1 Multiple Choice Questions

The exam begins on the next page.

PHYSICS 1

SECTION I

Time—1 hour and 30 minutes

50 Questions

Note: To simplify calculations, you may use $g = 10$ m/s^2 in all problems.

Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

1. To estimate the height of a building, students release a ball from the top of the building and measure the time it takes to reach the ground. The calculated height turns out to be greater than the actual height. Which of the following could have caused the discrepancy?

   (A) Air resistance is not negligible.
   (B) The ball had a nonzero initial horizontal velocity.
   (C) The ball had a nonzero initial downward velocity.
   (D) The students started measuring the time after the ball was released.

2. A heavy toy truck collides with a lightweight toy car that is initially at rest. Frictional forces are negligible. After the collision, the car and truck move together. During the collision, which of the following is true?

   (A) The momentum lost by the truck equals the momentum gained by the car.
   (B) The kinetic energy lost by the truck equals the kinetic energy gained by the car.
   (C) The magnitude of the car's acceleration equals the magnitude of the truck's acceleration.
   (D) The center-of-mass speed of the car-truck system decreases.

3. A satellite of mass M_s is orbiting a planet of mass M_p in a circular orbit of radius R_0. What is the kinetic energy of the satellite?

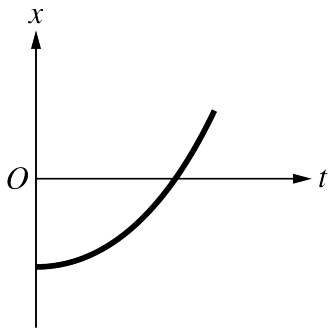
   (A) $\dfrac{GM_pM_s}{2R_0}$
   (B) $\dfrac{GM_pM_s}{R_0}$
   (C) $\dfrac{GM_pM_s}{2R_0^2}$
   (D) $\dfrac{GM_pM_s}{R_0^2}$

4. A sphere is initially held at rest a distance R_0 above the center of a planet of mass M_0. The weight of the sphere at this initial location is W_0. The sphere is then moved to a new location above the same planet so that the weight of the sphere is $2W_0$. Which of the following expressions represents the strength of the gravitational field at the new location of the sphere?

   (A) $\dfrac{GM_0}{4R_0^2}$
   (B) $\dfrac{GM_0}{2R_0^2}$
   (C) $\dfrac{GM_0}{R_0^2}$
   (D) $\dfrac{2GM_0}{R_0^2}$

5. A marble is released from rest at the top of a ramp of height h. The marble rolls down the ramp without slipping. The translational speed of the marble at the bottom of the ramp is v. Which of the following correctly compares v to $\sqrt{2gh}$?

   (A) $v < \sqrt{2gh}$
   (B) $v = \sqrt{2gh}$
   (C) $v > \sqrt{2gh}$
   (D) The translational speed cannot be compared to $\sqrt{2gh}$ without knowing the slope of the ramp.



6. The graph shows the position x as a function of time t for a bicycle moving in a straight path. Which of the following graphs best represents the velocity v of the bicycle as a function of time t?

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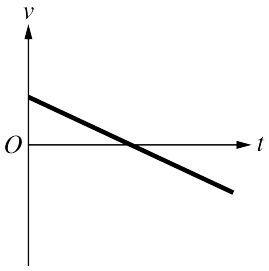

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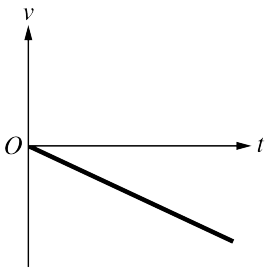

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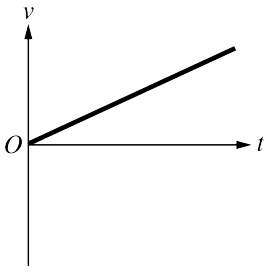

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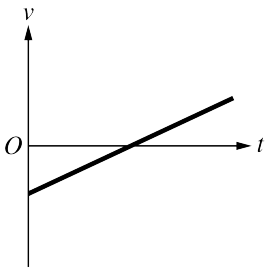
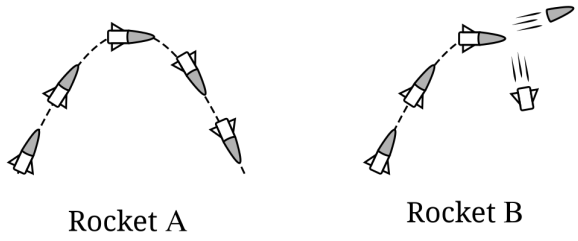




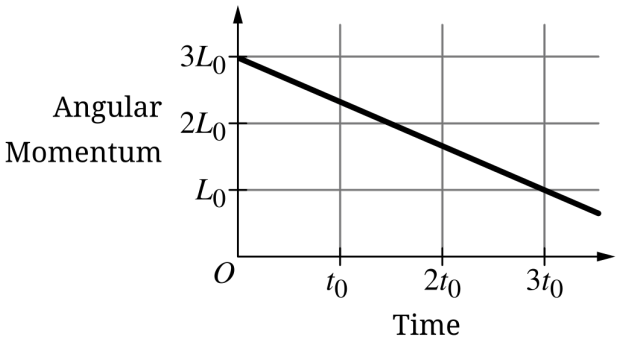
7. Two identical rockets, A and B, are launched into the air at the same angle with the same initial speed. Rocket A remains intact throughout its trajectory, as shown on the left. Rocket B separates into two pieces at the top of its trajectory, as shown on the right. Which of the following best explains why the trajectory of the center of mass of Rocket B follows the same trajectory as that of the center of mass of Rocket A?

(A) No external force is exerted on the center of mass of either rocket.

(B) The total mechanical energy of both rockets remains constant.

(C) Gravitational forces are the only external forces exerted on both rockets.

(D) The momentum of the center of mass of both rockets remains constant.



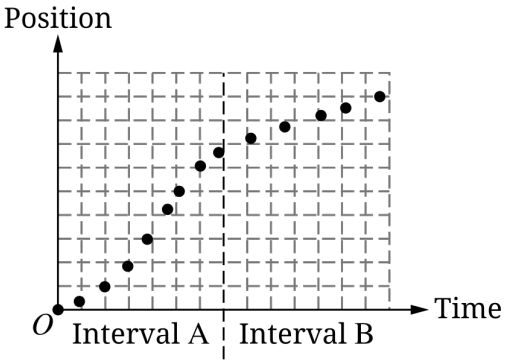
8. The graph shows the angular momentum L of a wheel about its axle as a function of time . What is the magnitude of the net torque on the wheel?

(A) $\dfrac{2L_0}{3t_0}$

(B) $\dfrac{L_0}{t_0}$

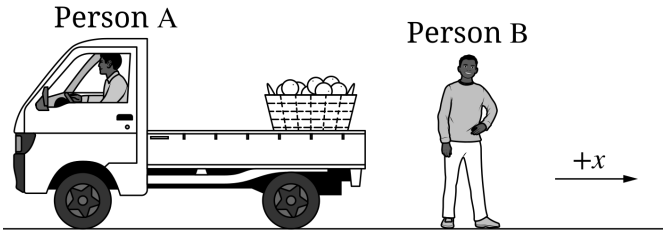
(C) $3L_0t_0$

(D) $6L_0t_0$



9. The graph shows the position of an object as a function of time. Which of the following correctly describes the speed of the object for the given time intervals?

	Time Interval A	Time Interval B
(A)	Constant speed	Constant speed
(B)	Constant speed	Changing speed
(C)	Changing speed	Constant speed
(D)	Changing speed	Changing speed



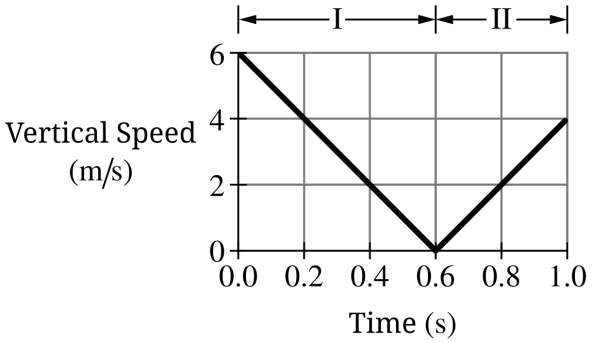
10. A basket of apples is at rest on the back of a truck that is driven by Person A, as shown. The truck accelerates in the $-x$-direction, and the basket of apples remains at rest relative to the truck. Which of the following describes the relative motion of the basket of apples as the truck accelerates in the $-x$-direction?

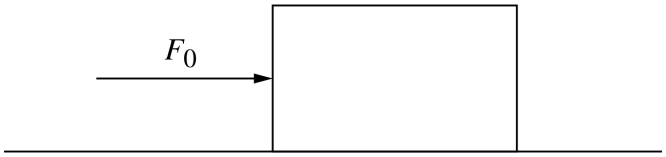
(A) The basket accelerates in the $-x$-direction in the reference frame of Person A.

(B) The basket accelerates in the $-x$-direction in the reference frame of Person B.

