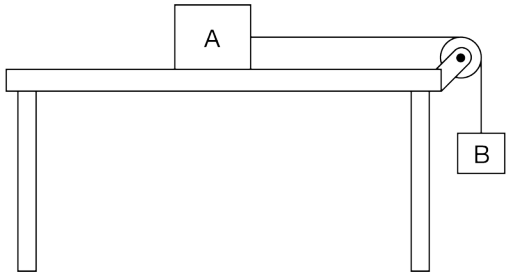
- ☐ 1 point is earned for indicating the angular momentum will be constant, with an attempt at justification.
- ☐ 1 point is earned for indicating that there is no net torque on the system.

Example Response:

The angular momentum is constant since there is no net torque on the system.

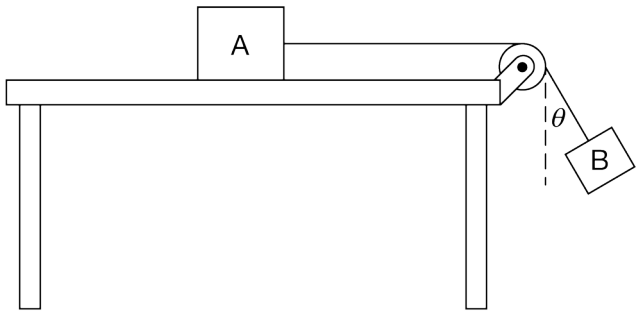
chapter2partb

10. 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).

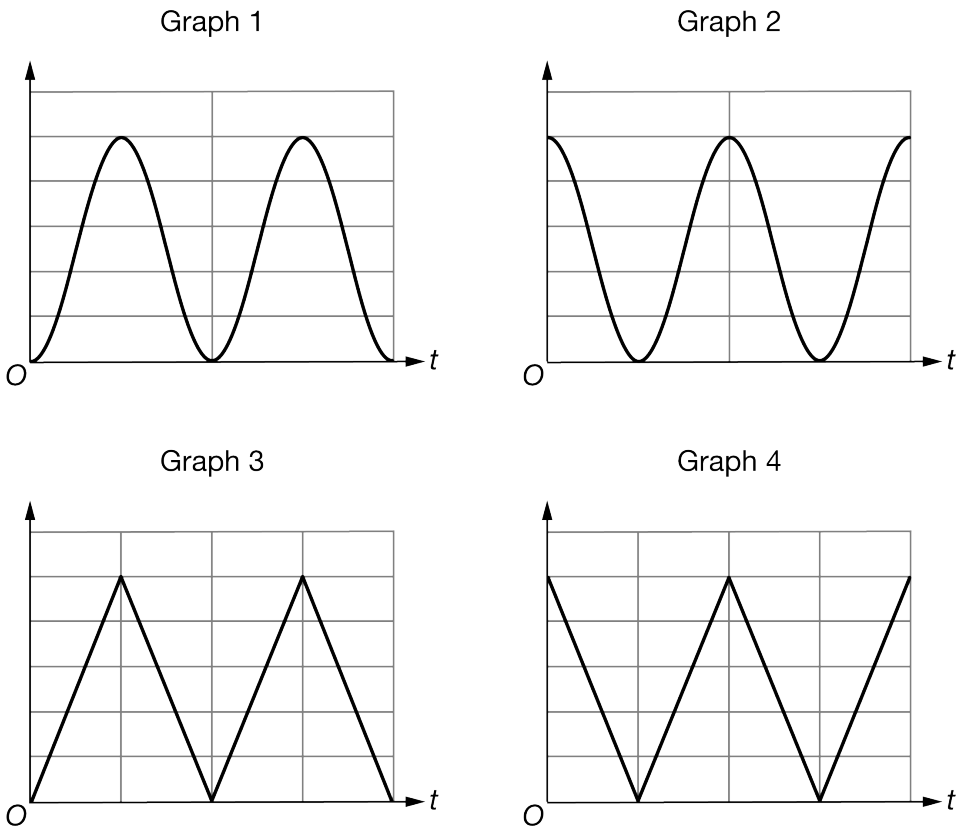
(a) What is the magnitude of the frictional force acting on block A? Justify your answer.



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.

chapter2partb



(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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

The response does not accurately include

- ☐ 1 point is earned for a valid justification of why the friction force is either T_1 or $m_B g$.

chapter2partb

Example Response:

The horizontal forces on block A must sum to zero because block A is not accelerating, so the friction force must be equal to T_1.

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

The response accurately includes **three** of the following criteria.

- ☐ 1 point is earned for indicating that Graph 1 is the correct graph for kinetic energy as a function of time.
- ☐ 1 point is earned for a justification that the initial speed of the block is zero and so the initial kinetic energy of the block is zero.
- ☐ 1 point is earned for a statement that includes that the kinetic energy as a function of time is not linear because it is based on a sinusoidal function.

Example Response:

Graph 1. The block is released from rest, so the kinetic energy must be zero at t = 0. This eliminates graphs 2 and 4. Kinetic energy is proportional to velocity-squared, and the velocity is a sinusoidal function. The square of a sinusoid is depicted in graph 1, not graph 3.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5	6 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for indicating that object B is moving at the bottom in circular motion.
- ☐ 1 point is earned for indicating that since Block B is moving in circular motion, the acceleration or net force is toward the center of the circle or upward when at the lowest point.
- ☐ 1 point is earned for indicating that the tension is larger than when Block B is at rest
  OR
  larger than $m_B g$, or larger than T_1.
- ☐ 1 point is earned for indicating that the new string tension is greater than the maximum possible static friction on block A.
- ☐ 1 point is earned for indicating that since block A is accelerating to the right, the net force must be to the

chapter2partb

right.

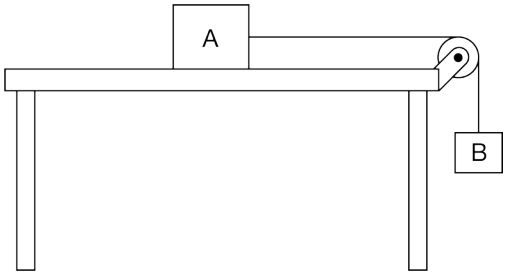
- [ ] 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

When block B is swinging and is at the bottom of its motion, it is in circular motion and has an upward acceleration and net force. Therefore, the tension in the string is now greater than $m_B g$ *or* T_1*. Because block A accelerates to the right, there is a net force to the right, which must result from the tension being greater than the maximum possible static friction force.*

chapter2partb

11. 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.

