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. Two identical cars, Car 1 and Car 2, are both moving along a straight, level road. At time $t = 0$, both cars have a velocity of $+10$ m/s.

   Car 1 continues to move at a constant velocity, while Car 2 has a constant acceleration of -1 m/s^2. What is the speed of the center of mass of the two-car system at $t = 10$ s?

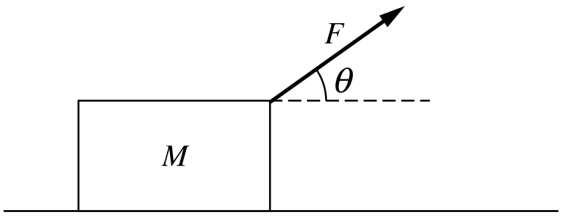
   (A) 15 m/s
   (B) 10 m/s
   (C) 5 m/s
   (D) 0 m/s

2. Two identical elevators are lifted at constant speeds. Work is done on the first elevator at a rate P_1 as it is lifted a distance h_0 in time Δt. Work is done on the second elevator at a rate P_2 as it is lifted a distance $2h_0$ in time $4\Delta t$. How does P_2 compare to P_1?

   (A) $P_2 = 4P_1$
   (B) $P_2 = 2P_1$
   (C) $P_2 = \frac{1}{2}P_1$
   (D) $P_2 = \frac{1}{4}P_1$

3. A cart of mass m is traveling at velocity v to the right when it has a perfectly elastic collision with a cart of mass $3m$ that is at rest. Immediately after the collision, the cart of mass $3m$ moves with a velocity $\frac{v}{2}$ to the right. What is the velocity of the cart of mass m immediately after the collision?

   (A) Zero
   (B) v to the right
   (C) $\frac{v}{2}$ to the left
   (D) $3v$ to the left



4. A block of mass M, initially at rest, is pulled along a horizontal frictionless surface by a force of magnitude F applied at an angle θ to the horizontal, as shown above. The force is exerted on the block for a distance of d, accelerating the block to speed v_f. Which of the following expressions is equal to the work done by the applied force?

   (A) Fd

   (B) $Fd\sin\theta$

   (C) $mgd\cos\theta$

   (D) $\frac{1}{2}Mv_f^2$

5. Block 1 slides to the right at 2 m/s on a frictionless, horizontal surface toward Block 2, which is initially at rest. After the collision, Block 1 moves to the right at 1m/s and Block 2 moves to the right at 3 m/s. Are the data provided sufficient to determine whether the collision is elastic? Why or why not?

   (A) Yes, because the ratio of the blocks' masses can be determined.

   (B) Yes, because the total momentum can be calculated before and after the collision.

   (C) No, because the blocks' masses are unknown.

   (D) No, because it is not stated whether the blocks are permanently deformed during the collision.

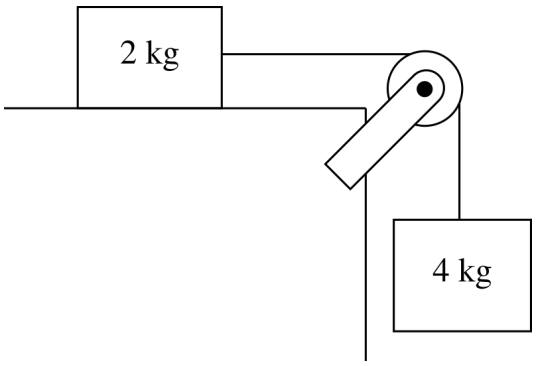
6. A 1000 kg spacecraft is traveling through deep space at a speed of 500 m/s when its thrusters turn on and exert a force opposite its original direction of motion. When the thrusters turn off, the spacecraft is traveling opposite the original direction at 500 m/s. What is the average force the thrusters exert on the spacecraft?

   (A) 0 N

   (B) 5×10^4 N

   (C) 1×10^6 N

   (D) It cannot be determined without knowing how long the thrusters were on.



7. Two blocks with different masses are attached by a string, as shown above. One block hangs vertically, and the other block rests on a frictionless surface. The blocks are released from rest. The procedure is repeated with blocks of different mass in each position. For which of the following systems will the blocks have the same acceleration as the original system?

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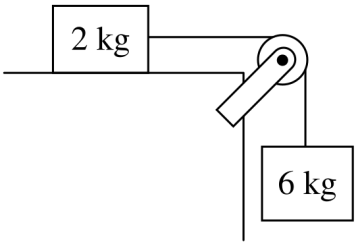

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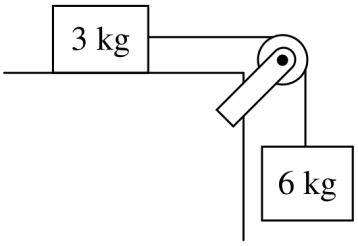

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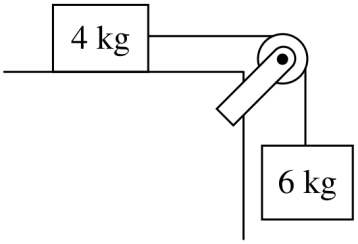

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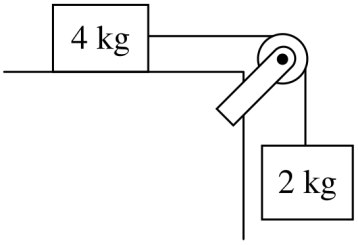
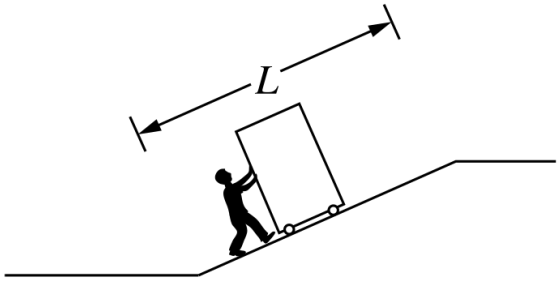
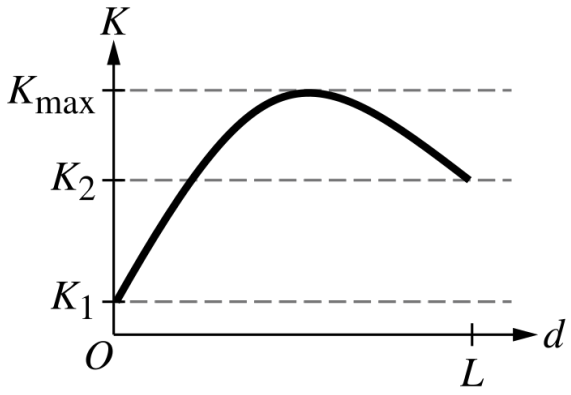






8. A person pushes a box up a ramp of length L, as shown. The graph above shows the kinetic energy K of the box as a function of its position d along the ramp. The net work done on the box while it is on the ramp equals

   (A) $K_{\max}$

   (B) K_2

   (C) $K_{\max} - K_1$

   (D) $K_2 - K_1$

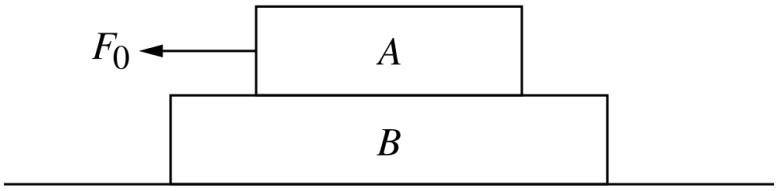
9. A simple pendulum consisting of a massive bob attached to a lightweight wire oscillates at small angles to the vertical. Which of the following changes will result in a significantly higher oscillation frequency for the pendulum?

   (A) Shortening the wire

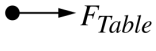
   (B) Using a bob with twice as much mass

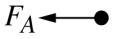
   (C) Doubling the amplitude of oscillation

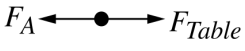
   (D) Taking the pendulum to a planet where the gravitational acceleration is less than g



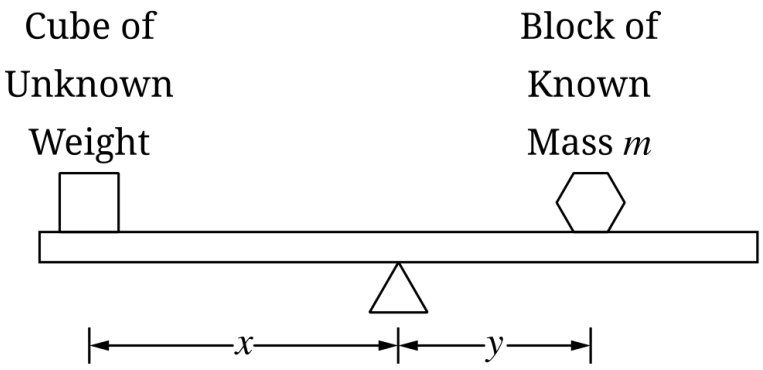
10. Books A and B are stacked on top of one another on a table, as shown in the figure. A force F_0 is exerted to the left on Book A, and the books move together to the left at a constant speed. Which of the following best represents the directions of the horizontal forces, if any, exerted on Book B?

(A) 

(B) 

(C) 

(D) There are no horizontal forces exerted on Book B.