(C) The basket remains at rest in the reference frame of Person B.

(D) The basket remains at rest in the reference frame of both Person A and Person B.





11. A student standing on the ground throws a ball to another student who stands on a platform that is raised above the ground. The ball's vertical speed as a function of time is shown in the graph above. Time interval I is from 0.0 s to 0.6 s while the ball is moving upward. Time interval II is from 0.6 s to 1.0 s while the ball is moving downward. Which of the following methods will allow the students to best estimate the total vertical displacement of the ball during the total time interval shown?

    (A) Find the slope of the line of best fit for all of the data. Then multiply the result by the total time interval shown.

    (B) Average the slopes of the lines of best fit for time intervals I and II. Then multiply the result by the total time interval shown.

    (C) Calculate the sum of the areas under the curves for time intervals I and II.

    (D) Calculate the difference between the areas under the curves for time intervals I and II.

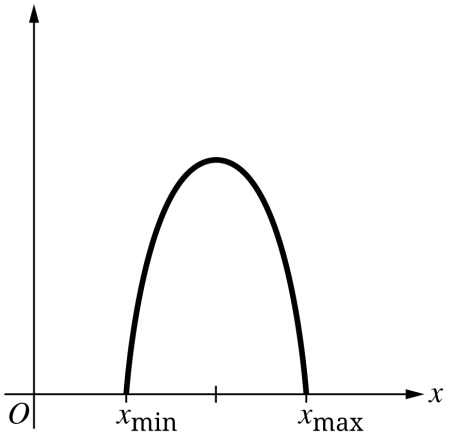
12. Students are sliding a block along a rough surface by exerting a force F_0 on the block parallel to the surface. Which of the following is correct for F_f, the magnitude of the frictional force between the block and the surface?

    (A) F_f is greater when the students slide the block faster.

    (B) F_f is greater when the surface on which the block slides is inclined at an angle.

    (C) F_f is greater when the block is turned so that it slides on a face with a larger area.

    (D) F_f can have a different value when the block is at rest than when the block is moving.



13. A block attached to a spring oscillates between two positions, x_{min} and x_{max}, on a horizontal surface. The graph shown plots a quantity as a function of the position of the block. Which of the following quantities when plotted on the vertical axis would result in the graph shown?

    (A) The kinetic energy of the spring-block system

    (B) The magnitude of the force exerted by the spring on the block

    (C) The potential energy of the spring-block system

    (D) The total mechanical energy of the spring-block system

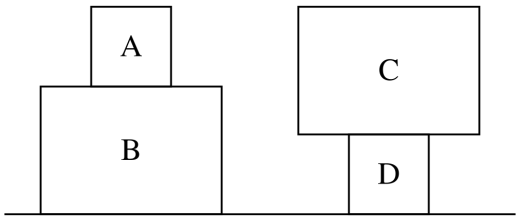
14. Block A of mass m_0 slides with constant velocity v_0 across a horizontal surface toward Block B of mass $\frac{1}{2}m_0$ that is initially at rest. The blocks collide and stick together. What is the kinetic energy of the two-block system after the collision?

    (A) $\frac{1}{6}m_0v_0^2$

    (B) $\frac{1}{3}m_0v_0^2$

    (C) $\frac{1}{2}m_0v_0^2$

    (D) $\frac{2}{3}m_0v_0^2$



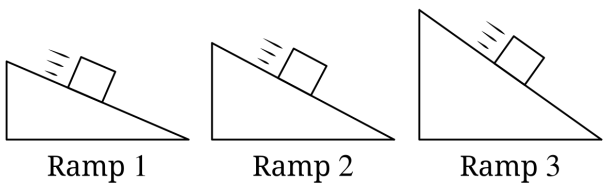
15. The diagram shows four blocks, A, B, C, and D, at rest. Blocks A and D have mass m_0, while blocks B and C have mass M_0, where $M_0 > m_0$. Which of the following correctly ranks the blocks according to the magnitudes of the net forces exerted on the blocks?

    (A) A=B=C=D

    (B) (A=D)<(B=C)

    (C) A<D<C<B

    (D) A<C<B<D



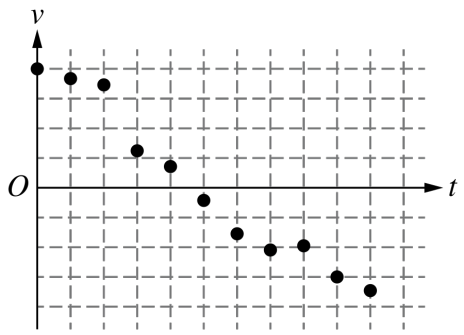
16. Three identical blocks, A, B, and C, slide on three different rough ramps, 1, 2, and 3, respectively. Ramp 3 is steeper than Ramp 2, which is steeper than Ramp 1, as shown. The blocks slide with constant velocities. Which block, if any, experiences the greatest net force?

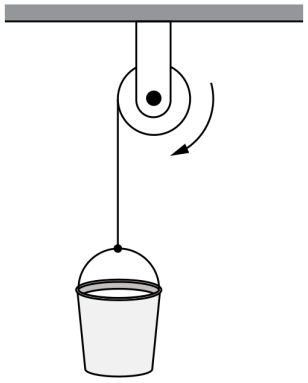
    (A) Block A

    (B) Block B

    (C) Block C

    (D) All blocks experience the same net force.





17. The graph shows the measured values of the velocity v as a function of time t for an object moving in a straight line. For the time interval shown on the graph, which of the following statements is correct?

    (A) The object starts from rest.

    (B) The object reverses direction.

    (C) The object has a speed that decreases at a constant rate during the entire time interval.

    (D) The object moves in the negative direction during the entire time interval.

18. A bucket is attached to a long, lightweight string that is wrapped around a pulley that has nonnegligible mass, as shown. The pulley is given an initial clockwise rotation and then rotates with negligible friction. The angular momentum of the pulley about the pulley's center has magnitude L, and the torque exerted by the string on the pulley about the pulley's center has magnitude τ. Which of the following correctly describes the changes, if any, in τ and L while the pulley is rotating clockwise?

	τ	L
(A)	Stays constant	Stays constant
(B)	Stays constant	Decreases
(C)	Decreases	Stays constant
(D)	Decreases	Decreases



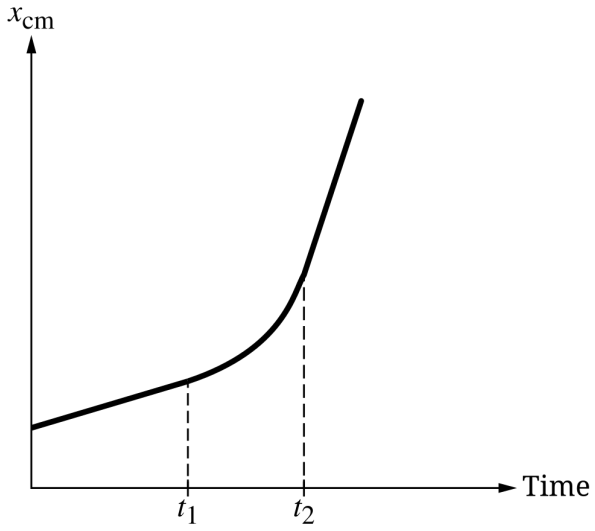
19. A block with mass m_0 slides with negligible friction at a speed of v_0 across a horizontal surface. At $t = 0$, the block collides with a spring with unknown spring constant that is attached to the wall, as shown. At $t = t_1$, the spring is compressed a distance Δx and the block is momentarily at rest. Which of the following correctly describes how, if at all, the average force exerted on the block from $t = 0$ to $t = t_1$ could be calculated?

(A) Divide the change in the block's momentum from $t = 0$ to $t = t_1$ by time t_1.

(B) Multiply the change in the block's kinetic energy from $t = 0$ to $t = t_1$ by distance Δx.

(C) The average force cannot be calculated because the block's acceleration from $t = 0$ to $t = t_1$ is not constant.

(D) The average force cannot be calculated because the spring constant is not known.



20. Two identical objects move along a horizontal track. The graph represents the position of the center of mass of the two-object system $x_{\mathbf{cm}}$ as a function of time. Both objects initially move at a constant speed in the same direction. Which of the following could explain the change in motion in the time interval between t_1 and t_2?

(A) An external force in the $+x$-direction was exerted on one of the objects.

(B) An external force in the $-x$-direction was exerted on one of the objects.

(C) An external force in the $+y$-direction was exerted on one of the objects.

(D) Two equal and opposite horizontal forces were exerted on both objects.