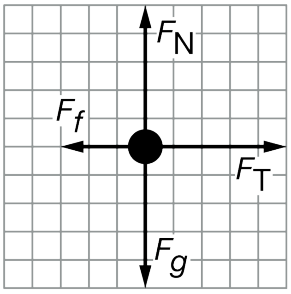


Figure 1

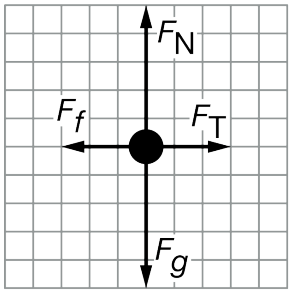


Figure 2

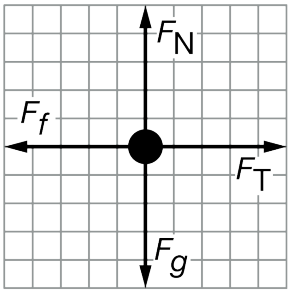


Figure 3

(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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

chapter2partb

The response accurately includes

- [ ] 1 point is earned for a valid explanation for why the tension is equal to the weight.

Example Response:

When block A is at rest, block B is at rest. So, the tension in the string must be equal to the weight of block B, $T_1 = m_B g$.

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

The response accurately includes **all** of the following criteria.

- [ ] 1 point is earned for indicating that Figure 2 is the correct free body diagram.
- [ ] 1 point is earned for an explanation which addresses that the forces must add to zero because the system is in equilibrium.
- [ ] 1 point is earned for explanation which addresses that the force of friction must be less than the normal force.

Example Response:

The system is at rest, so the forces must add to zero, and F_f *and* F_T *must be equal in magnitude. Friction also must be less than the normal force because* $\mu < 1$ *and the maximum force of friction is mu times the normal force. Therefore, Figure 2 correctly depicts the forces on Block A.*

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5	6 ✓

The response accurately includes **all** of the following criteria.

- [ ] 1 point is earned for indicating that as the mass was added to the top of block B, the tension in the string increased.
- [ ] 1 point is earned for indicating that while block A was not moving, the static friction force was equal to the tension.
- [ ] 1 point is earned for indicating that the static friction force is not constant but can vary up to a maximum value.
- [ ] 1 point is earned for indicating that block A moved as soon as the tension was greater than the maximum

chapter2partb

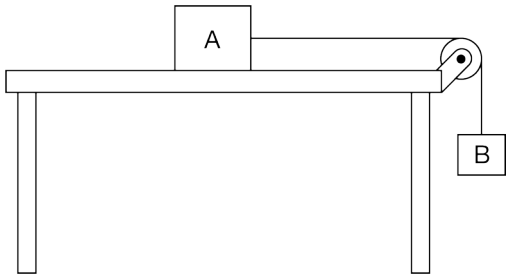
static friction force.

- ☐ 1 point is earned for indicating that when the tension on block A is greater than the static friction force, the block experiences a net force and accelerates to the right.
- ☐ 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

As mass was added to the top of block B, the tension in the string was increasing. As the tension was increasing, the static friction force was increasing, to keep block A at rest. Once the additional mass reached a value m_0, the tension increased past the maximum value of static friction. Since the forward tension force is greater now than the friction force, block A accelerates to the right.

12. 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 $\mu m_A g$. 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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

chapter2partb

0	1 ✓

The response accurately includes

- ☐ 1 point is earned for a valid explanation of why the student is incorrect.

Example Response:

The student is incorrect because $\mu m_A g$ is the maximum static friction force, and the static friction force could be less than that value.

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for indicating that T_2 is less than T_1.
- ☐ 1 point is earned for indicating that when the block is at rest, the tension in the string, $T_1$is equal to the weight of block B.
- ☐ 1 point is earned for indicating that when the block is accelerating downward, the net force must be downward, so T_2 must be less than the weight of block B.

Example Response:

If block B is accelerating downward, the net force must be downward. That means the gravitational force on B is greater than the tension, T_2. When the block was at rest, $T_1$was equal to the force of gravity on B, so therefore T_2 is less than T_1.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5	6 ✓

The response accurately includes **all** of the following criteria.

chapter2partb

- ☐ 1 point is earned for indicating that the block-pulley system has the same amount of work done on it by gravity in both cases
  OR
  For indicating that there is the same gravitational potential energy change in both cases.
- ☐ 1 point is earned for indicating that the blocks-pulley system has the same amount of energy dissipated by friction in both cases.
- ☐ 1 point is earned for indicating that both systems have the same total kinetic energy change.
- ☐ 1 point is earned for indicating that when the pulley has mass, there is rotational kinetic energy and thus the blocks have less translational energy.
- ☐ 1 point is earned for concluding that the blocks will have less speed when the pulley has nonnegligible mass.
- ☐ 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

The gravitational potential energy of blocks-pulley-earth system is reduced as Block B falls, so the kinetic energy and thermal energy of the system are increased by an equivalent amount. The overall change in kinetic energy is the same whether or not the pulley has mass, since the same amount of thermal energy is produced by friction when Block A moves a distance d. When the pulley has mass, some of the kinetic energy will be in the form of rotational kinetic energy, so less translational kinetic energy can be acquired by the blocks and they will therefore have less speed.

Part C - Alternate solution

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5	6 ✓

The response accurately includes **all** of the following criteria.

- ☐ *1 point is earned for applying Newton's second law and recognizing that the pulley's mass increases the mass of the accelerating system.*
- ☐ *1 point is earned for recognizing that the translational acceleration of the system is reduced when the pulley has mass.*
- ☐ *1 point is earned for recognizing that mass in the pulley gives it rotational inertia.*
- ☐ *1 point is earned for indicating that the torque required to turn the pulley affects the translational motion of the blocks.*
- ☐ *1 point is earned for concluding that the blocks have less speed when the pulley has more mass.*
- ☐ *1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.*