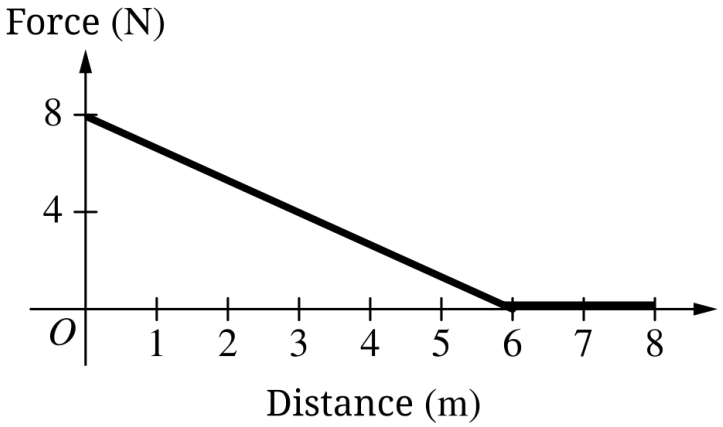
11. A student who does not have access to a scale wishes to determine the weight of a cube using the setup shown. A fulcrum is placed beneath the midpoint of a meterstick and the cube is placed on the meterstick a distance x from the fulcrum. A small block of known mass m is placed on the meterstick on the other side of the fulcrum at a distance $y < x$, such that the meterstick is balanced and horizontal. Which of the following expressions is equal to the weight of the cube?

(A) $\dfrac{mgx}{y}$

(B) $\dfrac{mgy}{x}$

(C) $\dfrac{mgx}{x+y}$

(D) $\dfrac{mgy}{x+y}$



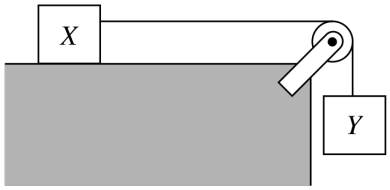
12. The graph shows the net horizontal force exerted on a 3 kg box as a function of the distance the box has moved along a horizontal track. If the box started at rest, the speed of the box when it has moved 8 m is

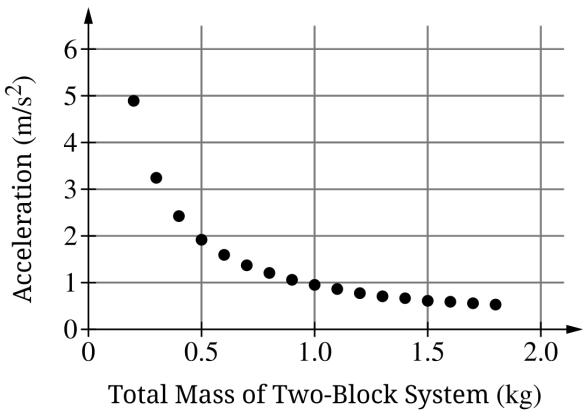
(A) 64 m/s

(B) 24 m/s

(C) 8 m/s

(D) 4 m/s





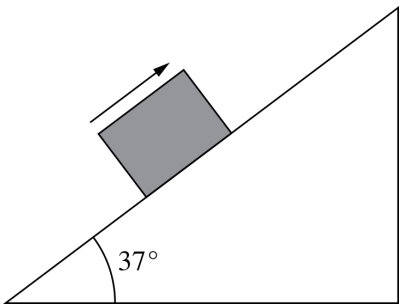
13. Block X rests on a frictionless, horizontal surface and is connected to Block Y by a light string that passes over a frictionless pulley of negligible mass, as shown. A student releases the blocks from rest and measures the acceleration of Block Y. The student then performs several more trials, adding mass to the two-block system in each trial. The graph above shows the acceleration of Block Y as a function of the total mass of the two-block system. Which of the following best describes how the mass was added to the two-block system?

(A) In each trial, mass was only added to Block X.

(B) In each trial, mass was only added to Block Y.

(C) In each trial, mass was added equally to Block X and Block Y.

(D) In each trial, mass could have been added to either Block X, Block Y, or both.



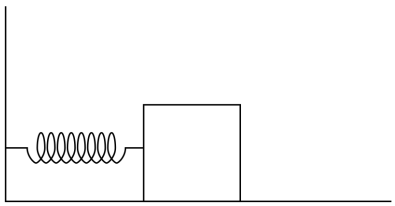
14. After receiving a brief push, a box slides up a ramp that is at an angle of 37° with the horizontal, as shown. The gravitational force on the box is 40 N, and the kinetic frictional force is 9 N directed down the ramp. What is the net force on the box as it slides up the ramp?

    (A) 49 N up the ramp

    (B) 15 N up the ramp

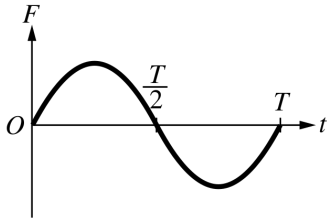
    (C) 9 N down the ramp

    (D) 33 N down the ramp

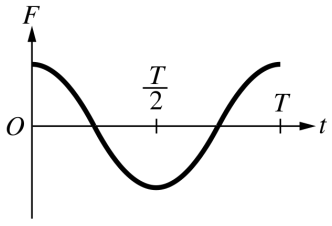


15. A block is attached to a spring, the other end of which is attached to a wall, as shown above. The block is pushed toward the wall from its equilibrium position, compressing the spring, and then is released from rest at time $t = 0$. There is no friction between the block and the horizontal surface. Assuming right to be the positive direction, which of the following graphs could represent the restoring force F versus time t for one period T of the oscillation of the block?

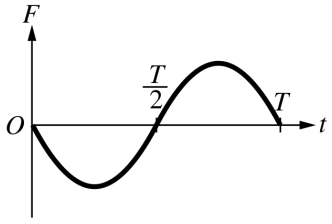
(A)



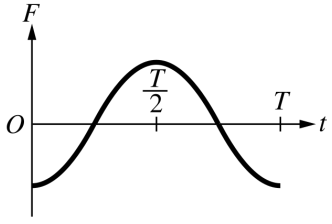
(B)

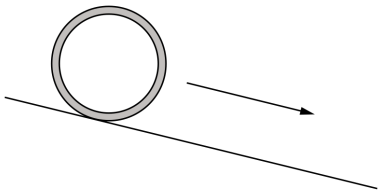


(C)



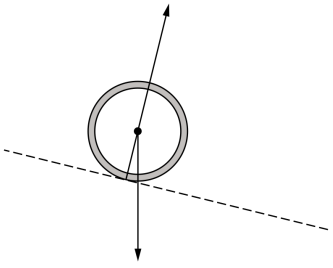
(D)



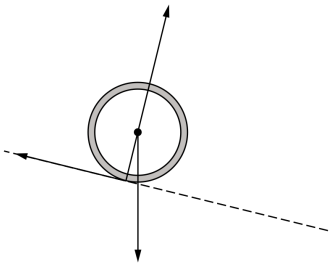


16. The figure shows a ring rolling down an inclined plane without slipping. Which of the following diagrams, once properly labeled, represents the forces acting on the ring, with the tail of each vector starting at the point of application of the force? (The dot represents the center of the ring.)

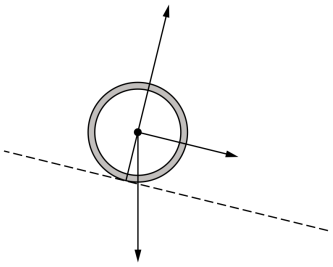
(A)



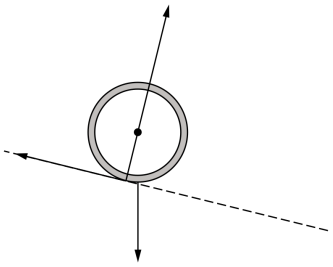
(B)

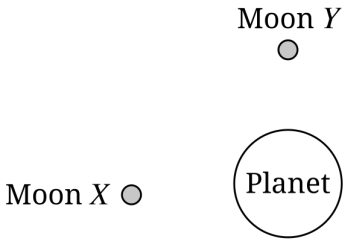


(C)



(D)





17. The figure above shows a planet with two moons, X and Y. The net gravitational force exerted on the planet by the two moons has magnitude F. If the mass of each moon is doubled, the net gravitational force exerted on the planet would have magnitude

(A) $2F$

(B) $2\sqrt{2}F$

(C) $4F$

(D) $4\sqrt{2}F$

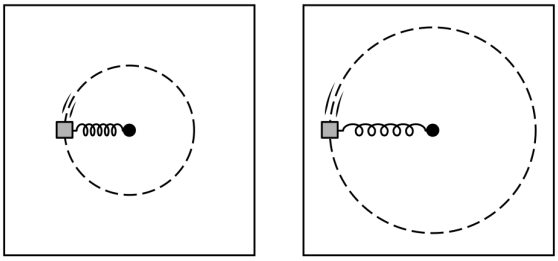


Table 1 Table 2

Top View

18. Two identical blocks are each attached to an end of identical ideal springs, with the other end of each spring fixed in place on a level table, as shown. The blocks move with negligible friction in circular paths with different constant speeds. The block on Table 2 moves with a greater speed in a circle of larger radius than the block on Table 1. Which of the following relations correctly describes the work W done by the spring on the block during one full rotation for the two blocks?