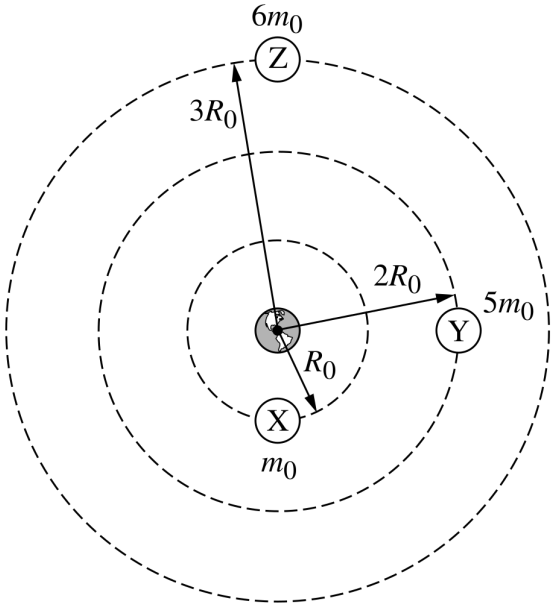
21. Cart X collides with Cart Y, which is initially at rest. After the collision, Cart X and Cart Y are moving in opposite directions. The collision lasts 0.3 s, and the average force exerted on Cart Y by Cart X is 10 N. What is the magnitude of the change in momentum of Cart X during the collision?

(A) 1.5 kg·m/s

(B) 3.0 kg·m/s

(C) 4.5 kg·m/s

(D) The change in momentum of Cart X cannot be determined without knowing the masses and change in velocity of both carts.



Note: Figure not drawn to scale.

22. Satellites X, Y, and Z travel in circular orbits around Earth. The mass of each satellite and the distance of each satellite from Earth's center are shown. Which of the following compares the magnitudes of the gravitational forces F_X, F_Y, and F_Z exerted on satellites X, Y, and Z, respectively, by Earth?

(A) $F_X > F_Y > F_Z$

(B) $F_X > F_Z > F_Y$

(C) $F_Y > F_X > F_Z$

(D) $F_Z > F_Y > F_X$

23. A string is used to pull a block up a ramp such that the block travels with a constant speed while remaining in contact with the ramp. Frictional forces are nonnegligible. Which of the following statements correctly predicts how the absolute value of the work done by gravity W_g on the block compares to the absolute value of the work done by the string W_s on the block as the block travels up the ramp?

(A) $W_g > W_s$ because the block remains entirely in contact with the ramp due to the gravitational force.

(B) $W_g > W_s$ because the block travels in a direction that has horizontal and vertical components.

(C) $W_g < W_s$ because the work done on the block by Earth is zero.

(D) $W_g < W_s$ because mechanical energy is dissipated by friction.

24. Two identical objects, 1 and 2, are initially at rest. Object 1 remains at rest while Object 2 begins to accelerate in the $+x$-direction. Which of the following claims regarding the location of the center of mass of the two-object system is correct?

(A) The location of the center of mass does not change.

(B) The location of the center of mass moves in the $+x$-direction at a constant speed.

(C) The location of the center of mass accelerates in the $+x$-direction and is located between the two objects.

(D) The location of the center of mass accelerates in the $+x$-direction and is located at the same location as Object 2.

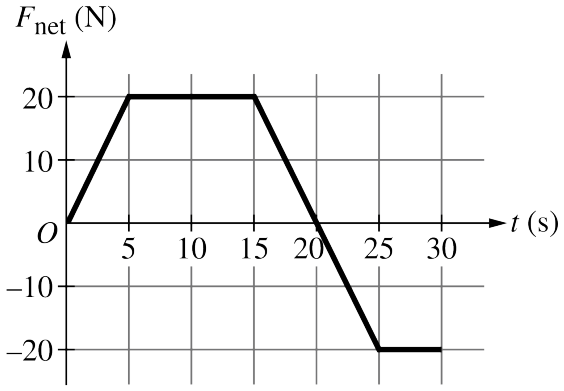
25. A block is initially at rest at the bottom of a ramp. A student pulls the block along the ramp to the top of the ramp using a string. Frictional forces are negligible. The student measures the mass of the block and the speed of the block at the top of the ramp. Which of the following lists the fewest additional measurements required to estimate the total work done on the block as it moves from the bottom of the ramp to the top of the ramp?

(A) No additional measurements necessary

(B) The distance the block travels along the ramp

(C) The distance the block travels along the ramp
The force exerted on the block by the string as the block travels up the ramp

(D) The distance the block travels along the ramp
The force exerted on the block by the string as the block travels up the ramp
The angle of the ramp with the horizontal



26. A crate of mass 75 kg is initially at rest on a horizontal surface. The graph shows the net horizontal force F_{ext} exerted on the crate as a function of time t. At $t = 30$ s, what is the approximate speed of the crate?

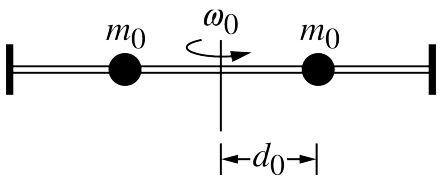
(A) 2 m/s

(B) 4 m/s

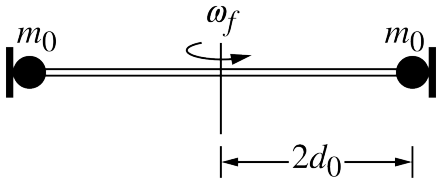
(C) 6 m/s

(D) 8 m/s

Questions 27-29



Initial State



Final State

Note: Figures not drawn to scale.

Consider a system that consists of two beads and a thin rod of negligible mass. In the initial state, the beads, each of mass m_0, are attached with their centers a distance d_0 from the center of the rod. The rod is freely rotating with angular speed about a fixed vertical axis through the center of the rod, as shown. Then, an internal mechanism releases the beads and they slide with negligible friction outward until the beads hit the end stops. In the final state, the centers of the beads are a distance $2d_0$ from the center of the rod, which is rotating with an angular speed ω_f, as shown. The curved arrows in the figures indicate the directions only, not the magnitudes, of the angular speeds.

27. Which of the following quantities of the beads-rod system at the initial and final state is the same?

(A) Angular momentum
(B) Period of rotation
(C) Rotational inertia
(D) Rotational kinetic energy

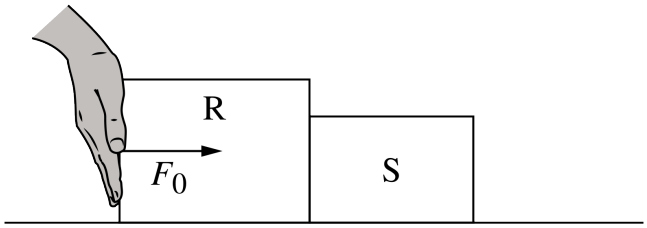
28. The tangential speed v of the beads can be represented by $v = \omega r$, where ω is the angular speed and is the distance of the bead from the vertical axis. Which of the following correctly compares the magnitude of the net force exerted on one of the beads in the initial state to the magnitude of the net force exerted on the same bead in the final state?

(A) The magnitude of the net force is the same and zero in both states.
(B) The magnitude of the net force is the same and nonzero in both states.
(C) The magnitude of the net force is less in the final state.
(D) The magnitude of the net force is greater in the final state.

29. The rotational inertia I of the beads-rod system is $2m_0r^2$, where m_0 is the mass of each bead and r is the distance of each bead from the vertical axis. Which of the following is equal to the rotational speed of the rod in the final state, ω_f?

(A) $4\omega_0$
(B) $2\omega_0$
(C) $\frac{\omega_0}{2}$
(D) $\frac{\omega_0}{4}$

Questions 30-31



Box R of mass m_R and Box S of mass m_S, where $m_R > m_S$, are located on a horizontal surface, as shown. A constant horizontal force F_0 is exerted on Box R and causes the system to have an acceleration of magnitude a_0 to the right. The coefficient of kinetic friction between the surface and each box is μ_0.

30. Which of the following is a correct expression for the magnitude of the force F_0 exerted on Box R?

    (A) $(m_R + m_S)\mu_0 g$

    (B) $(m_R - m_S)\mu_0 g$

    (C) $(m_R + m_S)(a_0 + \mu_0 g)$

    (D) $(m_R + m_S)(a_0 - \mu_0 g)$

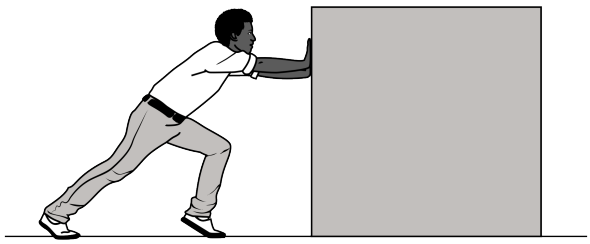
31. When the force F_0 is exerted on Box R, a student measures the acceleration of the boxes to be 1 m/s^2 to the right. Then the force is doubled to $2F_0$. Which of the following correctly describes the magnitude of the resulting acceleration of the boxes?

