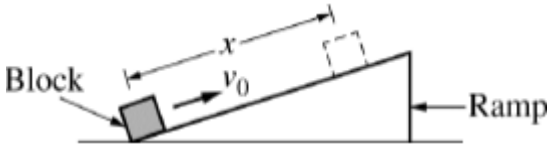
chapter2partb

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.



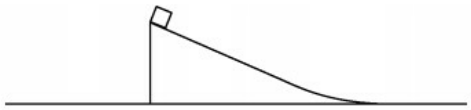
Up the Ramp Down the Ramp

(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).

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.

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

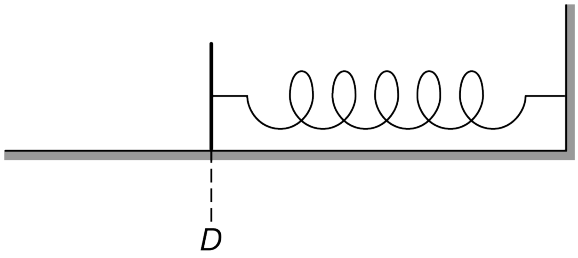


Figure 1. Spring at Relaxed Length

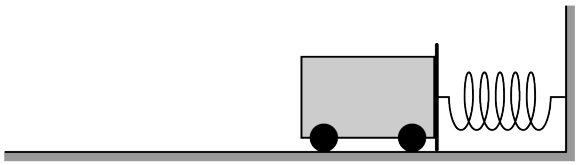


Figure 2. Cart Held Against Plate

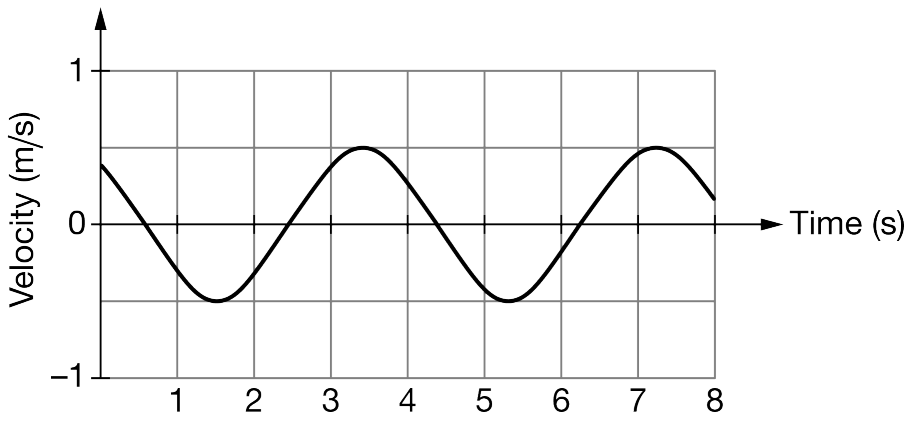
Students intend to use a cart-spring system to study motion. A vertical plate with negligible mass is attached to a horizontal spring of spring constant k. When the spring is at its relaxed length, the plate is at position D as indicated in Figure 1 above. A cart is glued to the plate. The cart is initially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



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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.

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

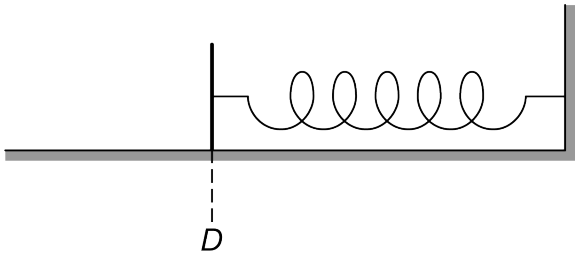


Figure 1. Spring at Relaxed Length

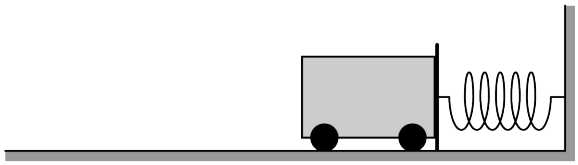


Figure 2. Cart Held Against Plate

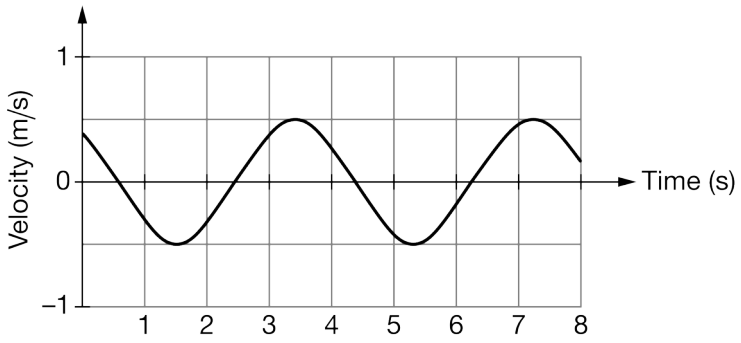
Students intend to use a cart-spring system to study motion. A vertical plate with negligible mass is attached to a horizontal spring of spring constant k. When the spring is at its relaxed length, the plate is at position D as indicated in Figure 1 above. A cart is glued to the plate. The cart is initially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



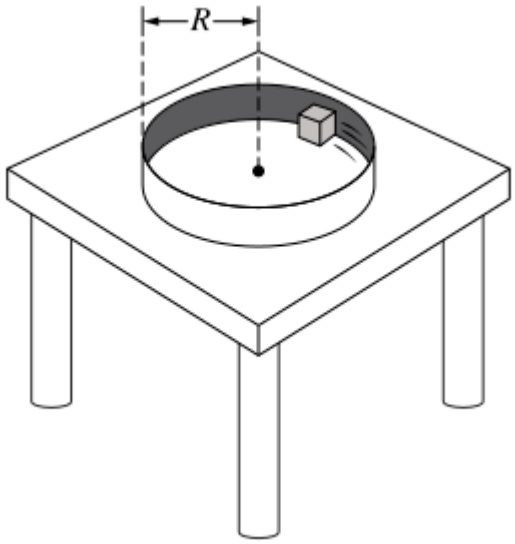
The cart is removed, and the plate is coated with very strong glue. The cart rolls to the right with positive velocity

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.