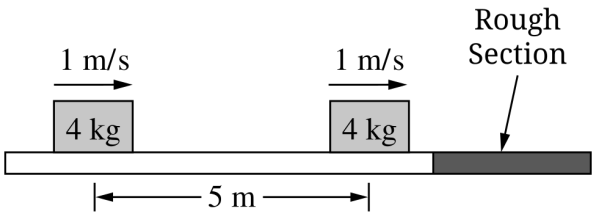
(A) $W_2 > W_1$

(B) $W_1 > W_2$

(C) $(W_1 = W_2) > 0$

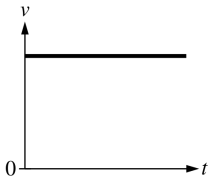
(D) $W_1 = W_2 = 0$

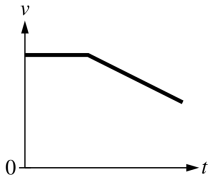
Questions 19-20

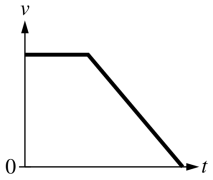


Two identical blocks of mass 4kg each travel to the right with speed 1m/s on a frictionless section of a horizontal surface, as shown in the figure above. The centers of the blocks are initially separated by 5m. The first block then encounters a rough section, with a coefficient of kinetic friction of 0.025 between the block and the rough section. The first block comes to rest after traveling 2m on the rough section. At this instant, the second block has not yet reached the rough section.

19. Which of the following graphs best represents the speed v of the center of mass of the two-block system as a function of time t from before the first block enters the rough section until the instant the first block comes to rest?

(A)


(B)


(C)


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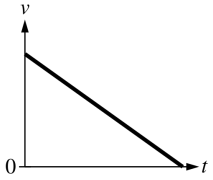
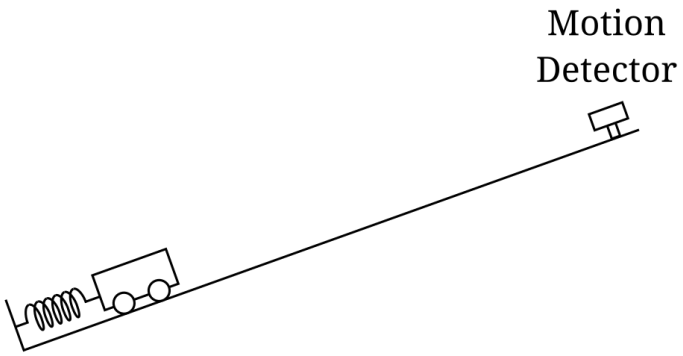


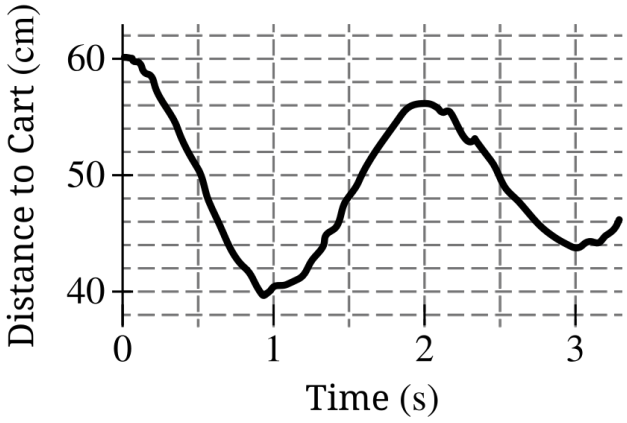
20. What is the change in the mechanical energy of the two-block system from when the two blocks are initially moving to the moment when the first block has come to rest?

(A) 0 J
(B) −0.25 J
(C) −2.0 J
(D) −4.0 J

Questions 21-23



A cart on an inclined track is connected to a spring that is fixed at the other end, as shown above. The spring is compressed by pushing the cart against it, and then the cart is released from rest. A motion detector at the other end of the track records the distance between the cart and the detector as a function of time, as shown in the graph below.



21. On the graph, the peak value occurring at $t = 2$s is lower than the value at $t = 0$s. Which of the following is most likely a contributing explanation?

    (A) Mechanical energy is dissipated by friction between the cart and the track.

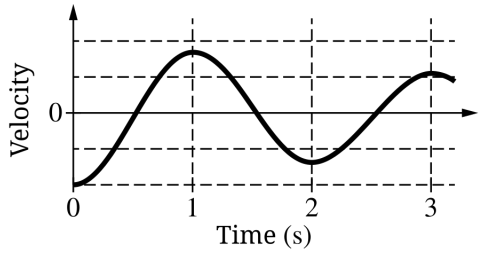
    (B) The spring is nonideal and exerts a nonlinear restoring force on the cart.

    (C) The mechanical energy of the cart-spring-Earth system includes both the elastic potential energy of the spring and gravitational potential energy.

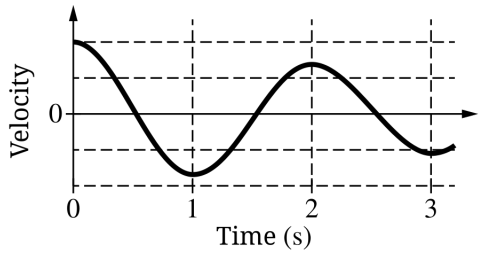
    (D) The kinetic energy of the cart includes both the rotational kinetic energy of the cart's wheels and the translational kinetic energy of the cart.

22. Which of the following graphs best represents the velocity of the cart as a function of time, where a positive velocity corresponds to motion away from the detector?

(A)



(B)



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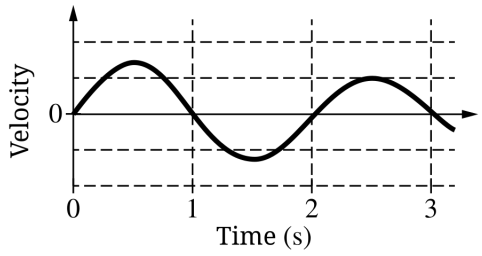

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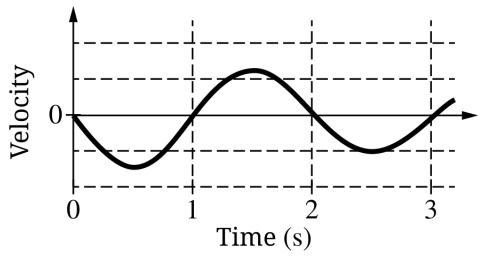


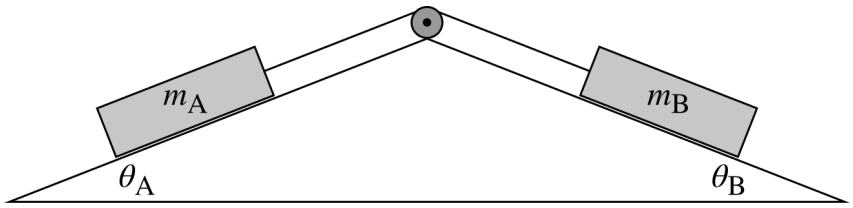
23. What is the cart's maximum displacement from its starting position?

    (A) 4 cm

    (B) 20 cm

    (C) 40 cm

    (D) 60 cm



Note: Figure not drawn to scale.

24. Two blocks with mass m_A and m_B are connected by a lightweight string that passes over a pulley with negligible mass and friction, as shown above. The blocks are free to move along frictionless inclined surfaces with angles θ_A and θ_B, respectively. For which of the following relationships between the masses and angles will the blocks always be in equilibrium?

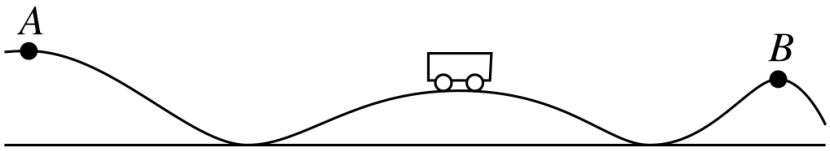
(A) $m_A = m_B$ and any angles

(B) $\sin\theta_A = \sin\theta_B$ and any masses

(C) $m_A \sin\theta_A = m_B \sin\theta_B$

(D) $m_A \sin\theta_B = m_B \sin\theta_A$

Questions 25-26



A cart of known mass is free to move on the frictionless track shown The cart is released from rest at Point A and rolls freely toward Point B, without losing contact with the track. The heights of points A and B are known.