    (A) 1 m/s^2

    (B) Between 1 m/s^2 and 2 m/s^2

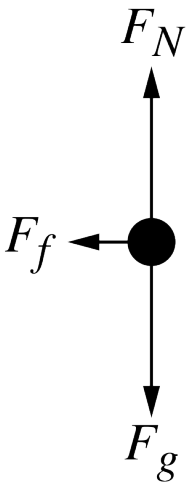
    (C) 2 m/s^2

    (D) More than 2 m/s^2

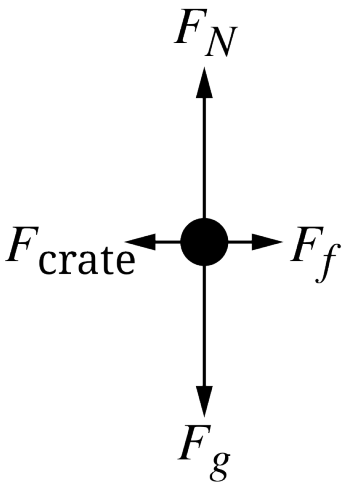


32. A person exerts a force of magnitude F_{create} on a crate, as shown in the figure, causing the crate to move with a constant velocity. There is nonnegligible friction between the crate and the floor and between the person's shoes and the floor. F_g is the magnitude of the weight of the person, F_N is the magnitude of the force exerted by the floor on the person, F_f and is the magnitude of the frictional force exerted by the floor on the person. Which of the following diagrams could represent the forces exerted on the person?

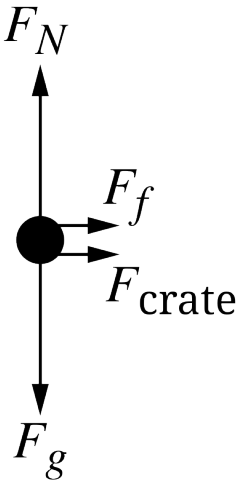
(A)



(B)



(C)



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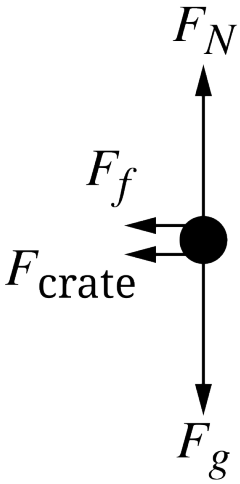


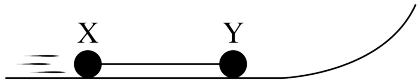


Figure 1

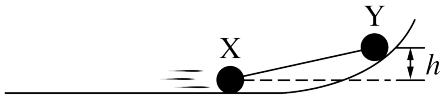


Figure 2

33. Sphere X and Sphere Y, each of mass m_0, are connected by a rigid rod of negligible mass. The two-sphere system slides with speed v_0 across a horizontal surface toward a curved ramp, as shown in Figure 1. When Sphere Y reaches a height of h, Sphere X is still on the horizontal surface, as shown in Figure 2. Frictional forces are negligible. What is the total kinetic energy of the two-sphere system at the instant shown in Figure 2?

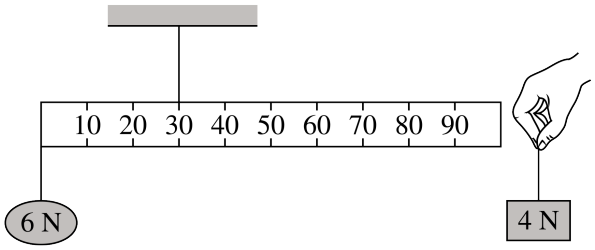
(A) $\frac{1}{2}m_0v_0^2 - \frac{1}{2}m_0gh$

(B) $\frac{1}{2}m_0v_0^2 - m_0gh$

(C) $m_0v_0^2 - m_0gh$

(D) $m_0v_0^2 - 2m_0gh$

Questions 34-36



A student suspends a uniform meterstick that weighs 3 N from the ceiling by a string attached at the 30 cm mark. While holding the meterstick horizontal, the student hangs an object that weighs 6 N from the left end of the meterstick. The student attaches a second object that weighs 4 N at a position x, measured from the left end of the meterstick, so that the meterstick remains horizontal and in static equilibrium.

34. Which of the following is the position x, measured from the left edge of the meterstick, at which the student attaches the 4 N object?

    (A) 30 cm
    (B) 45 cm
    (C) 60 cm
    (D) 75 cm

35. The string that suspends the static two-object-meterstick system is suddenly cut. Which of the following best describes the resulting motion of the system?

    (A) The system falls and rotates in the clockwise direction about the center of mass of the system.
    (B) The system falls and rotates in the counterclockwise direction about the center of mass of the system.
    (C) The system falls and rotates in the counterclockwise direction about the center of the meterstick.
    (D) The system falls without rotating.

36. What is the tension in the string that attaches the static two-object-meterstick system to the ceiling?

    (A) 0 N
    (B) 3 N
    (C) 10 N
    (D) 13 N

Spring	Mass of Block (kg)	Change in Length of Spring (cm)
A	0.10	5.0
B	0.20	4.0
C	0.15	6.0
D	0.12	3.0

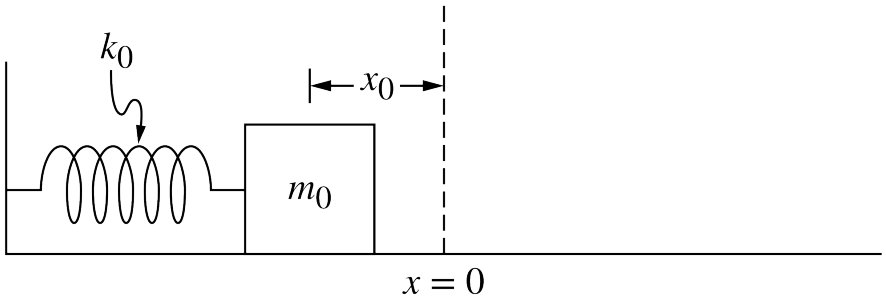
37. Four springs, A, B, C, and D, with the same unstretched length are attached to the ceiling, and a block is attached to each spring. The mass of each block and the resulting change in length of the spring as each block hangs in equilibrium are shown in the table. Each block is then pulled down a small distance y and released. Which spring will oscillate with the highest frequency?

(A) Spring A

(B) Spring B

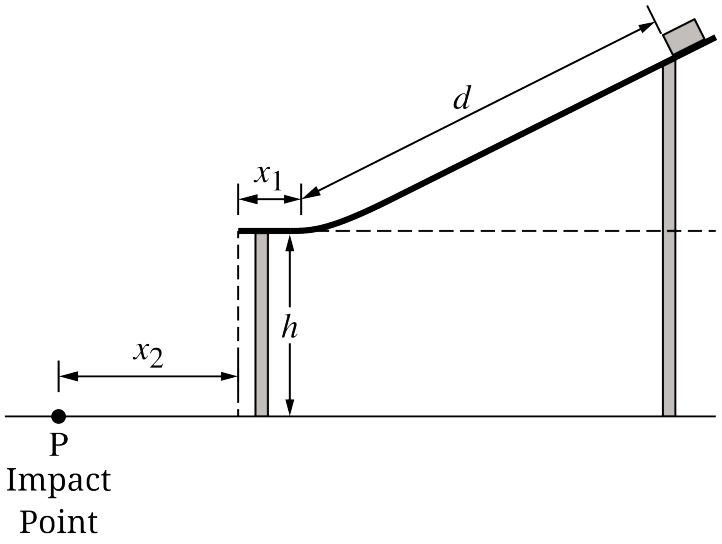
(C) Spring C

(D) Spring D



38. A block of mass m_0 on a horizontal surface is attached to a light spring of spring constant k_0 that is initially compressed a distance x_0 from its relaxed length, as shown. When the block is released from rest, the block-spring system oscillates with total mechanical energy E_0. Which combination of spring constant, initial compression length, and mass would result in the total mechanical energy of the block-spring system being equal to $2E_0$?

	Spring Constant	Initial Compression Length	Mass
(A)	$\frac{1}{4}k_0$	$2x_0$	$2m_0$
(B)	$\frac{1}{2}k_0$	$2x_0$	$2m_0$
(C)	$4k_0$	$\frac{1}{2}x_0$	m_0
(D)	$8k_0$	x_0	m_0



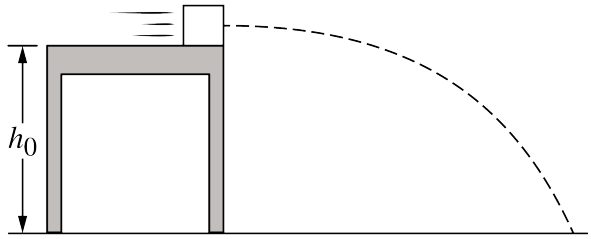
39. A student is conducting an experiment using the apparatus shown. A block is released from the top of an incline of an unknown angle and slides with negligible friction a distance d down the incline, across a horizontal section of track a distance x_1, and then off the table. The block falls a vertical distance h and lands on the ground at the impact point P at a horizontal distance x_2 from the edge of the table. Which two measurements could be used together, without any additional data, to determine the speed of the block as it leaves the table?