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.

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

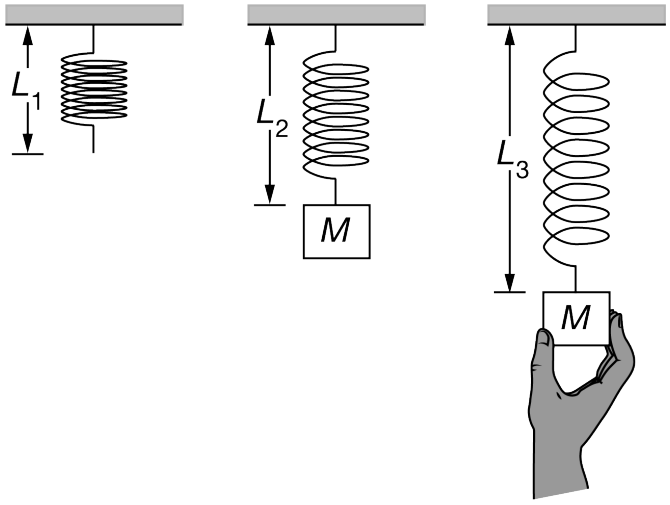

Figure 1 Figure 2 Figure 3

(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.

System 1: The block

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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.

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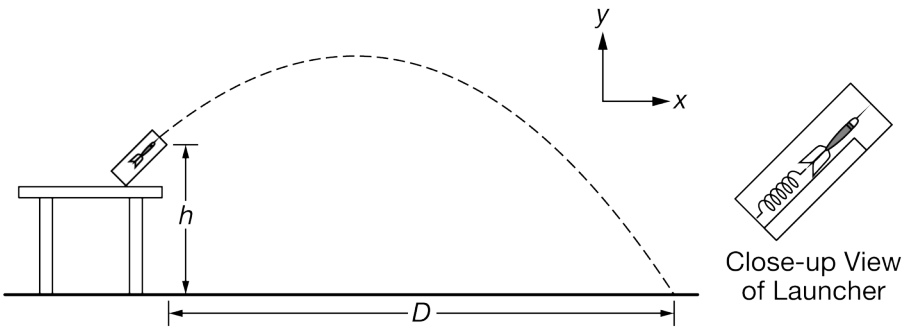
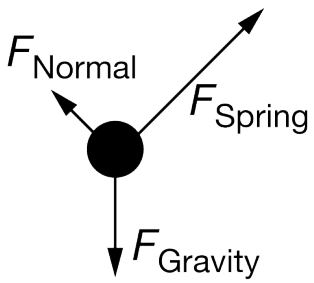
7. This question is a short free-response question. Show your work for each part of the question. (10 points, suggested time 15 minutes)

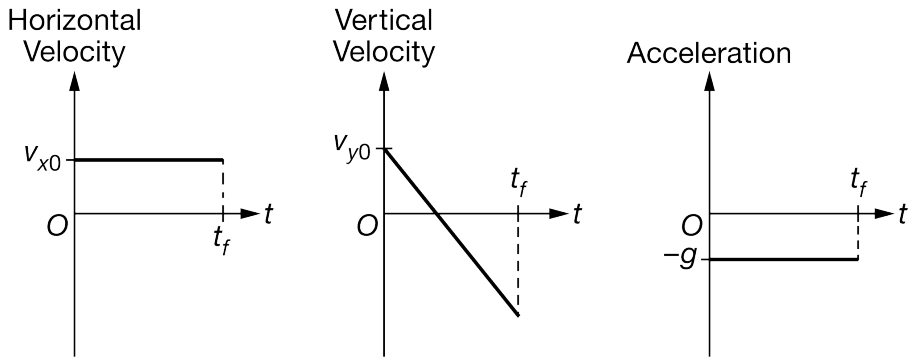


A launcher is used to launch a dart with initial speed v from a table at an angle, as shown above. The dart exits the end of the launcher at a height h above the floor and lands a horizontal distance D from the end of the launcher. A close-up view is included that shows the dart in the launcher immediately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



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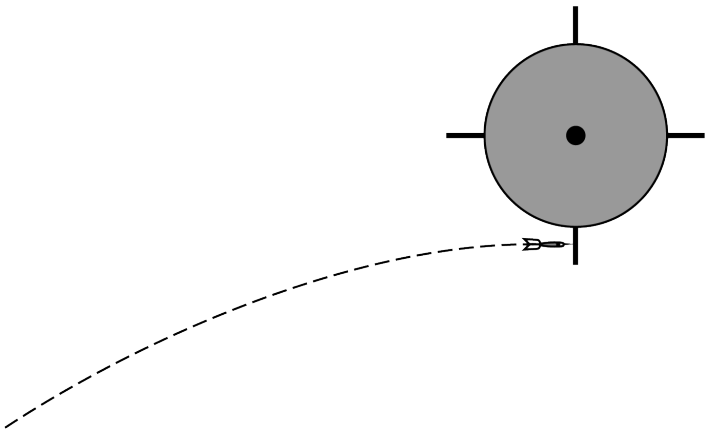
(b) Assuming the values of v_{x0}, v_{y0}, t_f, and g are known, which of the above graphs could lead to a determination of the distance D, and how could a student use the chosen graph to determine D ?