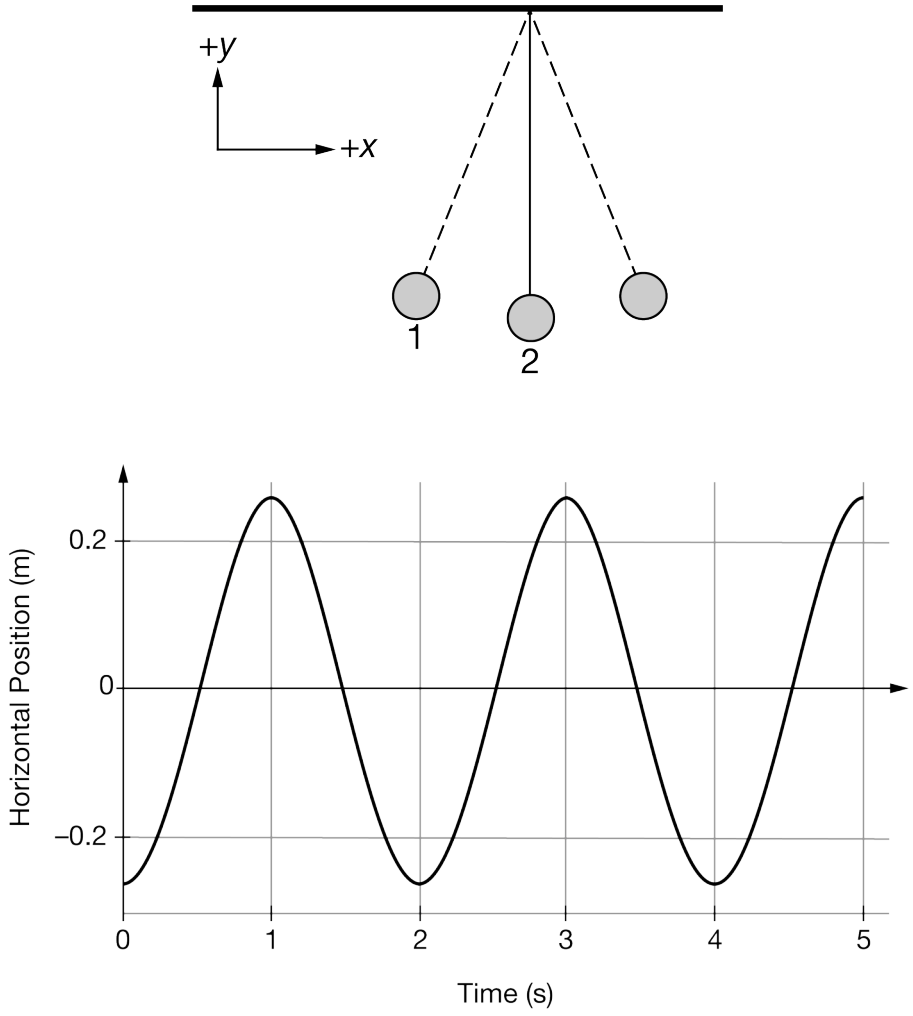
Example Response:

chapter2partb

When the pulley has mass, it has rotational inertia. To begin rotating, it must experience a net torque. This will affect the tensions on the blocks. Block B will have a greater upward tension than in the first case, the net force it experiences will be less, and its acceleration will be less. Because of this, when it falls a distance d, it will have less speed.

chapter2partb

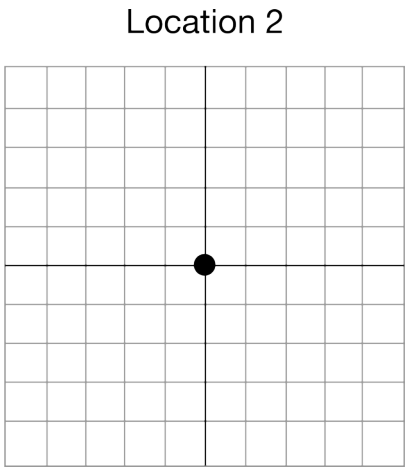
13. This question is a short free-response question. Show your work for each part of the question.



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.

chapter2partb



(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.

Part (a)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

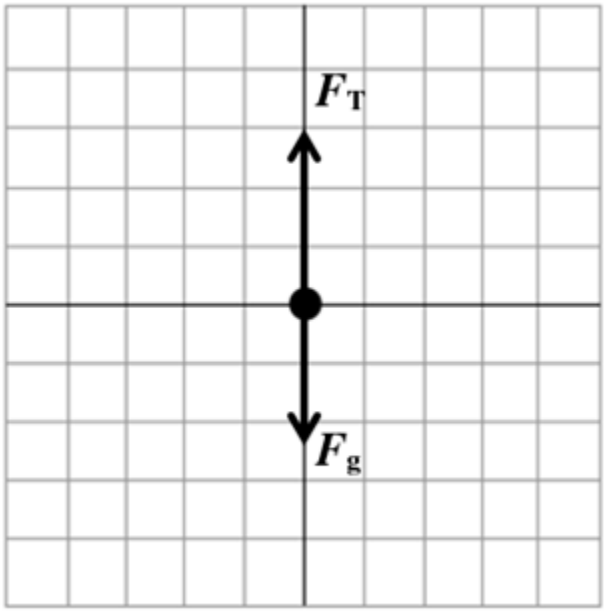
0	1	2 ✓

Student response accurately includes both of the following criteria.

- ☐ 1 point is earned for drawing an upward tension force and a downward force due to gravity
- ☐ 1 point is earned for drawing an upward tension force that has a larger magnitude than the force due to gravity

Example Response:

chapter2partb



Part (b)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

Student response accurately includes one of the following criteria.

Correct Answer: 0.068 J

- 1 point is earned for using the period of oscillation from the graph to determine the length of the string,
  Example Response:
  $T_p = 2\pi\sqrt{\frac{◈}{g}}$
  $\frac{T_p}{2\pi} = \sqrt{\frac{◈}{g}}$
  $\frac{{T_p}^2}{4\pi^2} = \frac{◈}{g}$
  $◈ = \frac{g{T_p}^2}{4\pi^2}$
  $◈ = \frac{(10\,\text{N/kg})(2.0\,\text{s})^2}{4\pi^2}$
  $◈ \approx 1.0\,\text{m}$
- 1 point is earned for using the correct trigonometric relationship to determine the maximum height of the sphere from its lowest position.
  Example Response:

chapter2partb

$$\Delta y = \diamondsuit - \diamondsuit \cos(\theta)$$
$$\Delta y = (1.0\,\text{m}) - (1.0\,\text{m})\cos(15^\text{o})$$
$$\Delta y \approx 0.034\,\text{m}$$

- [ ] 1 point is earned for correctly applying the conservation of energy to obtain an expression for the maximum kinetic energy of the sphere.

Example Response:

$$E_0 = E_f$$
$$U_{g0} + U_{s0} + K_0 + W_{\text{External}} = U_{gf} + U_{sf} + K_f$$
$$U_{g0} = K_f$$
$$K_f = mgy_0$$
$$K_f = (0.2\,\text{kg})(10\,\text{N/kg})(0.034\,\text{m})$$
$$K_f \approx 0.068\,\text{J}$$

Part (c)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

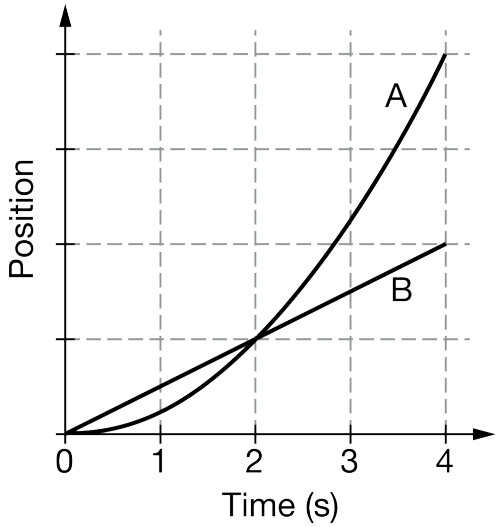
0	1	2 ✓

Student response accurately includes both of the following criteria.