(A) d and x_1

(B) d and x_2

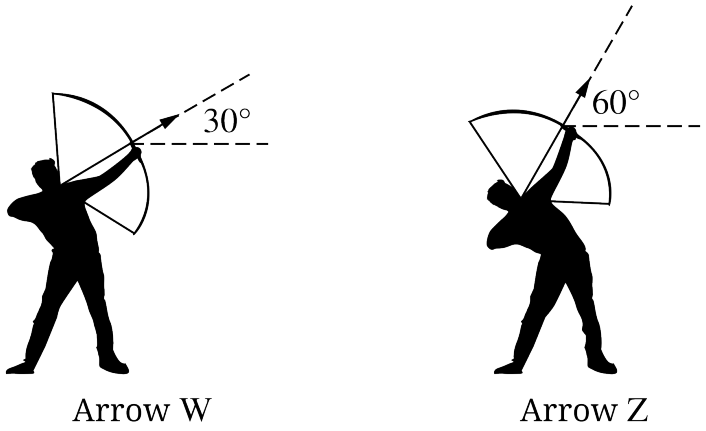
(C) h and x_1

(D) h and x_2

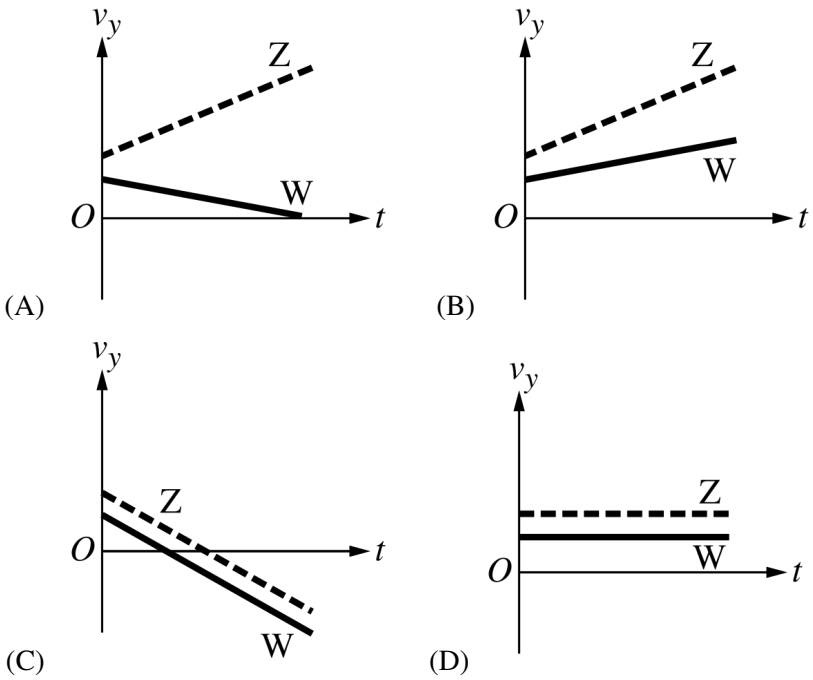


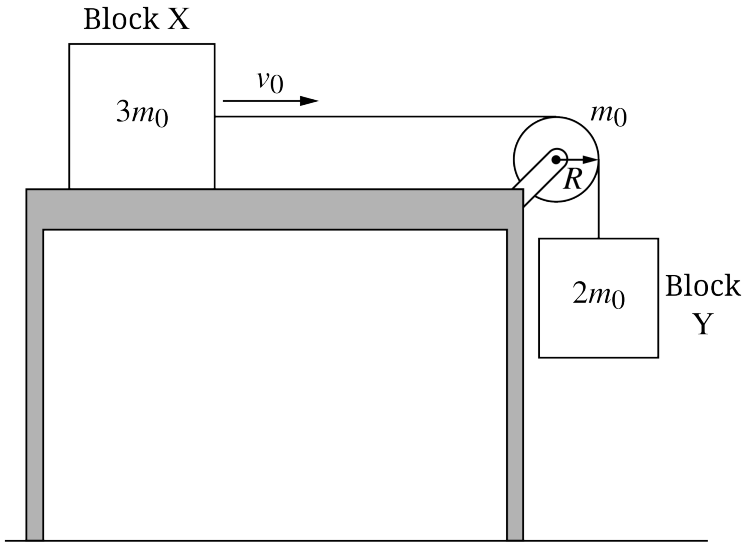
40. A block is launched horizontally from a table with speed v_0 at time $t = 0$. The table is a distance h_0 above the ground. Which of the following represents the kinetic energy K of the block and the potential energy U of the block-Earth system as functions of time as the block falls toward the ground?

	K	U
(A)	$\frac{m_0}{2}(v_0^2 - g^2t^2)$	$m_0 g\left(h_0 + \frac{gt^2}{2}\right)$
(B)	$\frac{m_0}{2}(v_0^2 - g^2t^2)$	$m_0 g\left(h_0 - \frac{gt^2}{2}\right)$
(C)	$\frac{m_0}{2}(v_0^2 + g^2t^2)$	$m_0 g\left(h_0 + \frac{gt^2}{2}\right)$
(D)	$\frac{m_0}{2}(v_0^2 + g^2t^2)$	$m_0 g\left(h_0 - \frac{gt^2}{2}\right)$



41. Arrows W and Z are launched at the same time with the same initial speed at angles of 30° and 60° from the horizontal, as shown. Which of the following graphs represents each arrow's vertical component of velocity v_y as a function of time t? Consider upward to be the positive y-direction.





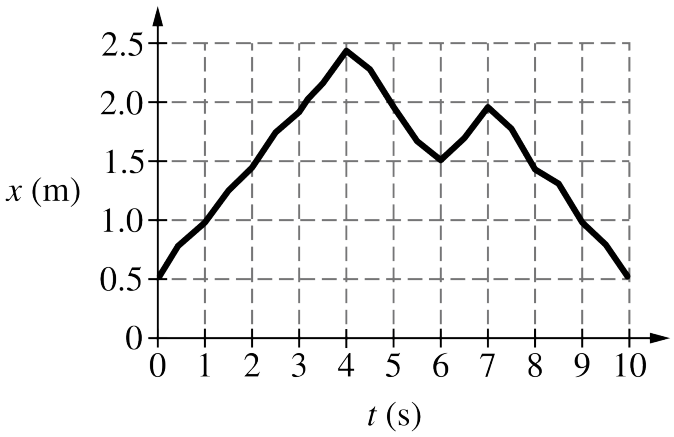
42. Block X of mass $3m_0$ is attached to Block Y of mass $2m_0$ by a string of negligible mass that passes over a pulley of rotational inertia $\frac{1}{2}m_0R^2$ about its central axis. At the moment shown in the figure, both blocks move with speed v_0. A student uses $K = \frac{1}{2}(3m_0)v_0^2 + \frac{1}{2}(2m_0)v_0^2$ to model the kinetic energy K of the system that contains the two blocks and the pulley as the blocks move and the pulley rotates. Which of the following statements justifies whether the student's equation can be used to model K?

(A) The equation can be used, because the kinetic energy of the pulley is negligible compared to the kinetic energies of the blocks.

(B) The equation can be used, because the kinetic energies of the blocks and pulley are represented in the equation.

(C) The equation cannot be used, because the kinetic energy of the system is greater than what is represented in the equation.

(D) The equation cannot be used, because the kinetic energy of Block X is horizontal and the kinetic energy of Block Y is vertical.



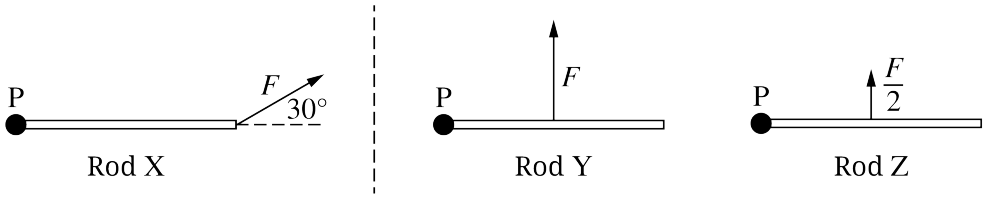
43. A student walks in a straight line in front of a motion detector. The graph shows the data of the student's position x as a function of time t. Which of the following statements regarding the student's motion from time $t = 0$ s to $t = 10$ s is correct?

(A) The distance traveled by the student is 0 m.

(B) The student's velocity is always positive.

(C) The student has an instantaneous velocity of 0 m/s at three distinct times.

(D) The student's average speed is 0 m/s.



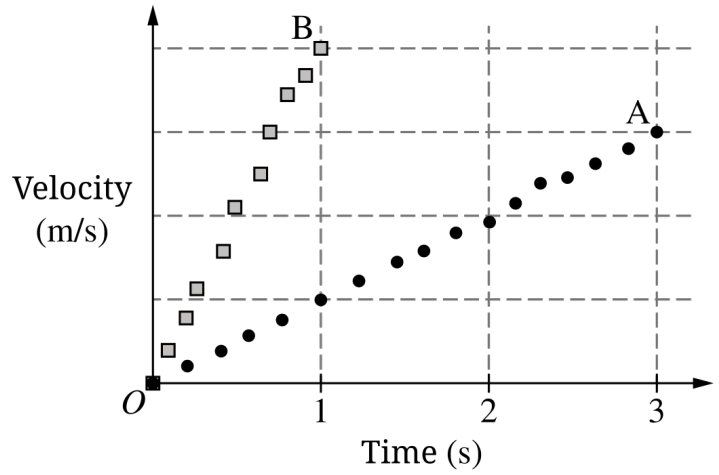
44. Forces are exerted on identical rods X, Y, and Z. The rods are each free to rotate about the pivot P on the left end of the rod. The forces exerted on rods Y and Z are applied to the midpoints of the rods. Which of the following identifies the rod that has the same torque about P as Rod X and provides correct reasoning?