(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.

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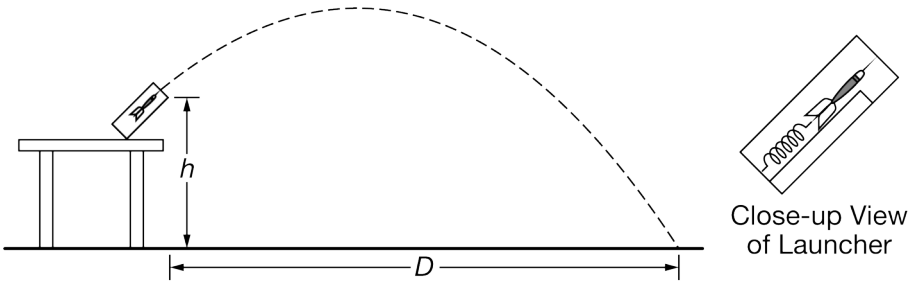
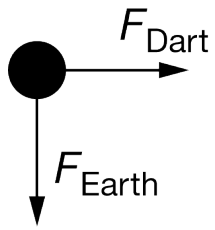
8. This question is a short free-response question. Show your work for each part of the question. (10 points, suggested time 15 minutes)

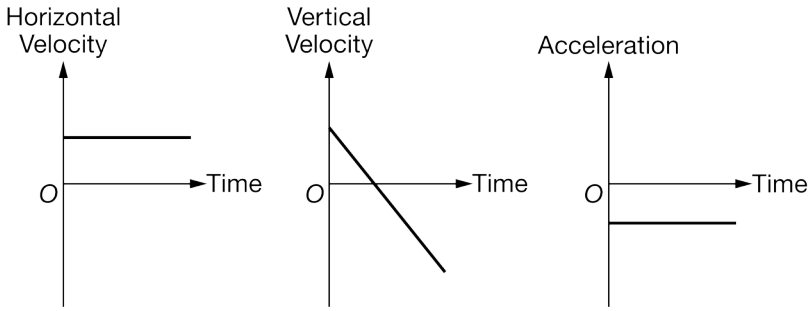


A launcher is used to launch a dart with initial speed v from a table at an angle, as shown above. The dart exits the end of the launcher at a height h above the floor and lands a horizontal distance D from the end of the launcher. A close-up view is included that shows the dart in the launcher immediately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

(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:

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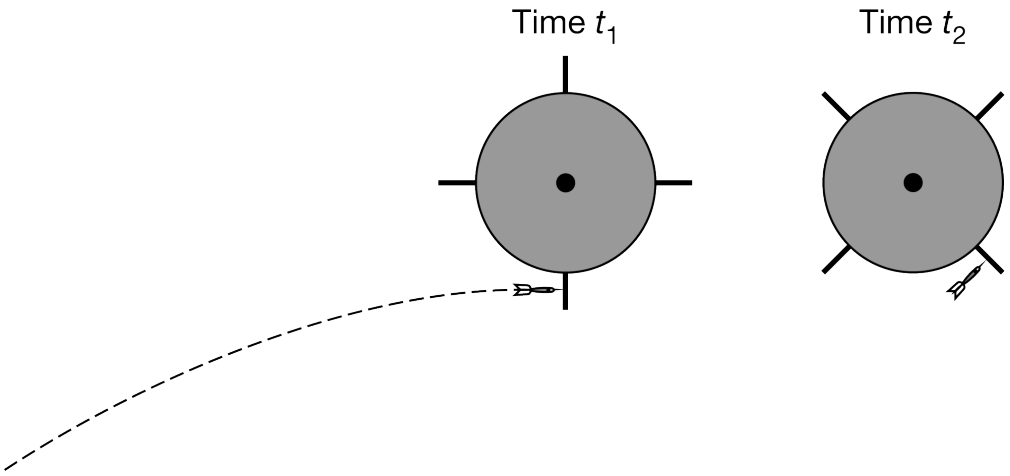
why the magnitude of the dart's velocity decreases until the dart reaches its highest point and why the magnitude of the dart's velocity does not decrease to zero.



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.

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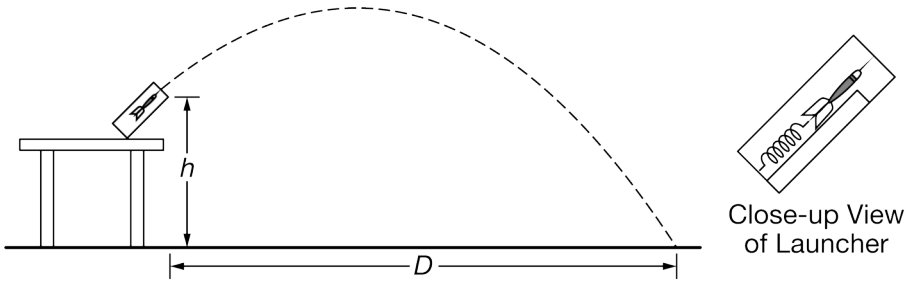
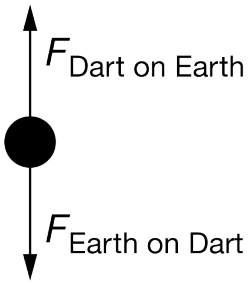
9. This question is a short free-response question. Show your work for each part of the question. (10 points, suggested time 15 minutes)