- [ ] 1 point is earned for stating that the period of oscillation will remain the same.
- [ ] 1 point is earned for stating that the period of oscillation for a pendulum only depends on the gravitational field strength (acceleration due to gravity) of the sphere at its location and the length of the pendulum.

chapter2partb

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



Two identical objects, A and B, move along straight, parallel, horizontal tracks. The graph above represents the position as a function of time for the two objects.

(a) At a time of 2 seconds, where the lines intersect, do the displacements of the two objects from their initial positions have the same magnitude? Briefly explain your answer.

(b) At a time of 2 seconds, where the lines intersect, do the velocities of the two objects have the same magnitude? Briefly explain your answer.

(c) At a time of 2 seconds, where the lines intersect, which object, if either, has a net force with a greater magnitude exerted on it? If the net force has the same magnitude for both objects, indicate this explicitly.

(d) In a clear, coherent paragraph-length response, explain your response to part (c). Be sure to reference and compare the graphed information for both objects A and B.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both two** of the following criteria.

- ☐ 1 point is earned for a statement that the two objects have the same displacement at 2 seconds.
- ☐ 1 point is earned for a justification that the lines represent position; and where they intersect, the objects

chapter2partb

are in the same place and began at the same place.

Example Response:

Since this graph is a position vs. time graph, and both objects start at the same position, and at $t = 2\ seconds$ *are at the same position, and displacement is equal to the change in position, both objects have the same displacement.*

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes **both two** of the following criteria.

- ☐ 1 point is earned for a statement that the two objects have different velocities or speeds at 2 seconds.
- ☐ 1 point is earned for a justification that the velocities are represented by the slope of the position vs. time graph, and at $t = 2$ s the slope of the lines are different, so the objects have different velocities.

Example Response:

Since this graph is a position vs. time graph, the slope of the position vs. time graph represents the velocity of each object. At $t = 2$ s *the slopes have different values, so the velocities are different.*

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

The response accurately includes

- ☐ 1 point is earned for a statement that a greater net force is exerted on object A.

Example Response:

A greater net force is exerted on object A.

Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

chapter2partb

0	1	2	3	4	5 ✓

The response accurately includes **all** of the following criteria.

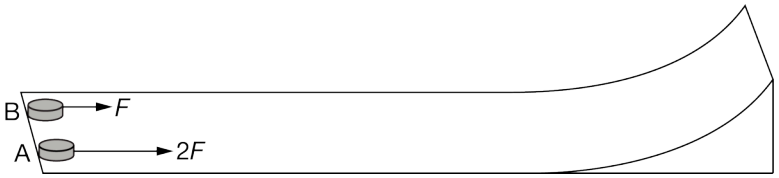
- ☐ 1 point is earned for a statement that the net force exerted on an object is proportional to the acceleration (or $\Sigma F = ma$).
- ☐ 1 point is earned for a justification that since the position vs. time for object B is a straight line with a constant slope (so speed is constant), the acceleration is zero and so it has a zero net force exerted on it.
- ☐ 1 point is earned for a statement that since the position vs. time for object A has a changing slope, its velocity is changing.
- ☐ 1 point is earned for a statement that since object A's velocity is changing it has a non-zero acceleration, and hence has a net force exerted on it.
- ☐ 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

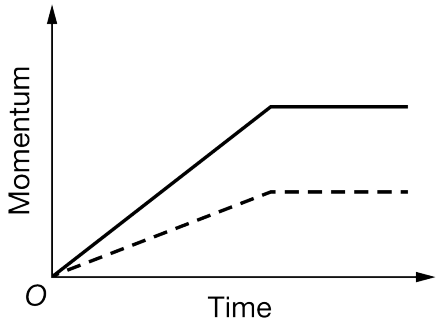
Since this graph is of position vs. time, the slope of the graph represents velocity. For object B, the slope is constant showing that the velocity of object B is constant, meaning that the acceleration is zero and also the net force exerted on object B is also zero. The slope of the position vs. time for object A is changing, which means that the velocity vs. time is changing, so the acceleration is non-zero which means that the net force is also non-zero because the net force exerted on the object is proportional to the acceleration. So, object A has the larger net force exerted on it.

chapter2partb

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



Two identical disks, A and B, are initially at rest at the left end of a track, as shown above. The track has a horizontal section and then curves upward at the right end. The disks are simultaneously pushed to the right for the same amount of time. Disk A is pushed by a horizontal force of magnitude $2F$, and disk B is pushed by a horizontal force of magnitude F. The forces are removed before the disks reach the curved section of the track, and there is negligible friction between the track and the disks.



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

(b) During the time interval that the forces are exerted on the disks, which disk, if either, travels a greater distance along the horizontal section of the track? If the disks travel the same distance, state this explicitly. Briefly explain your answer.

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

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

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

chapter2partb

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for a correct identification of disk A as being represented by the solid line.
- ☐ 1 point is earned for indicating the slope of the graph represents the applied force.
- ☐ 1 point is earned for indicating that the disk A graph should have a larger slope (because of the larger force).

Example Response:

The solid line represents disk A. The slope of the graph represents force because change in momentum equals Force times time. The slope of the solid line has a larger slope because disk A experiences a larger force.

Part A - Alternate Solution

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

*The response accurately includes **all** of the following criteria.*

- ☐ *1 point is earned for a correct identification of disk A as being represented by the solid line.*
- ☐ *1 point is earned for relating momentum to speed or velocity.*
- ☐ *1 point is earned for indicating that disk A has a larger acceleration, and this is related to the slope of the graph.*

Example Response:

The slope of the solid line has a larger slope because disk A experiences a larger force. This means that the acceleration of disk A is greater, which means that the speed after the same time is larger. Since momentum is proportional to the velocity of the disk, disk A will have a larger momentum and a steeper slope.

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

The response accurately includes

- ☐ 1 point is earned for a valid justification (e.g., Disk A has greater average speed over same time interval).

Example Response:

chapter2partb

Disk A travels further during the time when the force is applied. The average speed of disk A is larger over the time interval, so with a larger average speed over the same time, it will travel a greater distance.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

The response accurately includes

- ☐ 1 point is earned for correctly stating that disk A goes higher up the ramp.

Example Response:

Disk A goes higher up the ramp.

Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5 ✓

The response accurately includes **all** of the following criteria.