25. Which of the following is equal to the kinetic energy of the cart when it is at Point B?

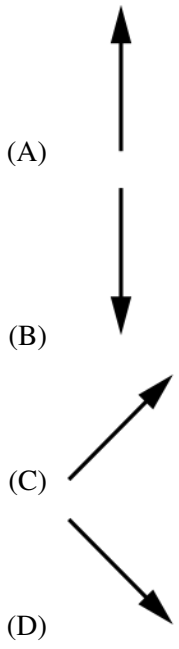
    (A) The gravitational potential energy of the Earth-cart system when the cart is at Point A

    (B) The gravitational potential energy of the Earth-cart system when the cart is at Point B

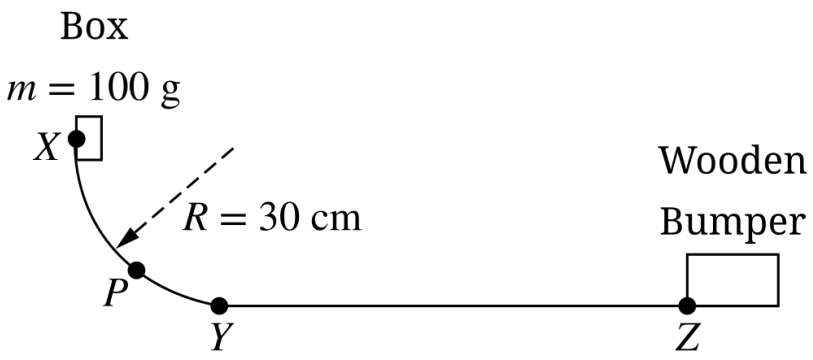
    (C) The difference between the gravitational potential energy of the Earth-cart system when the cart is at Point A and when it is at Point B

    (D) The sum of the gravitational potential energy of the Earth-cart system when the cart is at Point A and when it is at Point B

26. Which of the following best represents the direction of the net force exerted on the cart when it is at Point B?



Questions 27-28



A 100 g box initially at rest slides down a rough circular ramp and makes a smooth transition onto a level horizontal track of negligible friction, as shown above. At Point Z, the box collides with a fixed wooden bumper that brings the box to rest. The radius of the circular ramp is 30 cm.

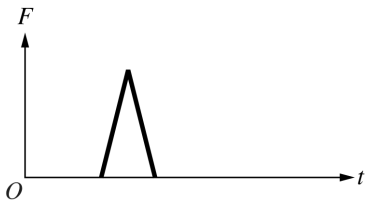
27. Take the gravitational potential energy of the box-Earth system to be zero when the box is at Point Y. One-third of the initial mechanical energy of the box-Earth system is dissipated as the box moves from Point X to Point Y. The speed of the box just before it hits the bumper is most nearly

(A) 1.4 m/s

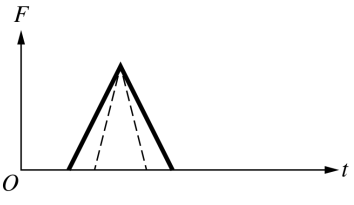
(B) 2.0 m/s

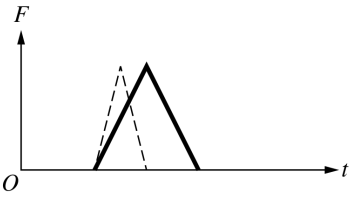
(C) 4.0 m/s

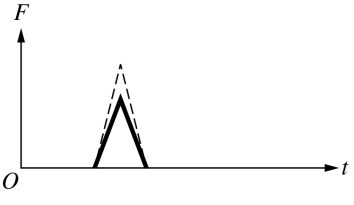
(D) 20 m/s

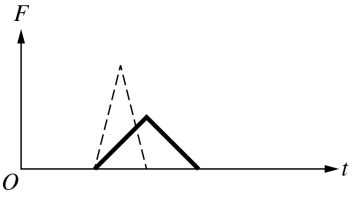


28. The graph above shows the magnitude F of the force the wooden bumper exerts on the box as a function of time t as the bumper brings the box to rest. If the wooden bumper is replaced by a bumper of the same size but made of a softer material, which of the following graphs could represent the magnitude of the force it exerts on the box? (An outline of the graph for the wooden bumper is shown as a dashed line for reference.)

(A)


(B)


(C)


(D)


29. Two balls of mass M and $2M$ are released from rest at the same time from the same height and fall straight down with negligible air resistance. Just before hitting the ground, the ball of mass M has kinetic energy K. What is the kinetic energy of the ball of mass $2M$ just before hitting the ground?

(A) K

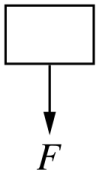
(B) $\sqrt{2}K$

(C) $2K$

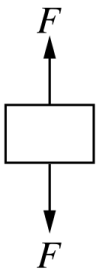
(D) $4K$

30. Four blocks of equal mass are moving at the same speed when different sets of forces are exerted on the blocks, as shown below, with the lengths of the arrows proportional to the magnitudes of the forces. Which of the following blocks could be losing kinetic energy?

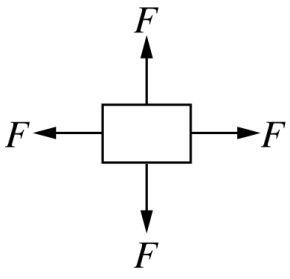
(A)



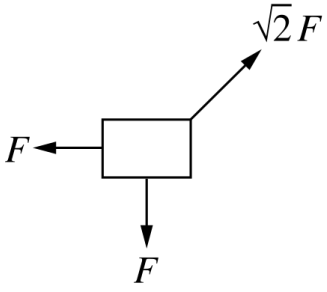
(B)



(C)



(D)



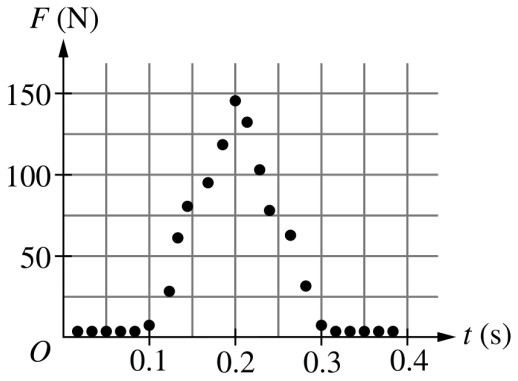
31. In an experiment on a horizontal track with low but nonzero friction, a student sets a block into motion at $t = 0$ s. At $t = 3$ s, the block collides with and sticks to another identical block. A motion detector records the velocity of each block from $t = 0$ s to $t = 6$ s. Which velocity measurements should the student use to determine whether the linear momentum of the two-block system changes during the collision?

(A) The velocity of each block immediately before and immediately after $t = 3$ s

(B) The average velocity of each block between $t = 0$ s and $t = 3$ s and the average velocity of each block between $t = 3$ s and $t = 6$ s

(C) The velocity of each block immediately before $t = 3$ s and the average velocity of each block between $t = 3$ s and $t = 6$ s

(D) The average velocity of each block between $t = 0$ s and $t = 3$ s and the velocity of each block immediately after $t = 3$ s



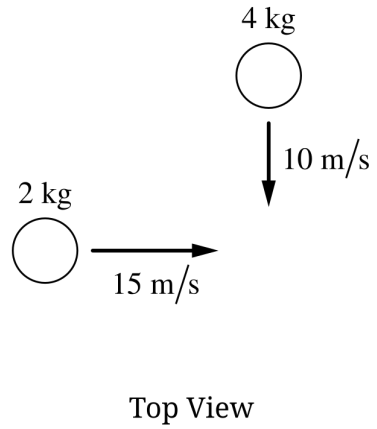
32. Cart A of mass 2.0 kg is initially traveling south at a speed of 5.0 m/s toward Cart B, which is traveling north. The two carts collide. The graph shows the magnitude F of the force exerted on Cart A by Cart B as a function of time t, as measured by a force sensor. If the ground is level and all other horizontal forces are negligible, what is the approximate velocity of Cart A at $t = 0.4$ s?

(A) 2.5 m/s south

(B) 2.5 m/s north

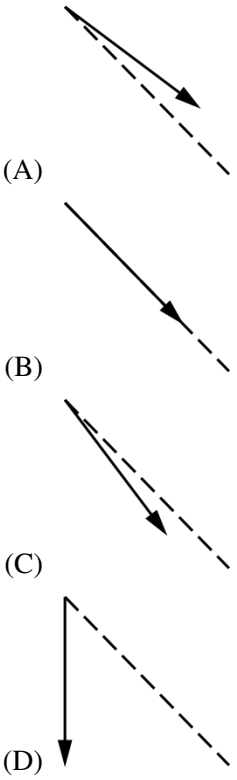
(C) 12.5 m/s south

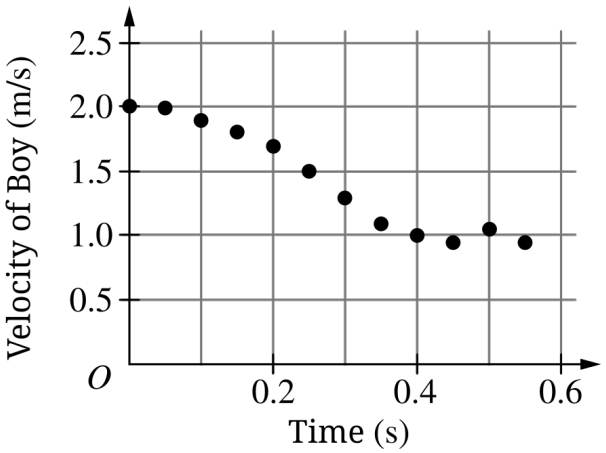
(D) 12.5 m/s north



Top View

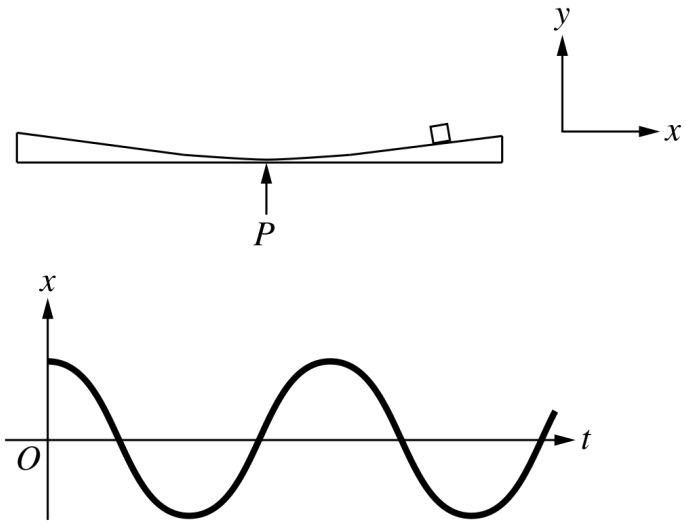
33. The figure above shows a top view of two objects sliding on a horizontal, frictionless surface, with masses and velocities indicated. The objects collide and stick together. Which of the following arrows best indicates the direction of motion of the center of mass of the two-object system after the collision? (The dashed line in each figure is 45° from the direction of motion of the 2 kg object.)