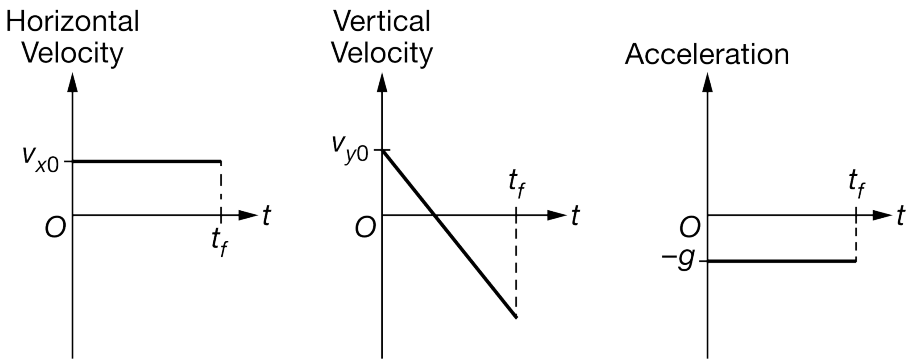


A launcher is used to launch a dart with initial speed v from a table at an angle, as shown above. The dart exits the end of the launcher at a height h above the floor and lands a horizontal distance D from the end of the launcher. A close-up view is included that shows the dart in the launcher immediately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



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

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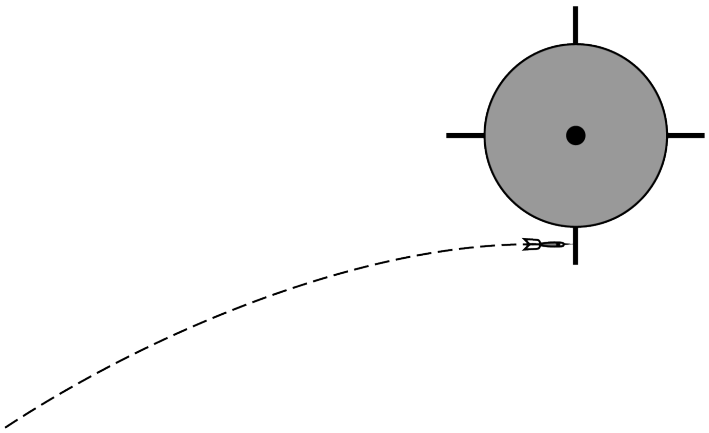
determination of the height h, and how could a student use the chosen graph to determine h ?

(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.

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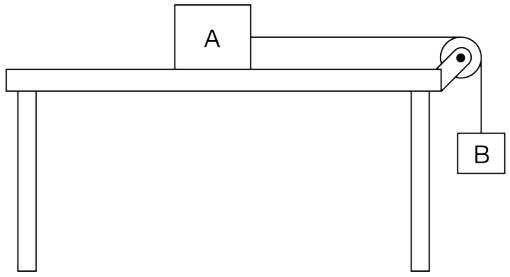
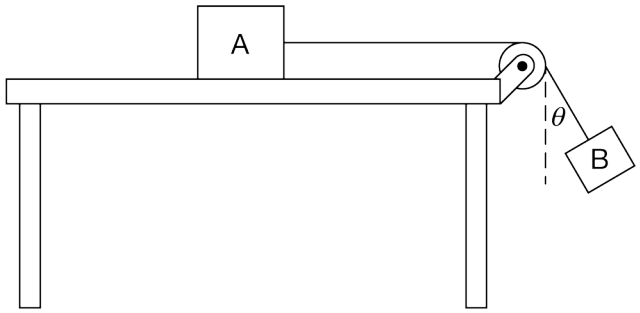
10. This question is a short free-response question. Show your work for each part of the question. (10 points, suggested time 15 minutes)



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.

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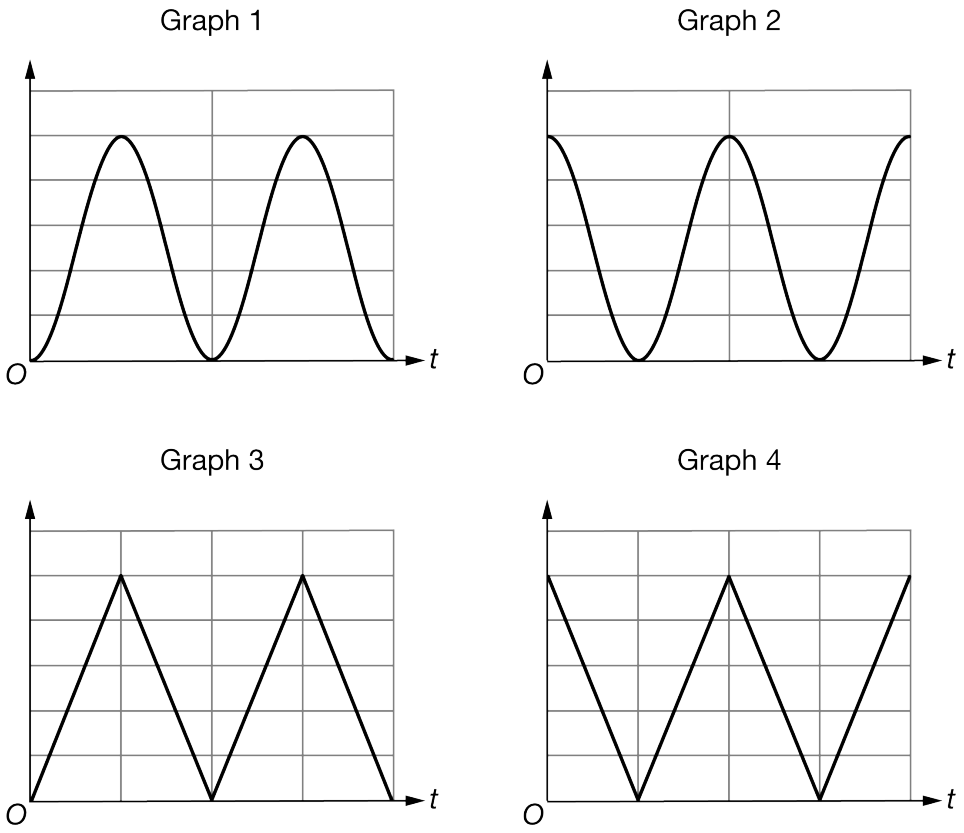