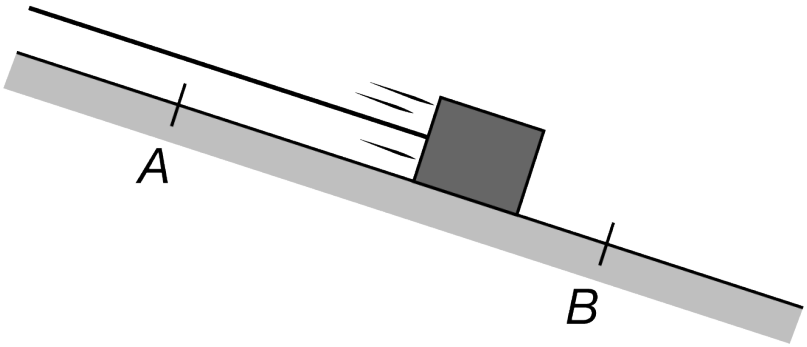
- ☐ 1 point is earned for correctly relating kinetic energy to speed.
- ☐ 1 point is earned for indicating conservation of energy.
- ☐ 1 point is earned for indicating that the disk with greater initial kinetic energy corresponds to greater gravitational potential energy at the top of the slide.
- ☐ 1 point is earned for indicating that the disk that corresponds to greater potential energy goes higher.
- ☐ 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

Because disk A has the greater speed at the end of the push, it will have more kinetic energy than disk B. Because mechanical energy of each disk-earth system will be conserved from when the disks are released until they reach their maximum heights, the disk with the largest kinetic energy will have the largest potential energy and since potential energy is related to the height reached, disk A will go the highest up the ramp.

chapter2partb

16.

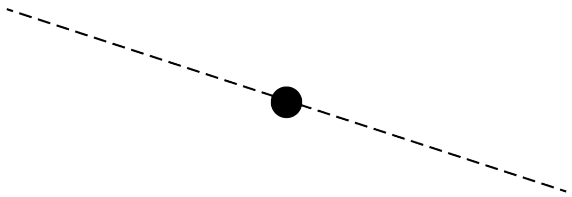


This question is a short free-response question. Show your work for each part of the question.

(7 points, suggested time 13 minutes)

A rope is used to lower a box down a ramp at a constant speed, as shown above. There is negligible friction between the box and the ramp, and the rope is parallel to the ramp. As the block moves down the ramp, its center passes by both points A and B.

(a) On the dot below, which represents the box, draw and label the forces (not components) that act on the box. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. The dashed line is drawn at the same angle as the ramp.



(b) In what follows, consider the system that includes the box and Earth only. (The rope and the ramp are NOT part of the system.) In a clear, coherent, paragraph-length response that may also contain diagrams and/or equations, do the following.

- Consider the forces exerted on the box by objects that are NOT part of the system. Explain why the work done by each force on the box-Earth system is either positive, negative, or zero.
- The total work done on the box-Earth system either increases, decreases, or results in no change to the total mechanical energy of the box-Earth system as the box moves from A to B. Identify which of these three happens in this scenario, and explain why.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

chapter2partb

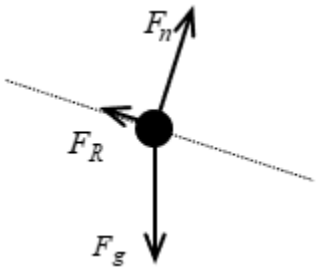
0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for at least one force drawn correctly and no extraneous forces.
- ☐ 1 point is earned for all three forces drawn and labeled correctly:
  force due to gravity downward,
  normal force up-and-rightward, perpendicular to the ramp, and
  force exerted by rope up-and-leftward, parallel to the ramp.

Scoring Note: Appropriate labels for the force due to gravity include: F_G, F_g, F_{grav}, W, mg, Mg, "grav force," "F Earth on block," "F on block by Earth," $F_{\text{Earth on block}}$, $F_{E,Block}$, $F_{Block,E}$. The labels G or g are not appropriate labels for the force due to gravity. F_n, F_N, N, "normal force", "ground force", or similar labels may be used for the normal force.

Example Response for part (a):



Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for indicating that the normal force does no work on the system because it is perpendicular to the box's motion.
- ☐ 1 point is earned for indicating that the force from the rope does negative work on the system because it is in the opposite direction to the box's motion.
- ☐ 1 point is earned for not indicating work done by any other force (to qualify for this point, the student needs to address either the work done by the normal force or tension force in the paragraph), **OR** for indicating that the work done by any other force is zero.

chapter2partb

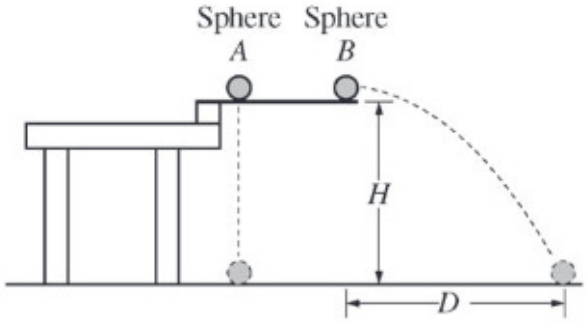
- [ ] 1 point is earned for indicating why the total work has a sign (+, −, or 0) that is consistent with statements made about the work done by individual forces, **OR** for indicating that the total work is negative because the total mechanical energy (or gravitational potential energy) decreases (the box moves to a lower position).
- [ ] 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response for part (a):

There are three forces acting on the box, the normal force, the gravitational force, and the force of the rope on the box. The gravitational force is internal to the system, so it does no work, and the normal force is perpendicular to the box's motion so it does no work either. The rope does negative work because it pulls against the box's direction of motion. The total work done on the system is negative because the mechanical energy of the system decreases as the box moves lower at a constant speed.

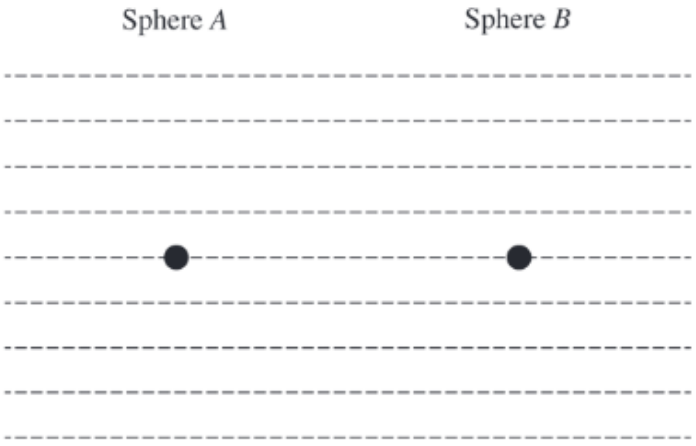
chapter2partb

17.