34. A 60 kg girl is standing at rest on an ice rink when an 80kg boy skating toward her gives her a push forward. The two skaters then keep sliding forward at different speeds, with negligible friction. The boy's velocity as a function of time, measured while the boy and girl are in contact, is shown above. What is the magnitude of the change in linear momentum $|\Delta p_{\text{boy}}|$ of the boy, and how do the magnitudes of the average forces exerted on the skaters compare?

	$\lvert\Delta p_{\text{boy}}\rvert$	Magnitudes of Average Forces
(A)	80 kg·m/s	The magnitudes of the forces are the same.
(B)	80 kg·m/s	The force exerted on the girl is greater than the force exerted on the boy.
(C)	160 kg·m/s	The magnitudes of the forces are the same.
(D)	160 kg·m/s	The force exerted on the girl is greater than the force exerted on the boy.



35. The figure shows a block at rest near the top of a track with two sections that are each inclined at the same small angle from the horizontal. The bottom of the track is at Point P. The block is released at time $t = 0$ and slides along the track with negligible friction. A student predicts that the x-position of the block as a function of time t is given by the curve in the graph above. Is the student's graph physically plausible? Why or why not?

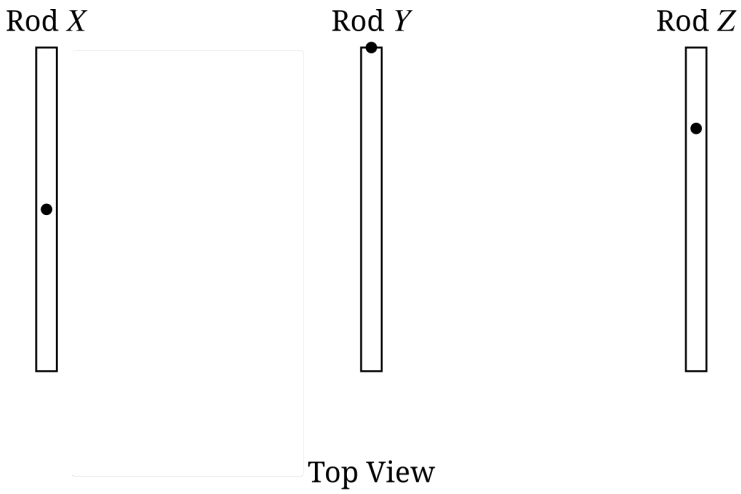
(A) Yes, because the net force on the block is always directed along the ramp toward Point P.

(B) Yes, because the net force gets bigger as the block moves through the center.

(C) No, because the gravitational force does not change direction.

(D) No, because the magnitude of the net force on the block is constant.

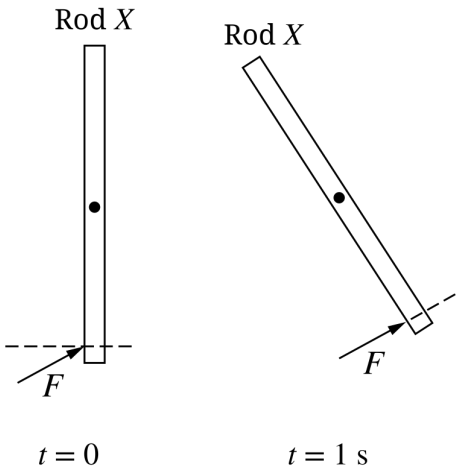
Questions 36-38

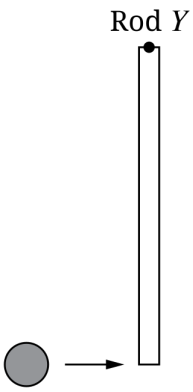


Identical uniform rods X, Y, and Z are free to rotate on a horizontal surface about vertical axles indicated by the dots in the diagram above. Frictional forces are negligible.

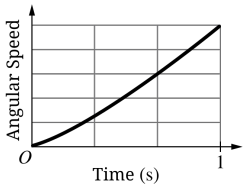
36. All three rods rotate with the same angular speed. How does the angular momentum L of each rod about its axle compare?

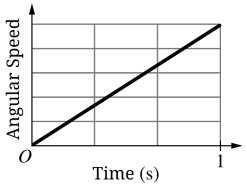
(A) $L_X = L_Y = L_Z$
(B) $L_Y > L_X > L_Z$
(C) $L_Y > L_Z > L_X$
(D) $L_Z > L_Y > L_X$

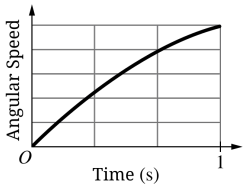


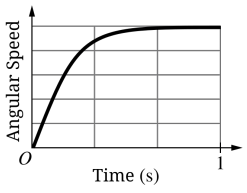


37. Rod X is free to rotate on a horizontal surface with negligible friction about a pivot through its center. At time $t = 0$ the rod is at rest and a force of magnitude F is exerted near the end of the rod at an angle, as shown in the figure on the left. As the rod rotates, the force remains constant in magnitude and direction until the rod is perpendicular to the force at time $t = 1$ s, as shown in the figure on the right. Which of the following graphs could show the rod's angular speed as a function of time between 0 and 1s?

(A)


(B)


(C)


(D)


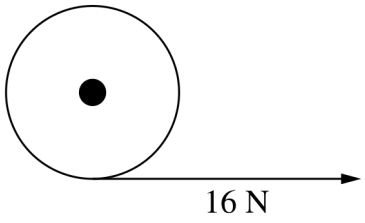
38. A lump of clay moves toward Rod Y, which is at rest, as shown. The rotational inertia of the clay with respect to the rod's axle is twice that of the rod. The clay collides with and sticks to the end of the rod, and during the collision the rod gains angular momentum L with respect to the axle. The change in angular momentum of the clay with respect to the axle during the collision is

(A) $-2L$

(B) $-L$

(C) $-\frac{L}{2}$

(D) 0



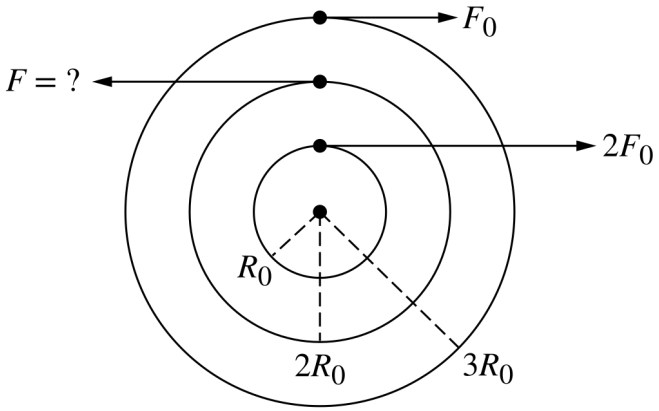
39. A wheel is initially at rest and is free to rotate on an axle through its center. The wheel has a radius of 0.5 m and a rotational inertia of 4 kg·m^2. A constant force of 16 N is exerted tangent to the edge of the wheel, as shown, for 10 s. What is the final angular speed of the wheel?

(A) 2 rad/s

(B) 20 rad/s

(C) 40 rad/s

(D) 80 rad/s



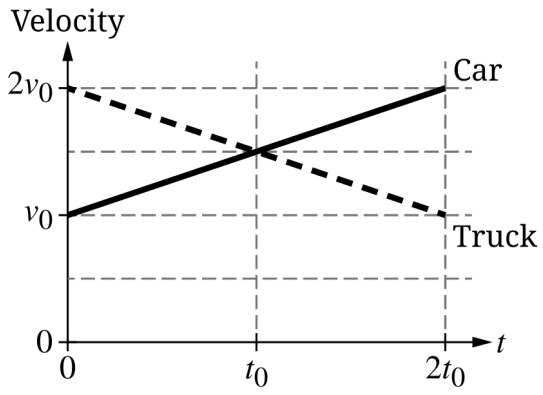
40. Three forces are exerted on a disk that is free to rotate with negligible friction around a pivot at the disk's center. The three forces are exerted at different locations on the disk, as shown by the arrows in the figure. What should the magnitude of the force exerted at a distance of $2R_0$ from the center be so that the net torque about the center is zero?

(A) $1.5F_0$

(B) $2.5F_0$

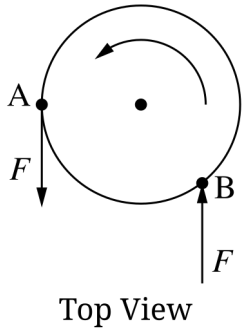
(C) $3F_0$

(D) $5F_0$



41. The graph represents the velocity as a function of time t of a car and a truck that travel along a straight road. Compare the distances traveled by the car and truck for two time intervals: from 0 to t_0 and from 0 to $2t_0$.