(b) Block A is held at rest while block B swings back and forth. Which of the graphs shown above best represents the kinetic energy of block B as a function of time *t* after it is released from rest at time $t = 0$? Explain your reasoning.

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

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

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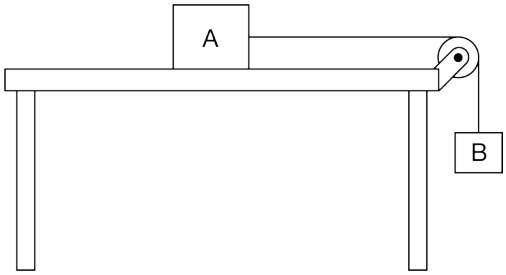
11. This question is a short free-response question. Show your work for each part of the question. (10 points, suggested time 15 minutes)



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.

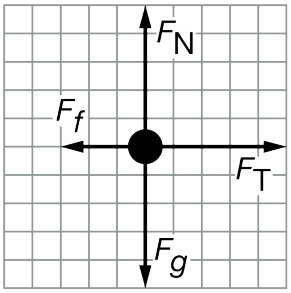


Figure 1

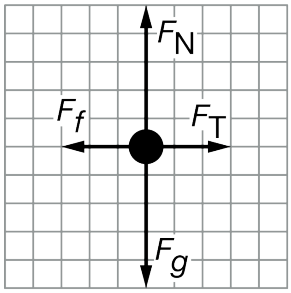


Figure 2

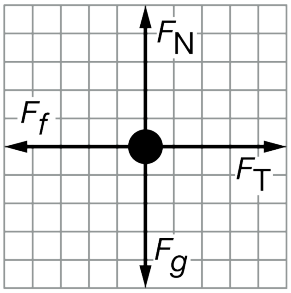


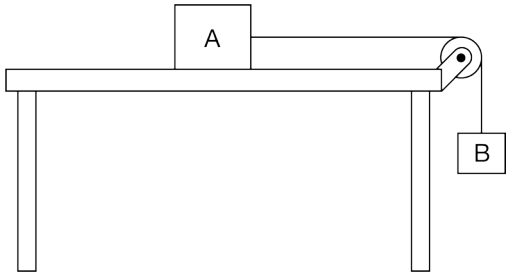
Figure 3

(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.

chapter2partb

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).

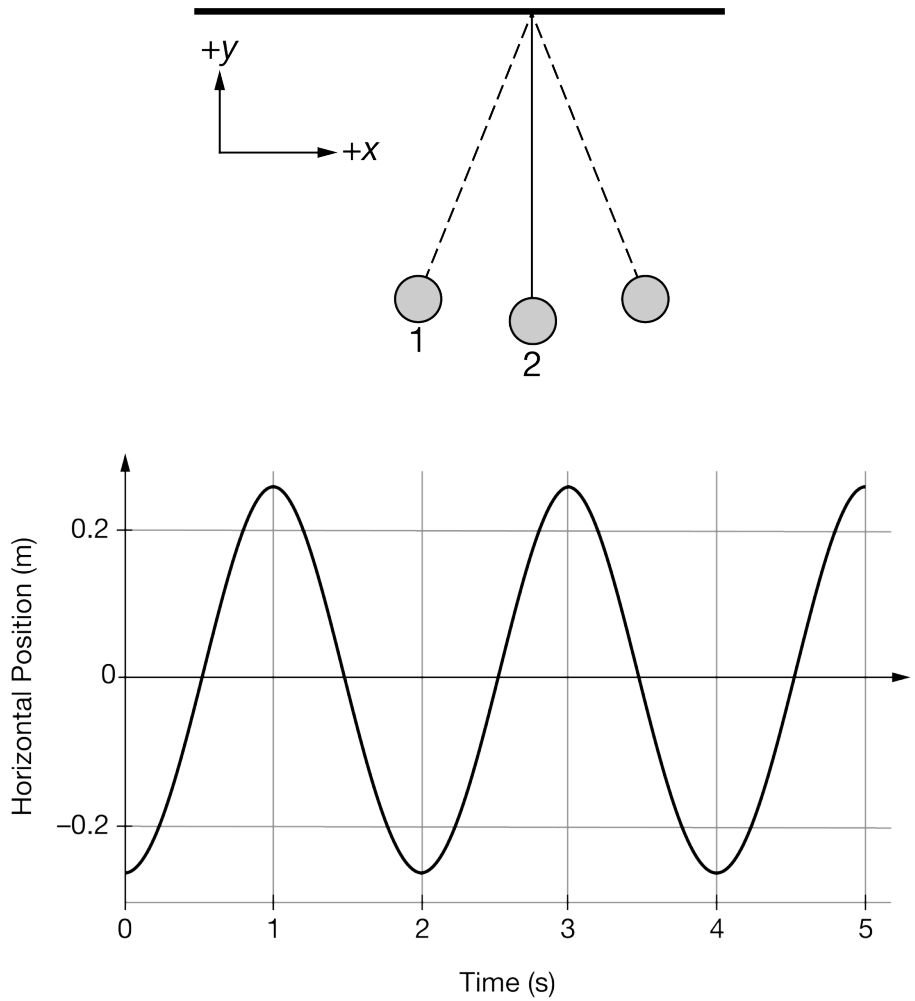
(a) A student claims the magnitude of the frictional force acting on block A must be equal to $\mu m_{\mathrm{A}} g$. Briefly explain why the student's claim is incorrect.