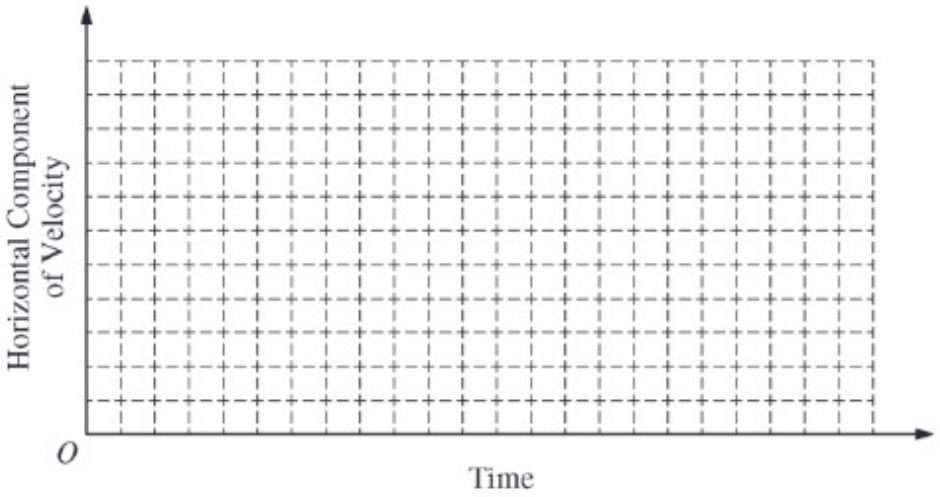
Two identical spheres are released from a device at time t = 0 from the same height H, as shown above. Sphere A has no initial velocity and falls straight down. Sphere B is given an initial horizontal velocity of magnitude v_0 and travels a horizontal distance D before it reaches the ground. The spheres 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 $\frac{t_f}{2}$.



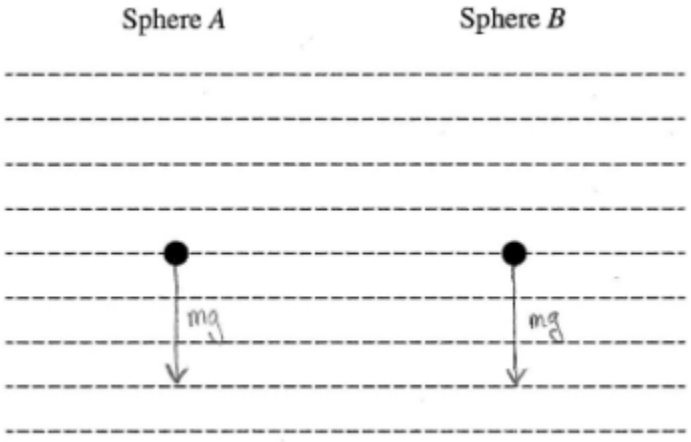
(b) On the axes below, sketch and label a graph of the horizontal component of the velocity of sphere A and of sphere B as a function of time.

chapter2partb



(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).

Part A

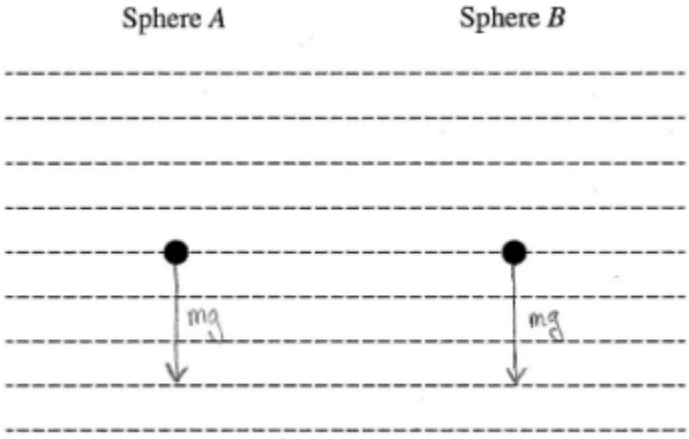


1 point is earned: For sketching only one force pointing straight down from each sphere and indicating that this force represents the force of gravity

0	1 ✓

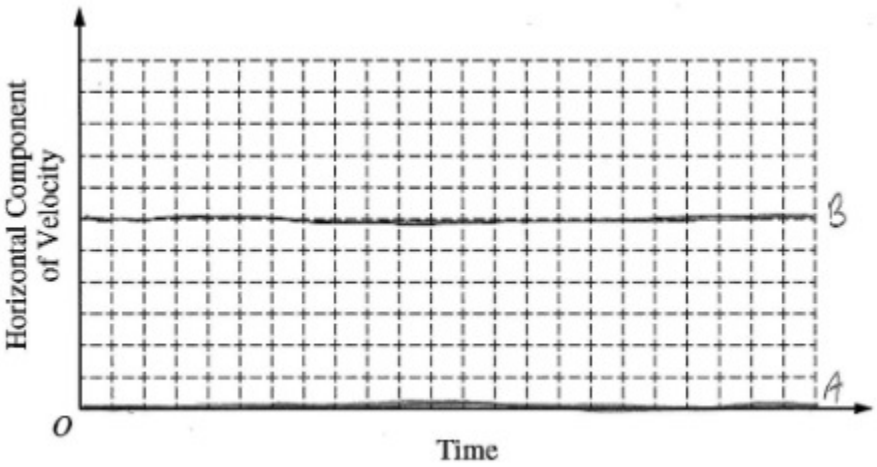
The student response earns all of the following points:

chapter2partb



1 point is earned: For sketching only one force pointing straight down from each sphere and indicating that this force represents the force of gravity

Part B

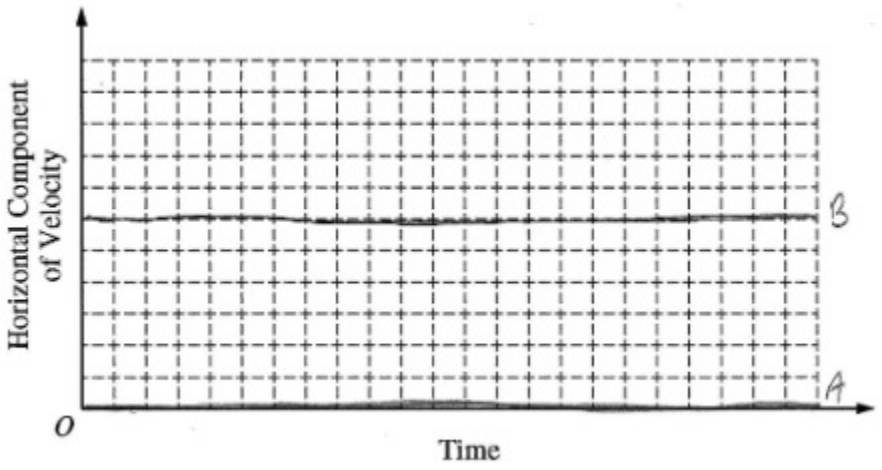


1 point is earned: For sketching a horizontal line at zero velocity for sphere *A*, and sketching a horizontal line at some non-zero velocity for sphere ***B***

0	1 ✓

The student response earns all of the following points:

chapter2partb



1 point is earned: For sketching a horizontal line at zero velocity for sphere *A*, and sketching a horizontal line at some non-zero velocity for sphere ***B***