(A) Rod Y, because the magnitude of the force exerted on Rod X is equal to the magnitude of the force exerted on Rod Y.

(B) Rod Y, because the magnitude of the perpendicular component of the force exerted on Rod X is half the magnitude of the force exerted on Rod Y, but the force on Rod X is exerted at twice the distance from P.

(C) Rod X, because the magnitude of the perpendicular component of the force exerted on Rod X is equal to the magnitude of the force exerted on Rod Z.

(D) Rod Z, because the magnitude of the force exerted on Rod X is twice the magnitude of the force exerted on Rod Z, but the force on Rod X is exerted at twice the distance from P.



45. The graph shows the velocity as a function of time for two objects, A and B. Which of the following correctly compares the displacement Δx_A of Object A after 3 s to the displacement Δx_B of Object B after 1 s and provides correct justification?

	Displacement	Justification
(A)	$\Delta x_A > \Delta x_B$	Object A travels for a greater time interval than Object B travels.
(B)	$\Delta x_A > \Delta x_B$	The area under the curve for Object A is greater than the area under the curve for Object B.
(C)	$\Delta x_A < \Delta x_B$	The slope for Object B is greater than the slope for Object A.
(D)	$\Delta x_A < \Delta x_B$	Object B has a greater final velocity than Object A has.

Directions: For each of the questions or incomplete statements below, two of the suggested answers will be correct. For each of these questions, you must select both correct choices to earn credit. No partial credit will be earned if only one correct choice is selected. Select the two that are best in each case and then fill in the corresponding circles that begin with number 131 on the answer sheet.

131. A block of unknown mass on a horizontal table is held at rest against a compressed horizontal spring. The block is launched by the spring and slides a short distance before coming to rest. Which of the following quantities can be used together to determine the amount of mechanical energy dissipated by friction after the block is released from rest? Select two answers.

(A) The spring constant of the spring

(B) The frictional force exerted by the table on the block

(C) The speed of the block after it loses contact with the spring

(D) The total distance that the block moves

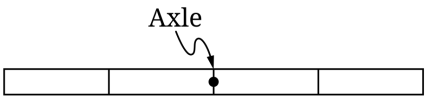
132. A block is suspended vertically by a spring, and the block-spring system oscillates with a period of 0.50 s. An identical block is attached to a lightweight string to form a pendulum that oscillates with a period of 0.75 s. Which of the following modifications, when implemented on its own, could result in the two periods being more nearly the same? Select two answers.

(A) Use a spring with a higher spring constant.

(B) Use a longer string.

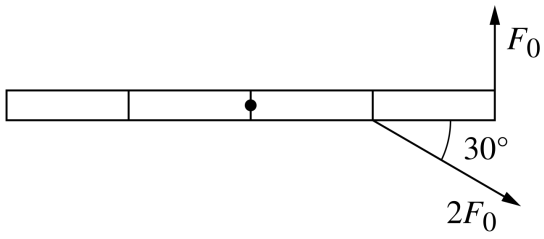
(C) Use heavier blocks.

(D) Repeat the procedure on a planet with a higher gravitational acceleration.

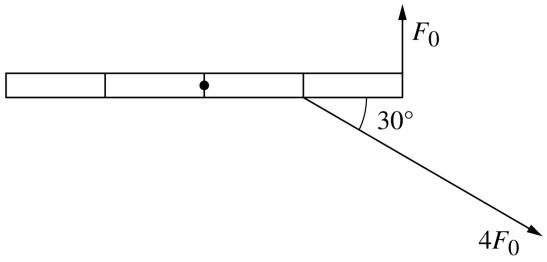


Top View

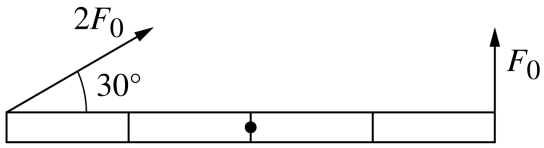
133. A uniform rod is free to rotate about a fixed vertical axle at its midpoint, as shown. Two forces are exerted on the rod. Which of the following scenarios represents a rod that is in static equilibrium? Select two answers.



(A)



(B)



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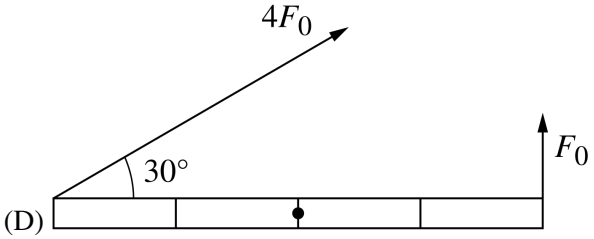
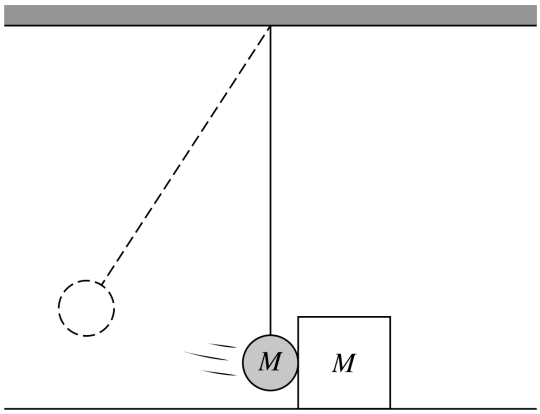


(D)



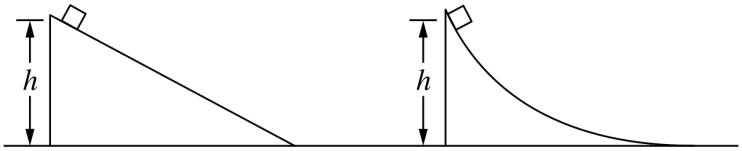
134. A ball of mass M is suspended from the ceiling by a lightweight string, displaced by a small angle from the vertical, and released from rest, as shown. The ball collides with a box, also of mass M, that sits at rest on a horizontal surface, causing the box to move to the right. Frictional forces are negligible. Which of the following describe possible observations of the ball's motion following the collision? Select two answers.

(A) The ball stops completely.

(B) The ball continues to the right but at a slower speed than the box does.

(C) The ball changes direction and moves to the left at a slower speed than the box does.

(D) The ball changes direction and moves to the left with a faster speed than the box does.



135. The figure shows two identical blocks held at height h near the top of two different ramps. The blocks are simultaneously released from rest and slide down the ramps with negligible friction. Which of the following quantities must be equal for both blocks? Select two answers.

(A) The speed of each block at the bottom of the ramp

(B) The time needed for each block to reach the bottom of the ramp

(C) The work done by the gravitational force on each block as the blocks slide down the ramp

(D) The magnitude of the average acceleration of each block as the blocks slide down the ramp

STOP
END OF SECTION I

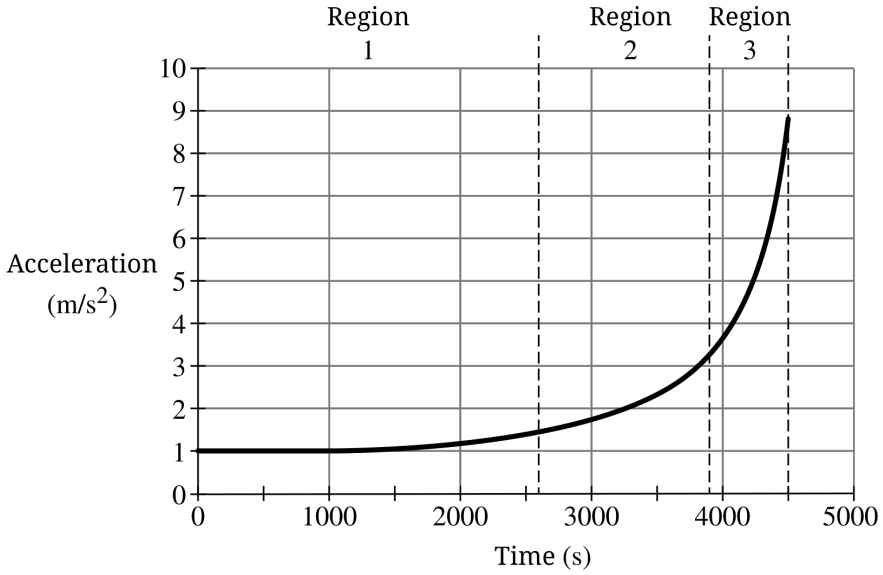
PHYSICS 1

SECTION II

Time—1 hour and 30 minutes

5 Questions

Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



1. (7 points, suggested time 13 minutes)

   An object is released from high above the surface of Planet A, which does not have an atmosphere. The object falls toward the surface of Planet A due to the gravitational field of Planet A only. The graph shows the magnitude of the acceleration of the object as a function of time until the object reaches the surface of the planet. The area bound by the curve and the horizontal axis is the same for regions 1, 2, and 3.