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

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

chapter2partb

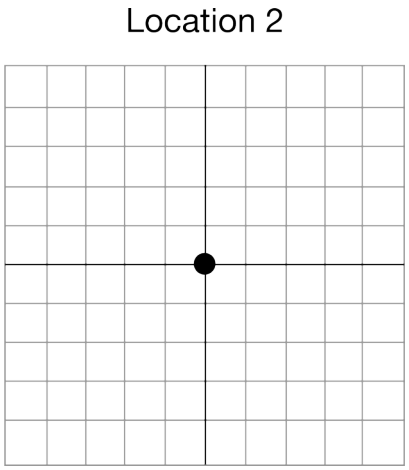
13. This question is a short free-response question. Show your work for each part of the question.



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



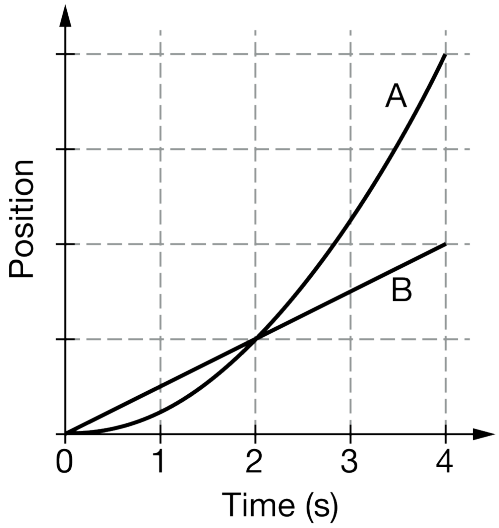
(b) Calculate the maximum kinetic energy of the sphere as it oscillates.

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.

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.

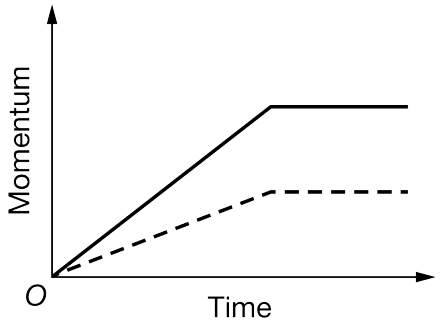
(d) In a clear, coherent paragraph-length response, explain your response to part (c). Be sure to reference and compare the graphed information for both objects A and B.

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 2*F*, 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.

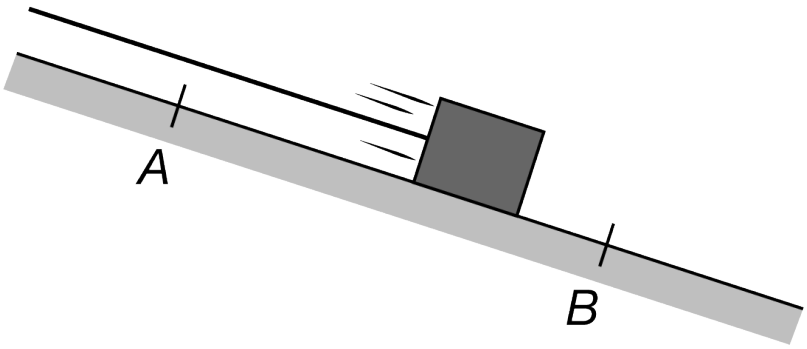
(b) During the time interval that the forces are exerted on the disks, which disk, if either, travels a greater distance along the horizontal section of the track? If the disks travel the same distance, state this explicitly. Briefly explain your answer.

(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).

chapter2partb

16.

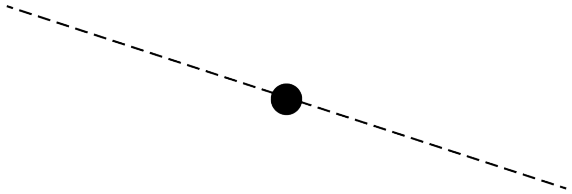


This question is a short free-response question. Show your work for each part of the question.

(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.

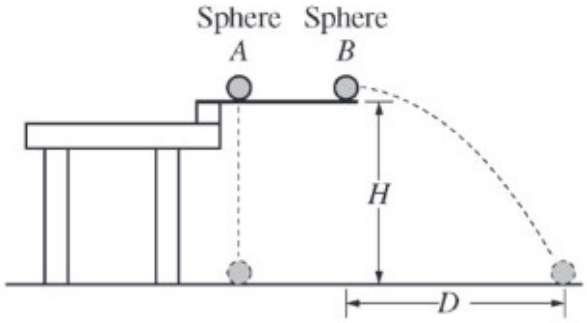


(b) In what follows, consider the system that includes the box and Earth only. (The rope and the ramp are NOT part of the system.) In a clear, coherent, paragraph-length response that may also contain diagrams and/or equations, do the following.