Part C

1 point is earned: For indicating that the difference in horizontal motion does not affect the vertical motion of the spheres

1 point is earned: For indicating that both spheres start with the same vertical velocity

1 point is earned: For indicating that both spheres have the same vertical acceleration

1 point is earned: For indicating that falling the same height would take the same time

1 point is earned: For no incorrect or irrelevant statements

0	1	2	3	4	5 ✓

The student response earns all of the following points:

1 point is earned: For indicating that the difference in horizontal motion does not affect the vertical motion of the spheres

1 point is earned: For indicating that both spheres start with the same vertical velocity

1 point is earned: For indicating that both spheres have the same vertical acceleration

1 point is earned: For indicating that falling the same height would take the same time

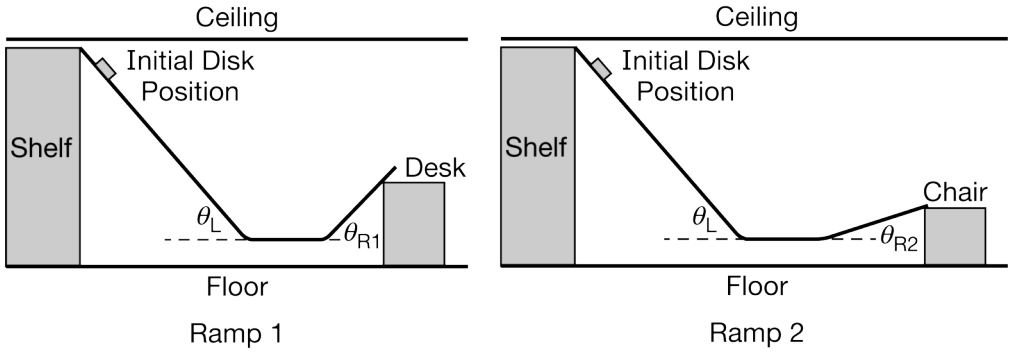
1 point is earned: For no incorrect or irrelevant statements

chapter2partb

18. 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.

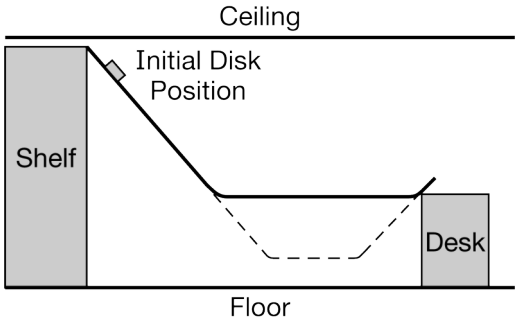


Note: Figures not drawn to scale.

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.

chapter2partb

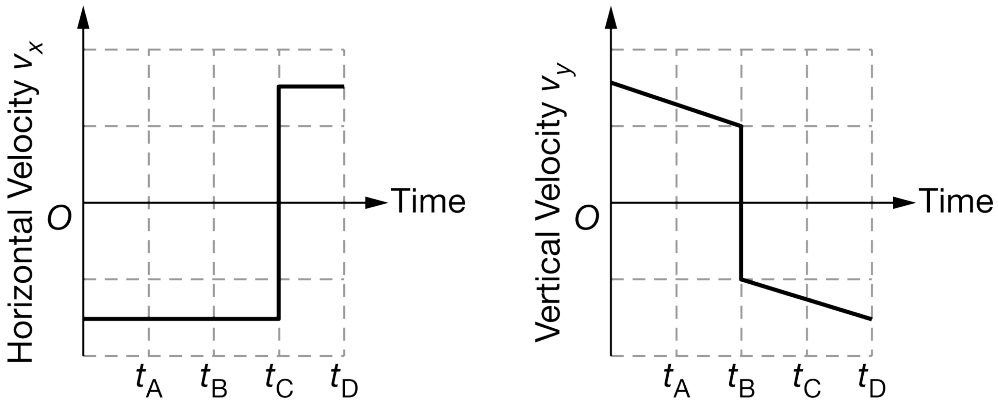


Ramp 3

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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

chapter2partb

0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for indicating that the disk has a greater speed as it leaves the right end of ramp 2 because more potential energy was converted to kinetic energy.
- ☐ 1 point is earned for stating that disk on ramp 2 will not go as high because it will have less potential energy (or disk on ramp 1 has more potential energy) due to conservation of mechanical energy
  OR
  For stating that disk on ramp 2 will not go as high because disk on ramp 2 has a lower initial vertical velocity (or disk on ramp 1 has a higher initial vertical velocity).

Example Response:

The disk has a greater speed when leaving the right end of ramp 2. A greater speed and smaller launch angle means that the horizontal velocity component at launch is greater for the disk on ramp 2. So the disk launched form ramp 2 will have a greater kinetic energy at the apex, and therefore less potential energy (in the disk-Earth system) and a lower height.

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for indicating that the speed of the disk on the flat section is less for ramp 3 since less potential energy has been converted to kinetic energy.
- ☐ 1 point is earned for indicating the flat section of the ramp is longer in ramp 3, so there is a greater distance to travel.
- ☐ 1 point is earned for concluding that since the speed on the flat section of ramp 3 is less and the distance is greater, the time must be greater as well.

Example Response:

For ramp 3, the change in potential energy of the disk-Earth system is less, so the disk has less kinetic energy and thus less speed on the flat section. Since the flat section of ramp 3 is also longer, and the disk is moving more slowly, the disk will spend more time on the flat section of ramp 3 than on the flat section of ramp 1.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

chapter2partb

0	1	2	3	4	5 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for correctly identifying the collision with the ceiling at time t_B.
- ☐ 1 point is earned for indicating that a collision with the ceiling will exert a force on the ball, accelerating it
  OR
  For saying that the force changes the vertical velocity of the ball
  OR
  For saying that the direction of the vertical velocity changes.
- ☐ 1 point is earned for correctly identifying the collision with a wall at time t_C.
- ☐ 1 point is earned for indicating that a collision with the wall will exert a force on the ball, accelerating it
  OR
  For saying that the force changes the horizontal velocity of the ball
  OR
  For saying that the direction of the horizontal velocity changes.
- ☐ 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