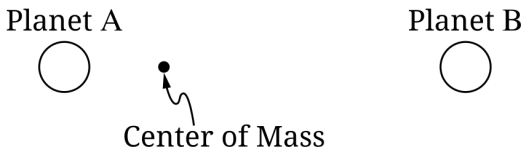
   (a) The object is released from $t = 0$ s rest at time and reaches the surface of the planet at time $t = 4500$ s.

      i. In addition to the information provided by the graph, which one of the following quantities is needed to calculate the magnitude of the net force exerted by the planet on the object?

      _____ Mass of the planet _____ Radius of the planet _____
      Mass of the object _____ Initial height of the object

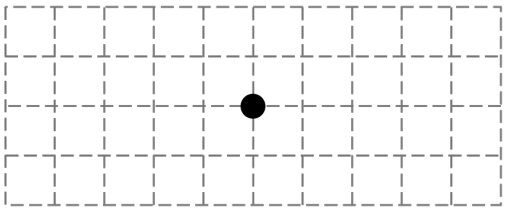
      ii. Determine the ratio of the gravitational force exerted on the object by Planet A at time $t = 4500$ s to the gravitational force exerted on the object by Planet A at time $t = 2600$ s.

   (b) Determine the ratio of the speed of the object at time $t = 4500$ s to the speed of the object at time $t = 2600$ s. Briefly justify your answer.



(c) At a later time, the object is launched from the surface of Planet A so that it travels to Planet B. The diagram shows Planet A, Planet B, and the center of mass of the two-planet system. The motion of each planet is negligible.

i. On the following dot, which represents the object, draw and label the gravitational forces F_A and F_B (not components) exerted by Planet A and Planet B, respectively, on the object when the object is at the center of mass of the system. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. Relative magnitudes of the forces must be indicated but not necessarily drawn to scale.



ii. As the object passes through the center of mass of the system, is the speed of the object increasing, decreasing, or remaining the same? Justify your answer.

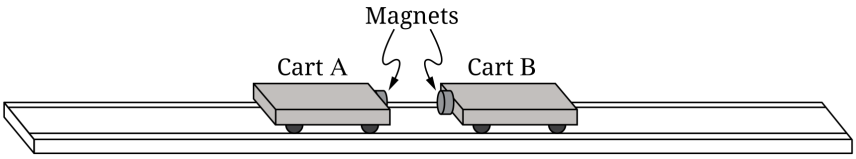


Figure 1

2. (12 points, suggested time 25 minutes)

Students are investigating collisions between Cart A and Cart B on a horizontal track, where frictional forces are negligible. A magnet is attached to each cart, as shown in Figure 1. The students give each cart a quick push so that the carts roll toward each other. As the carts approach each other, the magnetic interaction causes a slow collision in which the carts repel each other, momentarily come to a stop without touching, then reverse direction.

(a) The students wonder whether the collisions between the carts are elastic.

i. Design an experimental procedure that the students could use to determine whether the collisions are elastic.

In the first column of the table, list the quantities that would be measured in the experiment. In the next two columns of the table, define a symbol to represent each quantity and list the equipment that would be used to measure each quantity. Use as many rows as you need. Add rows to the space just below the table, if necessary.

In the space below the table, describe the overall procedure. Provide enough detail so that the students could replicate the experiment, including any steps necessary to reduce experimental uncertainty and increase confidence in the results. As needed, use the symbols defined in the table. You may include a simple diagram of the setup with the procedure.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement
Procedure (and diagram, if needed)		

ii. Describe the process of data analysis the students could use to decide whether the collisions between Cart A and Cart B are elastic.

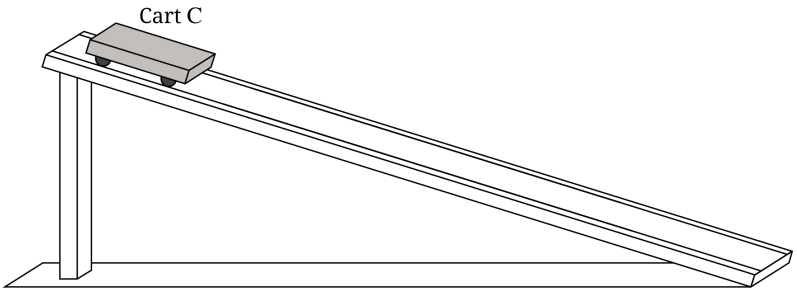


Figure 2

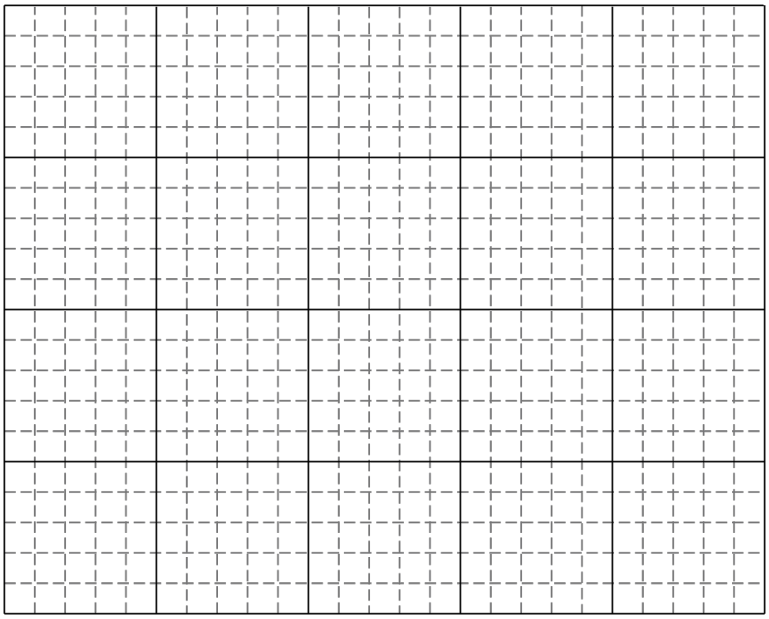
Another group of students perform an investigation where they roll a different cart, Cart C, from rest down a track that is angled above the horizontal, as shown in Figure 2. The students use their measurements to calculate the momentum of the cart at different times.

(b) The following table shows a sample of calculated momentum values of Cart as it rolls down the track.

i. On the following grid, plot the points from the data table to create a graph that can be used to determine the net force exerted on Cart C as it rolls down the ramp. Clearly scale and label all axes (including units), as appropriate. Draw a straight line that best represents the data.

Time (s)	Momentum (kg·m/s)
0.1	0.12
0.2	0.16
0.3	0.28
0.4	0.33
0.5	0.39

ii. What is the best way to use the graph to estimate the net external force exerted on Cart C as it rolls down the track?



iii. The students measure the mass of Cart C to be $m = 0.25$ kg. Assuming resistive forces are negligible, use the graph to determine the angle of the ramp.

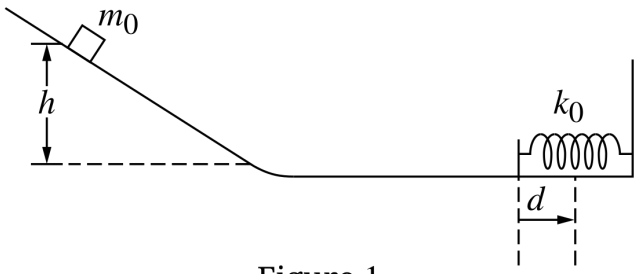


Figure 1

3. (12 points, suggested time 25 minutes)

In an experiment, a block is released from rest on a ramp, as shown in Figure . The block slides down an incline and across a horizontal surface, where it compresses a spring and then momentarily comes to rest. Frictional forces between the block and surfaces are negligible.

(a) The experiment is repeated, but the block is released from a greater height on the ramp. Will the new compression distance of the spring be greater than, less than, or equal to the original compression distance?

_____ Greater than _____ Less than _____ Equal to
Briefly justify your selection without deriving or using equations.

(b) Derive an expression for the distance d that the spring compresses. Express your answer in terms of the mass of the block m_0, the height h from which the block is released, the spring constant k_0, and physical constants, as appropriate.

(c) Does the equation you derived in part (b) agree with your reasoning in part (a)? Justify your answer.

(d) After the block compresses the spring, the block remains attached to the spring and oscillates. A student finds an incorrect equation for the period of oscillation T for the block-spring system on the Internet, $T = C\sqrt{\frac{h}{m_0 g}}$, where C is a constant with appropriate units. Explain why this equation does not make physical sense.

Figure 2 shows the same experiment with four horizontal positions indicated.