	0 to t_0	0 to $2t_0$
(A)	Greater for the truck	Greater for the car
(B)	Greater for the truck	The same for both objects
(C)	The same for both objects	Greater for the car
(D)	The same for both objects	The same for both objects



Top View

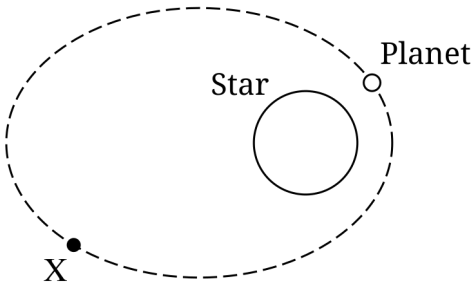
42. A uniform disk is initially spinning in a counterclockwise direction about an axis through its center. Two forces of equal magnitude F are then exerted at points A and B on the disk, as shown in the figure above. Which of the following correctly describes the effects of the two forces on the rotation at the instant shown?

(A) Both forces have the effect of slowing down the rotation by the same amount.

(B) Both forces have the effect of speeding up the rotation by the same amount.

(C) Both forces have the effect of speeding up the rotation, but the force at Point A has a greater effect than does the force at Point B.

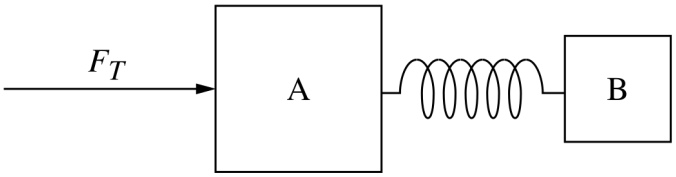
(D) The force at Point A has the effect of speeding up the rotation, while the force at Point B has the effect of slowing down the rotation.



Note: Figure not drawn to scale.

43. A planet of mass M is in orbit around a star, as shown. Which of the following best describes the change in the planet's rotational inertia about the center of the star and its angular momentum about the star as the planet travels from the position shown in the figure to the position marked with an X?

	Rotational inertia	Angular momentum
(A)	Increases	Greater for the car
(B)	Increases	Stays the same
(C)	Stays the same	Greater for the car
(D)	Stays the same	Stays the same



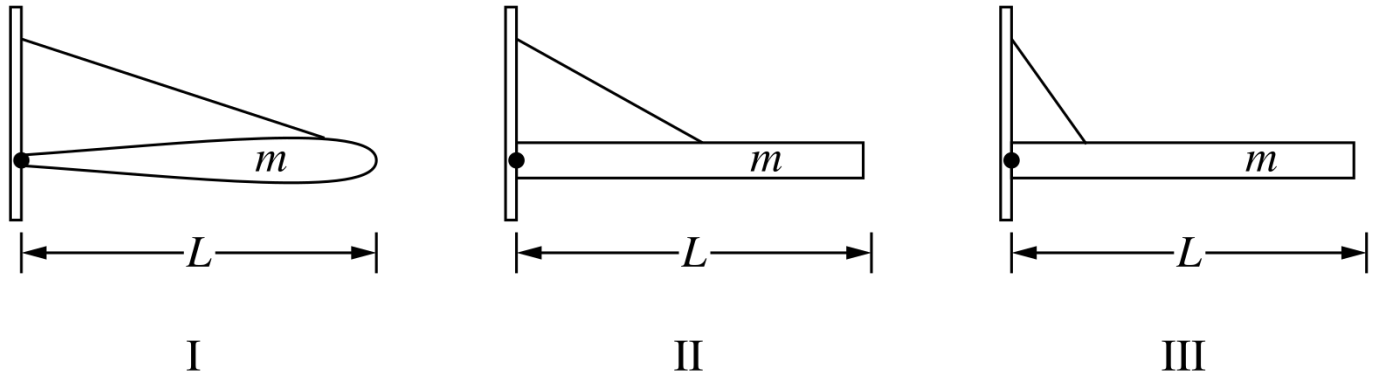
44. A system consists of two blocks of different masses connected by a spring of negligible mass. A force of magnitude F_T is exerted on the system, as shown above, giving it an acceleration to the right. The spring is uniformly compressed and is not oscillating. The spring exerts a force of magnitude F_A on Block A and a force of magnitude F_B on Block B. Which of the following is a correct relationship among the magnitudes of the three forces?

(A) $F_T = F_A = F_B$

(B) $(F_T = F_A) > F_B$

(C) $F_T > (F_A = F_B)$

(D) $F_T > F_A > F_B$



45. The three uniform solid objects shown above have the same mass m and length L. Each object is held at rest by a hinge and a cord attached to a rigid wall. Which of the following correctly ranks the magnitude of the torque τ exerted by gravity with respect to the hinge on each object?

(A) $\tau_{\mathrm{I}} = \tau_{\mathrm{II}} = \tau_{\mathrm{III}}$

(B) $\tau_{\mathrm{I}} > (\tau_{\mathrm{II}} = \tau_{\mathrm{III}})$

(C) $\tau_{\mathrm{I}} > \tau_{\mathrm{II}} > \tau_{\mathrm{III}}$

(D) $(\tau_{\mathrm{II}} = \tau_{\mathrm{III}}) > \tau_{\mathrm{I}}$

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 ball falls onto a horizontal surface and then bounces back into the air. At time t_1, the ball is at height h_1 above the surface and has a downward vertical speed v_1. At a later time t_2, the ball has bounced back up and is at height h_2 above the surface with an upward vertical speed v_2. Which of the following could be correct about h_2 and v_2? Select two answers.

(A) $h_2 = h_1$, $v_2 > v_1$

(B) $h_2 > h_1$, $v_2 < v_1$

(C) $h_2 > h_1$, $v_2 > v_1$

(D) $h_2 < h_1$, $v_2 = v_1$

132. Identical disks X and Y are on a horizontal, frictionless surface. Disk X slides with velocity $\vec{v}_0$ and collides elastically with Disk Y, which is initially at rest. The disks then move away from the collision point at different angles. Which of the following must be true after the collision? Select two answers.

(A) Disk X has the same kinetic energy as Disk Y.

(B) Disk X has the same momentum as Disk Y.

(C) The speed of Disk X is less than v_0.

(D) The velocity of the center of mass of the two-disk system is in the direction of The velocity of the center of mass of the two-disk system is in the direction of $\vec{v}_0$.

133. A machine exerts a force on an object of known rotational inertia. An engineer wants to know the change in angular momentum of the object for a given time interval. Which of the following can be measured as a function of time to provide the desired information? Select two answers.

(A) The instantaneous angular velocity of the object

(B) The instantaneous linear velocity of the object

(C) The instantaneous value of the force exerted on the object

(D) The instantaneous value of the torque exerted on the object

134. Two identical spheres, X and Y, are connected by a light string. A person holds Sphere X and lets Sphere Y hang straight down, then releases them from rest. Which of the following is true of the speed of the center of mass of the two-sphere system at time t while both spheres are falling? Select two answers.

(A) It is zero relative to Sphere X.

(B) It is zero relative to the ground.

(C) It is equal to gt relative to Sphere X.

(D) It is equal to gt relative to the ground.

Cart	Mass	Initial Velocity (m/s)	Velocity at Closest Approach (m/s)	Final Velocity (m/s)
X	3.0 kg	3.0 to the right	2.0 to the right	1.0 to the right
Y	?	1.0 to the left	2.0 to the right	5.0 to the right

135. Carts X and Y move toward each other on a level, frictionless track. The carts have magnets in their bumpers and begin to repel each other as they get closer. They reach a common velocity for an instant and then separate. Which of the following questions can be answered using only the data in the table? Select two answers.

(A) What is the mass of Cart Y?

(B) Which cart has a stronger magnet?

(C) Is mechanical energy dissipated during the collision?

(D) What maximum force is exerted on Cart X at the closest approach?

STOP
END OF SECTION I

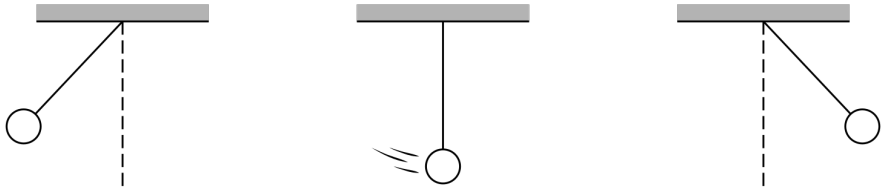
PHYSICS 1

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)

   A sphere attached to the end of a light string that makes an angle with the vertical is released from rest at time t_0 as shown above. At time t_1 the sphere is at the lowest point in its path, and at time t_2 it is momentarily at rest at its maximum height.