- 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.

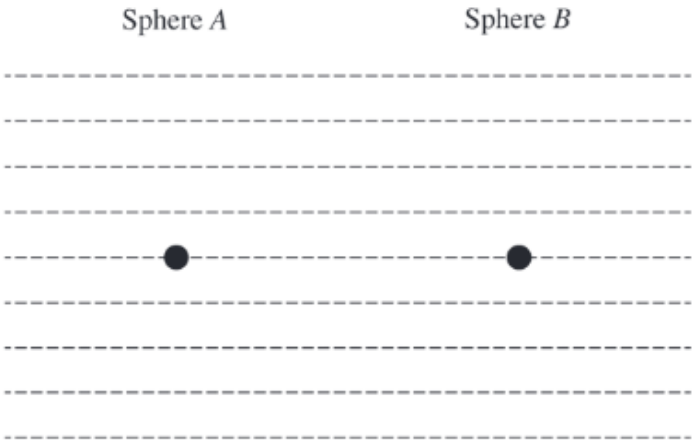
chapter2partb

17.



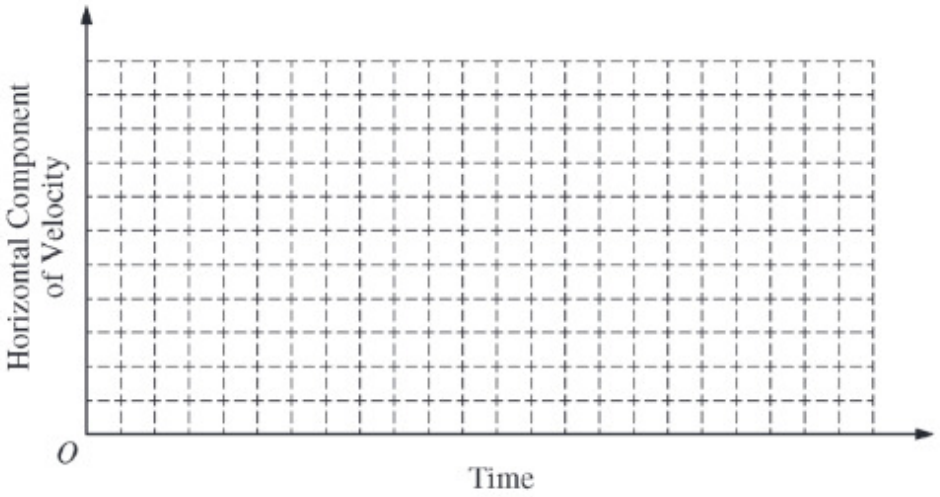
Two identical spheres are released from a device at time t = 0 from the same height H, as shown above. Sphere A has no initial velocity and falls straight down. Sphere B is given an initial horizontal velocity of magnitude v_0 and travels a horizontal distance D before it reaches the ground. The spheres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



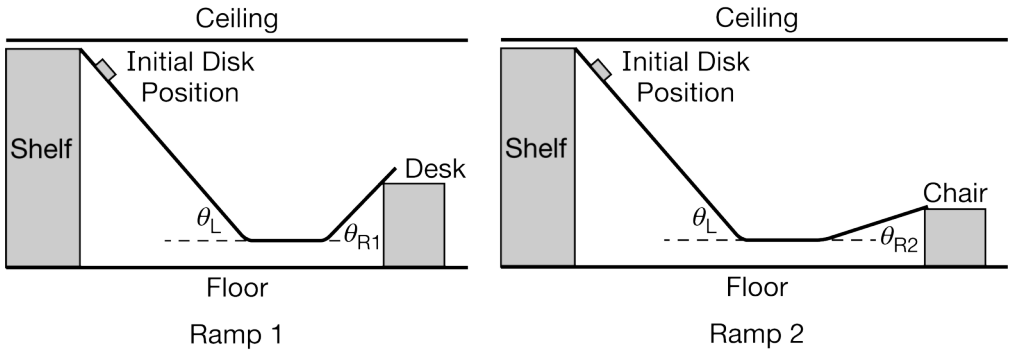
(c) In a clear, coherent, paragraph-length response, explain why the spheres reach the ground at the same time even though they travel different distances. Include references to your answers to parts (a) and (b).

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.

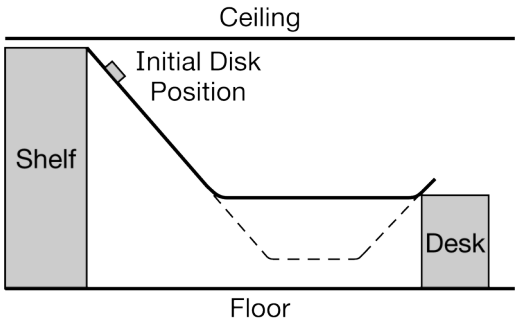


Note: Figures not drawn to scale.