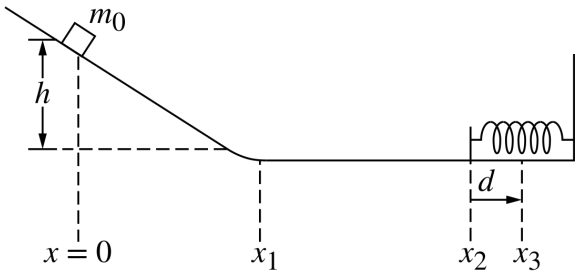


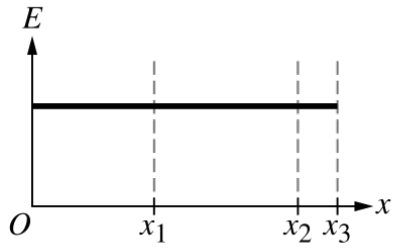
Figure 2

(e) Consider the following systems:

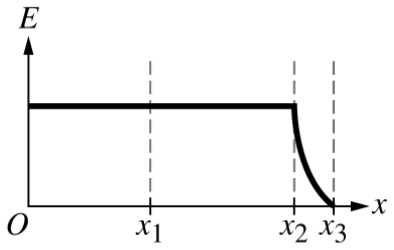
System A	Block only
System B	Block and Earth only
System C	Block, Earth, and spring

Each of the following graphs represents the mechanical energy E as a function of the horizontal position x of the block for one of the systems.

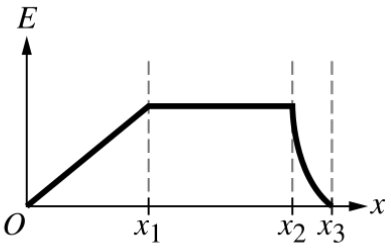
i. Under each graph, write the letter "A", "B", or "C" to indicate the system that is represented by the graph.



System_____



System_____



System_____

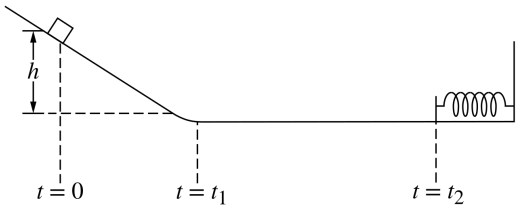
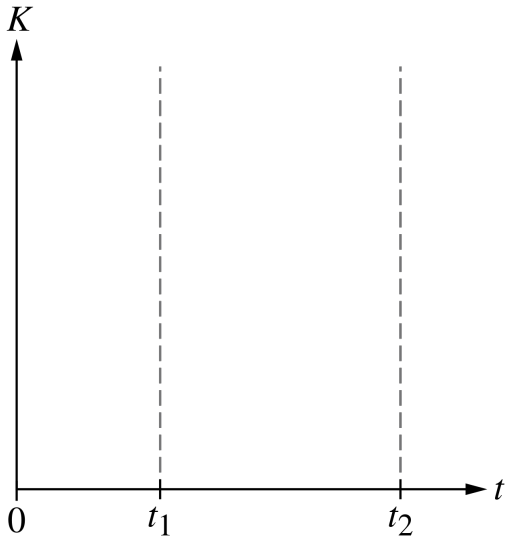
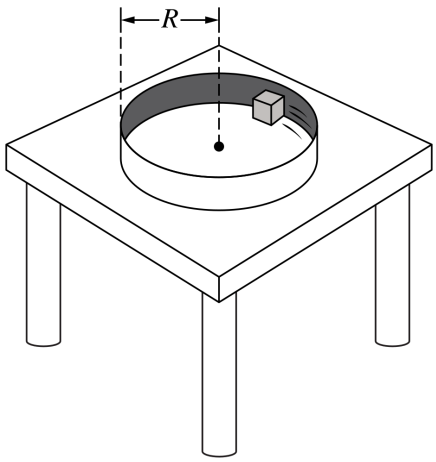


Figure 3

Figure 3 indicates the times the block is at three specific positions during the same experiment. The block is released from rest at $t = 0$. At time t_1, the block reaches the horizontal surface. Time t_2 indicates the time immediately before the block makes contact with the spring.

ii. On the following axes, sketch a graph of the kinetic energy K of the block as a function of time t from time $t = 0$ to time $t = t_2$.





4. (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.

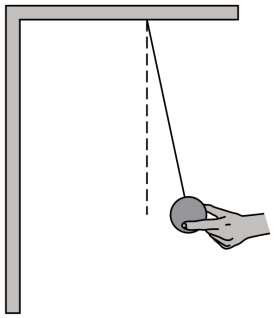


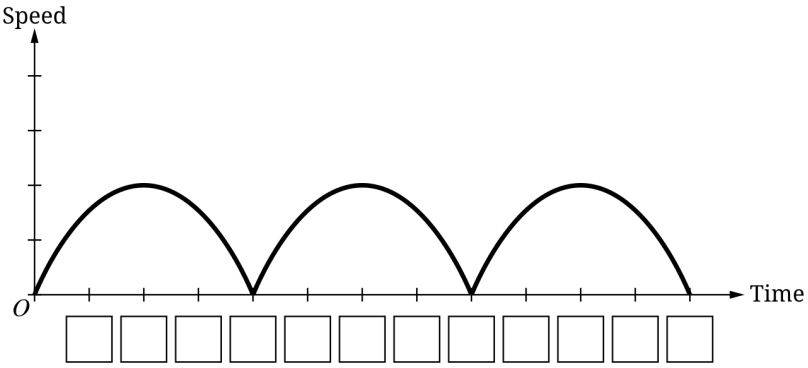
Figure 1

Note: Figure not drawn to scale.

5. (7 points, suggested time 13 minutes)

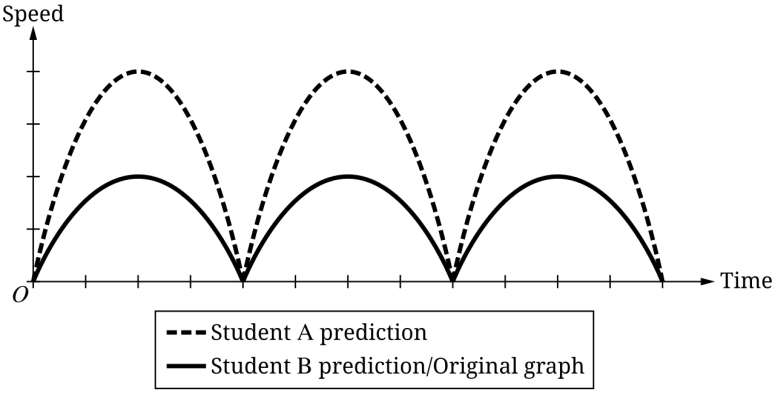
Student A and Student B conduct an experiment using a pendulum that consists of a metal sphere attached to a lightweight string that hangs from the ceiling, as shown in Figure . The students displace the pendulum a small angle from equilibrium and release it from rest at time .

(a) The students create the following graph of the speed of the sphere as a function of time.



i. The sphere first reaches the lowest point of its motion (when the string is vertical) at time $t = t_1$. Indicate time t_1 by writing "t_1" in the appropriate box below the horizontal axis.

ii. The students have a new pendulum, identical to the original except that its sphere has twice the mass. The students plan to repeat the experiment by releasing the new sphere from rest at the same small angle as before. Student A predicts the graph of speed versus time will look different, and Student B predicts it will look the same as the graph in part (a)(i). The students' predictions are shown in the following graph.



Which student's prediction is correct?

_____Student A _____Student B

Briefly explain your reasoning.

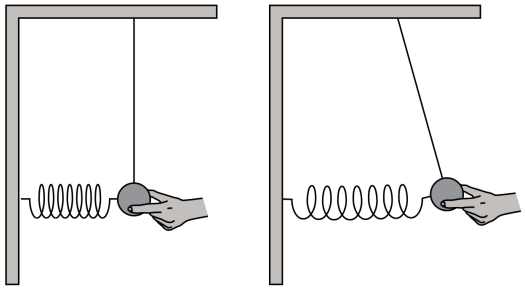


Figure 2 Figure 3

Note: Figures not drawn to scale.

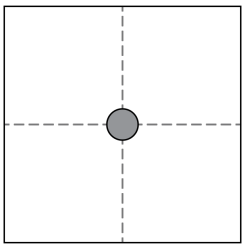
(b) The students attach one end of a light spring to the sphere of the original pendulum and the other end to the wall. Figure 2 shows the new setup when the spring is oriented horizontally at its relaxed length and the string is vertical. Figure 3 shows the pendulum when the students displace the sphere the same small angle as in part (a).

At time , the sphere is then released from rest at this position.

i. The sphere reaches the lowest point of its motion at time $t = t_2$. Compare t_2 to the time at which the sphere reaches its lowest point in part (a)(i), t_1. Is t_2 greater than, less than, or equal to t_1?

_____ $t_1 > t_2$ _____ $t_1 < t_2$ _____ $t_1 = t_2$
Briefly justify your reasoning.

ii. The following dot represents the center of mass of the sphere at time t_2 when the sphere reaches the lowest point of its motion. Draw a single arrow representing the direction of the instantaneous acceleration of the sphere. If the acceleration is zero, write "$a = 0$" next to the dot.



iii. After having passed its lowest point, the sphere continues moving toward the wall and momentarily comes to rest. At the moment when the sphere comes to rest, how does the magnitude of the angle the string makes with the vertical compare to the angle from which it was released? Explain your reasoning.

STOP
END OF EXAM