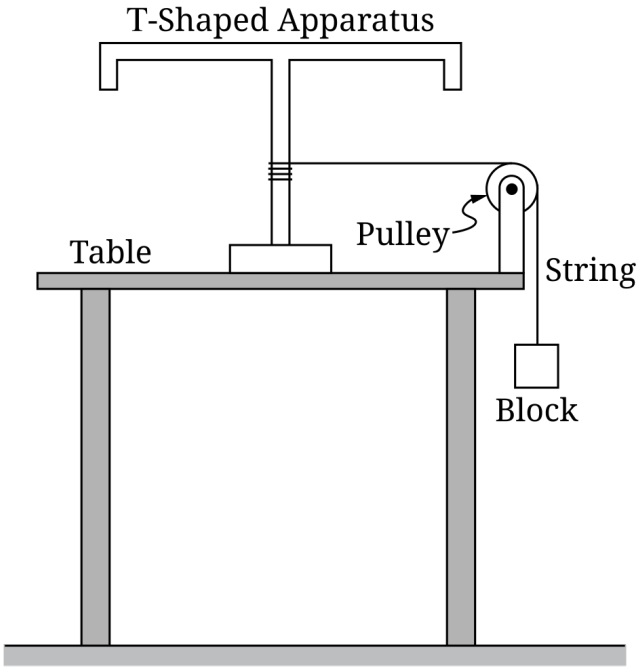
   (a) The dots below represent the sphere at times t_1 and t_2. On each dot, draw and label the forces (not components) exerted on the sphere at the corresponding time. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



(b) The magnitude of the tension force in the string at time t_1 is F_1, and at time t_2 is F_2. The gravitational force exerted on the sphere has a magnitude F_g. Rank F_1, F_2, and F_g from greatest to least in the spaces indicated below. Use 1 for the greatest magnitude, 2 for the next greatest, and so on. If any two or all three magnitudes are the same, use the same number for their ranking.

_____ F_1 _____ F_2 _____ F_g

In a clear, coherent paragraph-length response that may also contain figures and/or equations, justify your ranking.



2. (12 points, suggested time 25 minutes)

A light string is attached to a block, passes over a pulley, and is wrapped around a T-shaped apparatus, as shown above. The pulley has negligible rotational inertia and negligible friction, and the T-shaped apparatus rotates with negligible friction. The system is released from rest. As the block accelerates downward, it pulls the string, which causes the apparatus to start rotating.

Students in a physics lab first wish to determine the value of the block's constant downward acceleration once it is released from rest by observing it fall.

(a) Derive an equation for the acceleration of the block in terms of quantities that can be obtained from measurements made using only a meterstick and a stopwatch.

(b) Design an experimental procedure the students could use to collect the data needed to determine the block's linear acceleration a.

In the table at left below, list the quantities that would be measured in your experiment using the meterstick and the stopwatch. Define a symbol to represent each quantity.

In the space to the right of and below the table, describe the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table.

If needed, you may include a simple diagram of the setup with your procedure.

Quantity tobe Measured	SymbolforQuantity	Equipment forMeasurement	Procedure (and diagram, if needed)
		Meterstick	
		Stopwatch	

(c) Explain how the students should analyze the data from part (b) to determine the value of the block's constant linear acceleration a.

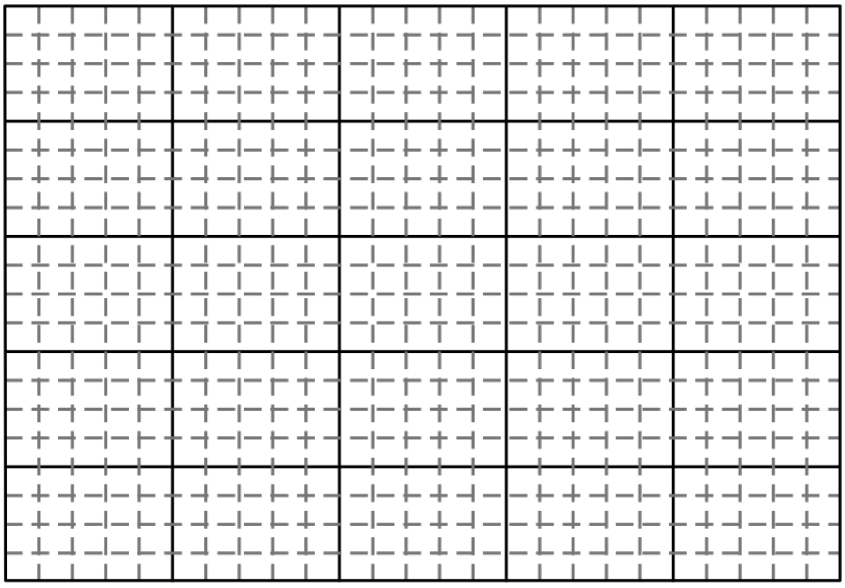
(d) The students produce the data table shown below for five blocks with different masses.

Mass of Block (kg)	Linear Acceleration of Block (m/s^2)	Angular Acceleration of T-shaped Apparatus (rad/s^2)	Tension in String (N)	Torque Exerted on T-shaped Apparatus by String (N·m)
0.200	0.34	27	1.87	0.0237
0.400	0.92	72	3.56	0.0453
0.600	1.37	108	5.11	0.0649
0.800	1.58	124	6.53	0.0830
1.000	1.93	152	7.84	0.0996

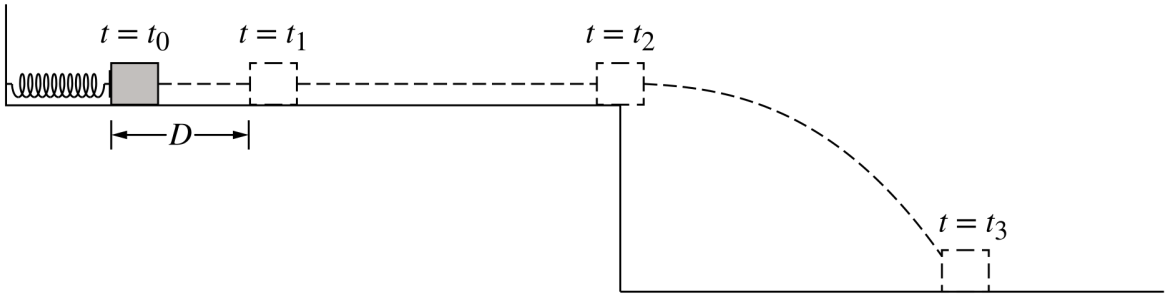
The students now want to determine the rotational inertia of the T-shaped apparatus.

i. Indicate below which quantities could be graphed to yield a straight line whose slope could be used to calculate a numerical value for the rotational inertia of the T-shaped apparatus.
Vertical axis _____
Horizontal axis _____

ii. Use the grid below to plot the data points for the quantities indicated in part (d)(i). Clearly scale and label all axes, including units as appropriate. Draw a straight line that best represents the data.



iii. Using the straight line from part (d)(ii), calculate a value for the rotational inertia of the T-shaped apparatus.

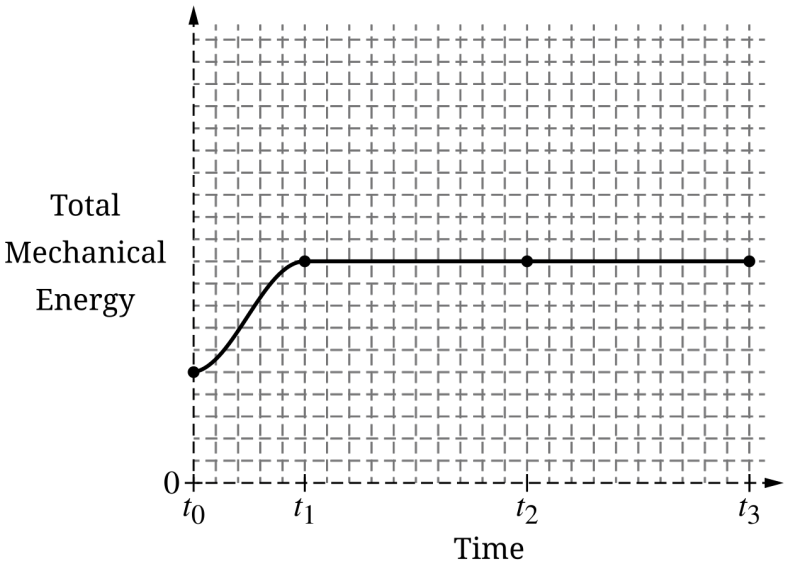


3. (12 points, suggested time 25 minutes)

A block is launched from a table by a compressed spring that is attached to a wall. The spring is initially compressed a distance D before the block is launched, as shown above. There is negligible friction between the block and the table.

At time $t = t_0$ the block is released from rest.
At $t = t_1$ the block loses contact with the spring.
At $t = t_2$ the block leaves the edge of the table.
At $t = t_3$ the block lands on the floor.

The graph below shows the total mechanical energy of the system containing the block and Earth from $t = t_0$ to immediately before $t = t_3$. The gravitational potential energy is defined to be zero when the block is on the floor.



Note: Time axis not drawn to scale.

(a) On the same axes, sketch a graph of the total mechanical energy of just the block from time t_0 to time t_3.

The procedure is repeated with a second block, Block 2, which is more massive than the original block, Block 1. Block 2 is placed on the table, and the spring is compressed the same distance D as before.

(b) For Block 2, is the horizontal distance traveled from the edge of the table to where it hits the ground greater than, less than, or equal to the corresponding distance for Block 1?
_____ Greater than _____ Less than _____ Equal to
Justify your answer.