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

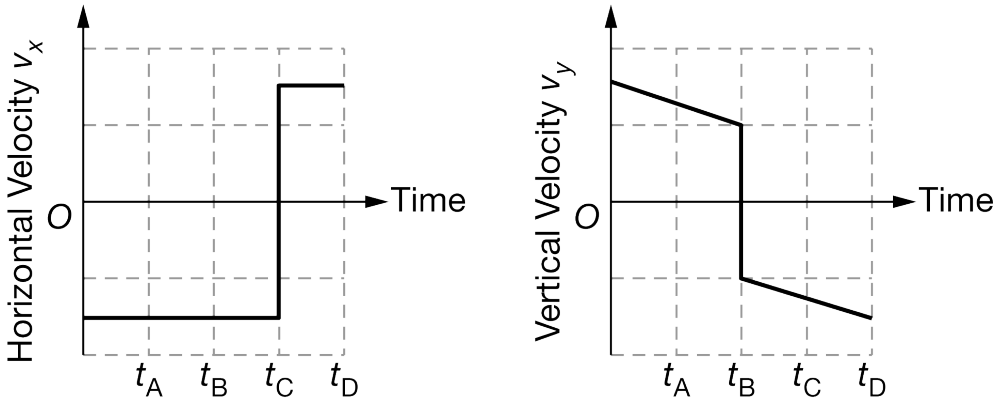


Ramp 3

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.

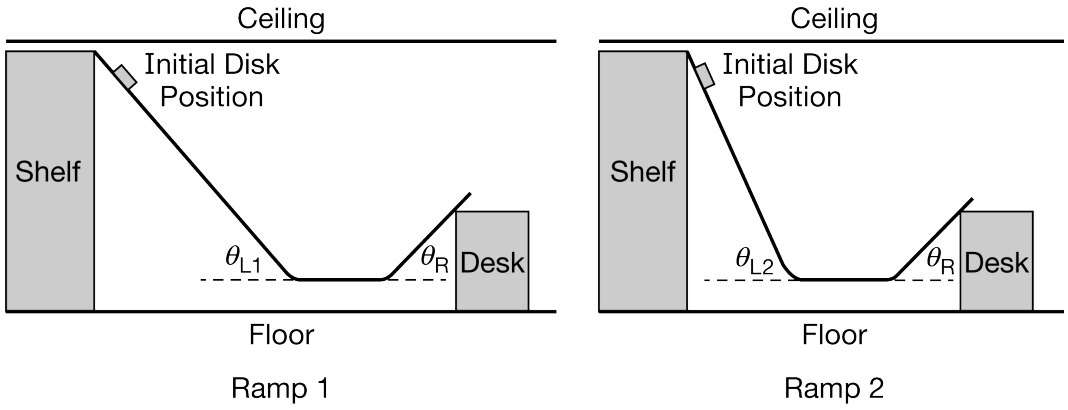
(c) During the time interval shown in the graphs, the ball has two collisions. In a clear, coherent, paragraph-length response, identify the times when these collisions occur using the times indicated on the graph, and explain how you know whether each collision is with the wall, the ceiling, or the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

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.

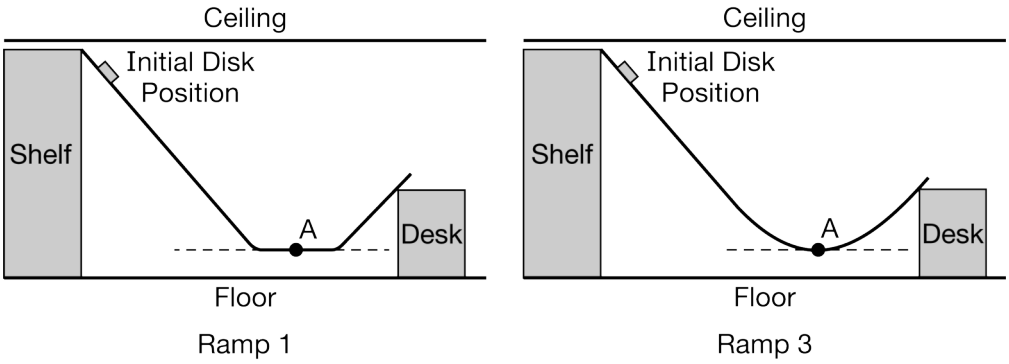


Note: Figures not drawn to scale.

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 $\theta_{\mathrm{L1}} < \theta_{\mathrm{L2}}$, and they keep the top of the ramp against the shelf as shown in the Ramp 2 configuration above so that the disk is released at the same height.

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

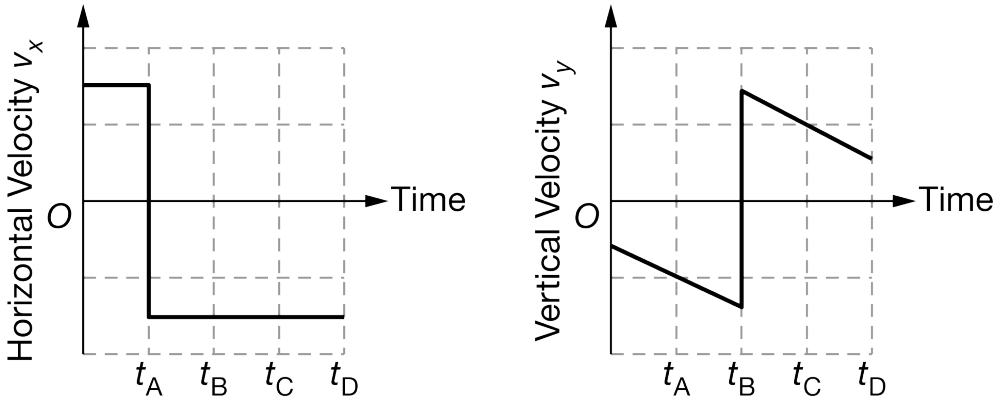
chapter2partb



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.