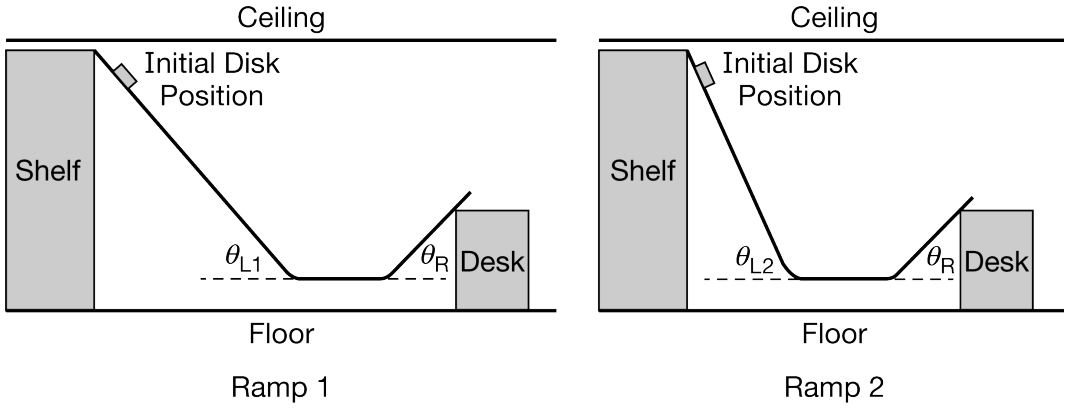
Each surface exerts a normal force; thus, the ceiling and floor exert vertical forces and the walls exert horizontal forces. When a net force is applied, there is an acceleration and a change in velocity. Thus, when there is a horizontal force exerted by the wall there is a change in the horizontal velocity, which happens at time t_C, so, the ball collides with the wall at t_C. When the vertical velocity changes from positive to negative at time t_B, there is a downward force, which only happens when the ball collides with the ceiling. So, the ball collides with the ceiling at t_B.

chapter2partb

19. 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.

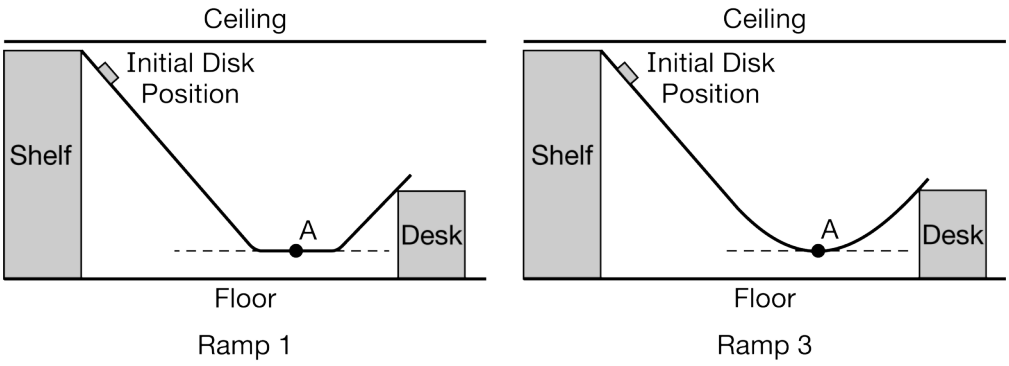


Note: Figures not drawn to scale.

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 $\theta_{L1} < \theta_{L2}$, 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.

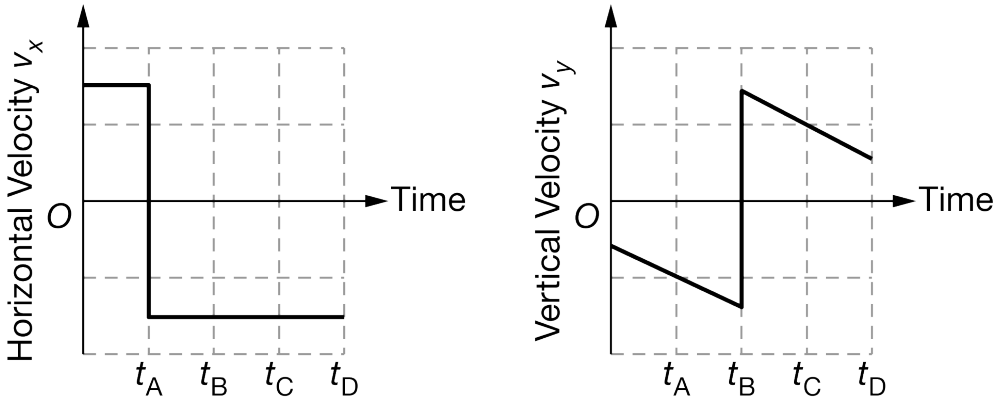
chapter2partb



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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

chapter2partb

0	1	2 ✓

The response accurately includes **both** of the following criteria.

- ☐ 1 point is earned for indicating that the disk has the same speed (or kinetic energy) as it leaves the right end of both ramps because the energy of the disk-Earth system is conserved.
- ☐ 1 point is earned for indicating that the vertical component of the velocity at the right end is the same, since both are launched at the same angle, so the disk reaches the same maximum height for both ramps.

Example Response:

The disk has the same change in height as it travels from the left end to the right end of the ramp, so the same amount of potential energy is converted to kinetic energy. Thus, the disk leaves the right end of both ramps at the same speed. Since it also leaves at the same angle, it will travel the same projectile path and have the same maximum height in both cases.

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for indicating that at point A on ramp 1, the block is moving at a constant velocity, so the net force is zero. Thus, the force by ramp 1 is equal to the disk's weight.
- ☐ 1 point is earned for indicating that at point A on ramp 3, the disk is moving in a circular path and thus has an upward net force.
- ☐ 1 point is earned for concluding that at point A on ramp 3, the normal force must be greater than the disk's weight, and thus greater than it was on ramp 1.

Example Response:

The disk on ramp 1 is traveling at constant velocity on the flat section. Thus, the normal force is equal to the weight of the disk. The disk on ramp 3 is executing circular motion, with an upward acceleration. Thus, the net force must be upward, and thus the normal force on ramp 3 is greater than the disk's weight. Thus, the normal force exerted on the block is greater for ramp 3.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

chapter2partb

0	1	2	3	4	5 ✓

The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for correctly identifying the collision with a wall at time t_A.
- ☐ 1 point is earned for indicating that a collision with the wall will exert a force on the ball, accelerating it
  OR
  For indicating that the force changes the horizontal velocity of the ball
  OR
  For indicating that there is a change in the direction of the horizontal velocity.
- ☐ 1 point is earned for correctly identifying the collision with the floor at time t_B.
- ☐ 1 point is earned for For indicating that a collision with the floor will exert a force on the ball, accelerating it
  OR
  For indicating that the force changes the vertical velocity of the ball
  OR
  For indicating that there is a change in the direction of the vertical velocity.
- ☐ 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

Each surface exerts a normal force; thus, the ceiling and floor exert vertical forces and the walls exert horizontal forces. When a net force is applied, there is an acceleration and a change in velocity. Thus, when there is a horizontal force by the wall there is a change in the horizontal velocity, which happens at time t_A, so the ball collides with the wall at t_A. When the vertical velocity changes from negative to positive at time t_B, there is an upward force, which only happens when the ball collides with the floor. So, the ball collides with the floor at t_B.