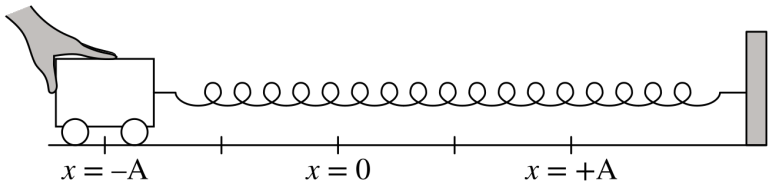
(c) Derive a general expression for X, the horizontal distance traveled by a block of mass m_B, from the edge of the table to where it hits the floor. Let k_0 represent the spring constant and h_0 represent the height of the tabletop above the floor. Express your answer in terms of D, m_B, k_0, h_0, and physical constants, as appropriate.

(d) Does your expression derived in part (c) support your reasoning in part (b)?
_____ Yes _____ No
Justify your answer.

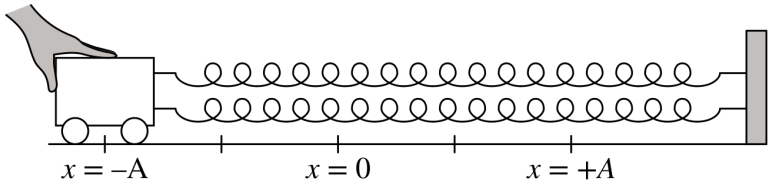
(e) Is the kinetic energy of Block 2 immediately after it leaves the spring the same as or different than the kinetic energy of Block 1 immediately after it leaves the spring?
_____ Same _____ Different
Justify your answer.

4. (7 points, suggested time 13 minutes)

The following two scenarios describe a cart attached to either one or two identical springs which are at their relaxed length when the cart is at position $x = 0$. In each scenario, the cart is pulled to position $x = -A$, is released from rest, and oscillates with negligible friction between $x = +A$ and $x = -A$.



Scenario 1



Scenario 2

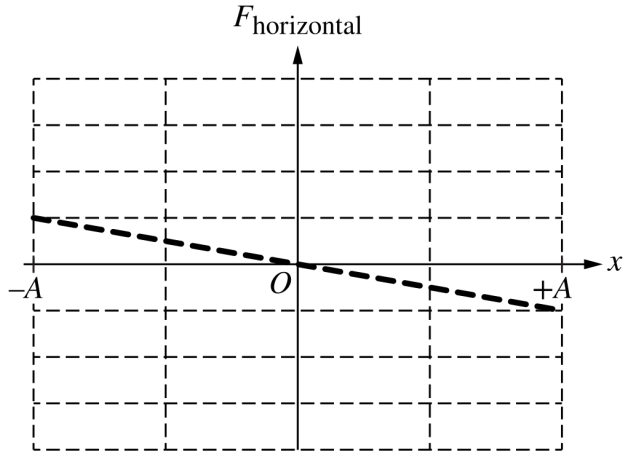
In Scenario 1, the cart is attached to the wall with one spring as shown. The total mechanical energy of the cart-spring system in Scenario 1 is E_1.

(a) For Scenario 1, derive an expression for the kinetic energy of the cart in terms of E_1 when the cart is at position $x = +\frac{A}{2}$.

(b) As shown in the figure for Scenario 2, a second identical spring is attached between the same cart and the wall before the cart is pulled to position $x = -A$.

i. Determine the total mechanical energy of the cart-springs system in Scenario 2 in terms of E_1.

ii. The maximum speed of the cart in Scenario 1 is v_1 and the maximum speed of the cart in Scenario 2 is v_2. Calculate the numerical value of the ratio $\frac{v_2}{v_1}$.



A student correctly sketches a graph of the horizontal component of the net force exerted on the cart by the spring in Scenario 1 as a function of position, as shown above with a dashed line.

(c) On the same graph above, using a solid line, sketch the horizontal component of the net force exerted on the cart in Scenario 2 with two springs attached.



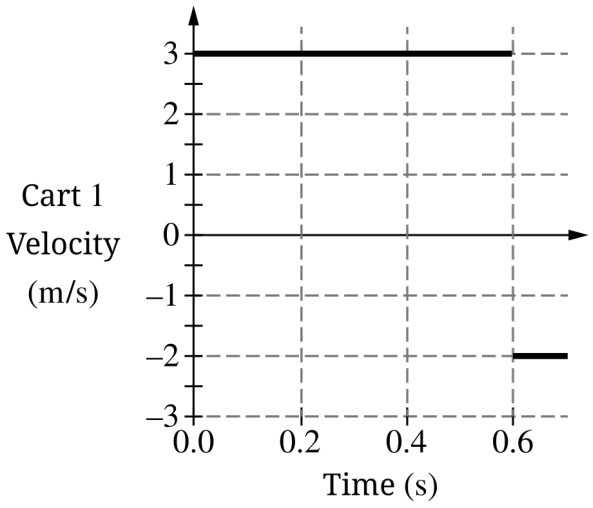
Note: Figure not drawn to scale.

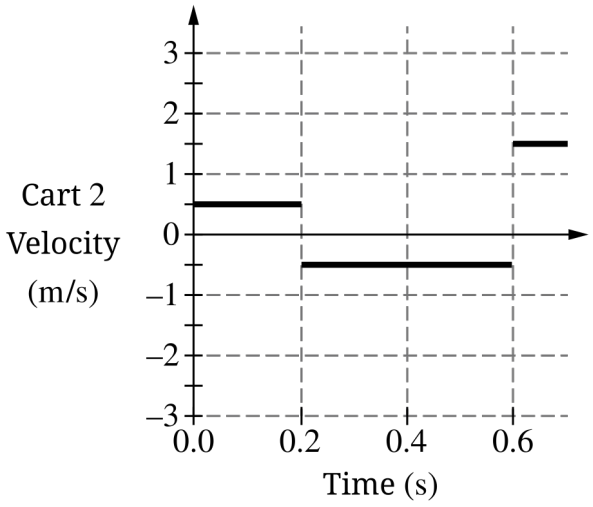
5. (7 points, suggested time 13 minutes)

Two carts are moving to the right on a straight, level track with negligible friction. At time $t = 0$, the carts are at the positions shown above. Cart 2 collides with and bounces off a wall at the right end of the track, after which the two carts collide.

Cart 1 has a mass of 0.20 kg and an initial velocity of 3.0 m/s to the right. Cart 2 has a mass of 0.5 kg and an initial velocity of 0.50 m/s to the right.

The graphs below show the velocity of each cart from $t = 0$ to sometime after the carts collide.



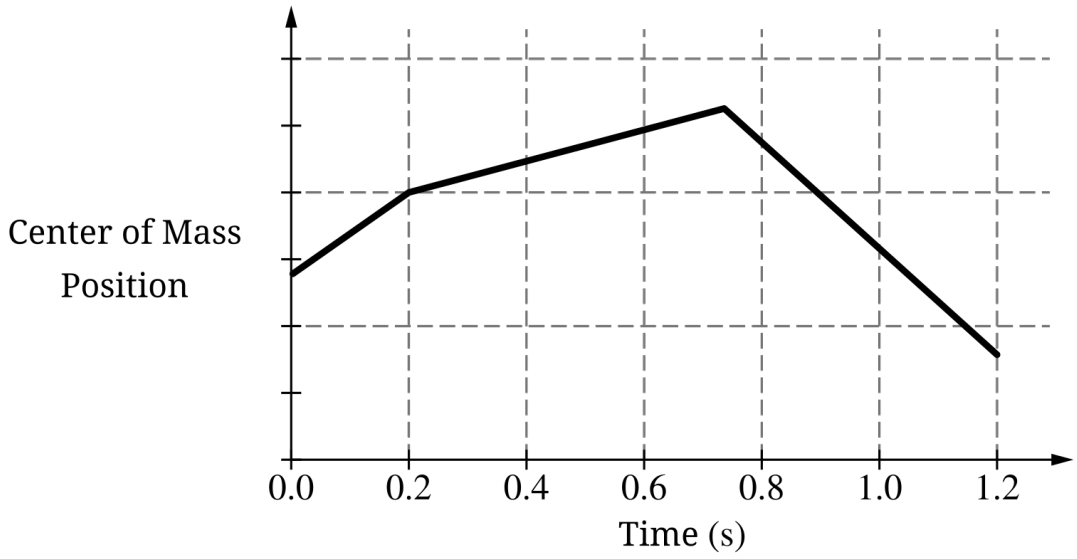


(a) Consider the system consisting of just Cart 2 when it bounces off the wall.

i. Is the momentum of Cart 2 the same before and after bouncing off the wall?
_____ Yes _____ No
Briefly justify your answer.

ii. Is the mechanical energy of Cart 2 the same before and after bouncing off the wall?
_____ Yes _____ No
Briefly justify your answer.

(b) Is the momentum of the two-cart system the same before and after the collision that occurs at $t = 0.6$s?
_____ Yes _____ No
Using calculations based on the information shown in the graphs, justify your answer.



(c) The graph above shows the position of the center of mass of the two-cart system for a longer time interval $0 < t < 1.2$ s. The slope of the graph changes at time $t = 0.2$ s and also at time $t = 0.73$ s, which are the two times at which Cart 2 bounces off the wall. However, the slope does not change at time $t = 0.6$ s, when the two carts collide.

i. Use physics principles to explain why the slope of the graph changes at $t = 0.2$ s and $t = 0.73$ s.

ii. Use physics principles to explain why the slope of the graph does not change at $t = 0.6$ s.

STOP
END OF EXAM