PHYSICS 1

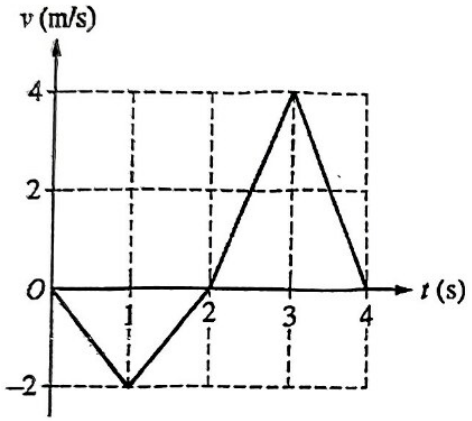
SECTION I

Time—1 hour and 30 minutes

50 Questions

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

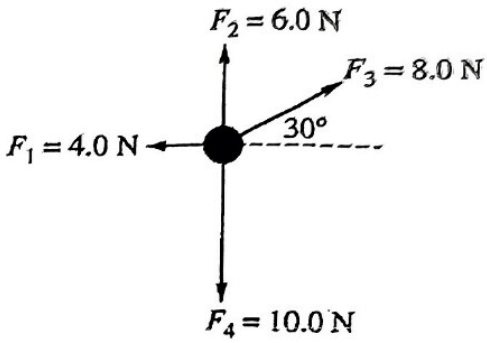
Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.



1. A toy car travels along a straight, horizontal track. The graph represents the velocity v of the car as a function of time t from $0 \le t \le 4$ s. Which of the following indicates the distance traveled by the car and the displacement of the car for the 4 s time interval shown?

	Distance Traveled	Displacement
A	0 m	0 m
B	2 m	2 m
C	6 m	0 m
D	6 m	2 m

(A) A
(B) B
(C) C
(D) D



2. The free-body diagram shown represents all the forces that are exerted on an object of mass 2.0 kg. Which of the following best approximates the magnitude of the acceleration of the object?

(A) Zero
(B) $1.5\ \text{m/s}^2$
(C) $2.0\ \text{m/s}^2$
(D) $3.0\ \text{m/s}^2$

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3. A person exerts a horizontal, rightward force on a box that is initially at rest, causing the box to accelerate to the right. The person remains at rest. Which of the following figures could represent the directions and relative magnitudes of the horizontal forces exerted on the person and on the box during the push?

(A) 

(B) 

(C) 

(D) 

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4. An experiment is conducted with two identical blocks, X and Y. In each of two trials, Block Y is initially at rest at the bottom of a ramp and Block X slides toward Block Y along a horizontal surface with the same constant speed. All frictional forces are negligible. In each trial, the blocks collide, causing Block Y to slide up the ramp. The collision is elastic in Trial 1, and the collision is inelastic in Trial 2. In which trial, if any, does Block Y reach a higher point on the ramp?

(A) Trial 1

(B) Trial 2

(C) Neither trial; Block Y reaches the same height in both trials.

(D) The relative heights that Block Y reaches in each trial cannot be compared without knowing the mass of the blocks and the initial velocity of Block X.

5. A block slides along a horizontal track at a constant speed toward a force sensor that is attached to a wall. The block collides with the force sensor, which measures the following data.

- Total time the block was in contact with the sensor
- Maximum force exerted on the sensor by the block
- Average force exerted on the sensor by the block

Which of the following calculations could be used to determine the magnitude of the change in momentum of the block during the collision?

(A) Multiply the maximum force by the total time.

(B) Multiply the average force by the total time.

(C) Divide the maximum force by the total time.

(D) Divide the average force by the total time.

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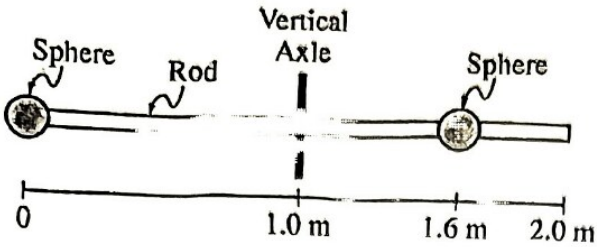

Side View

6. A uniform rod of length 2.0 m and negligible mass is mounted to and free to rotate about a vertical axle through its center. Two small, identical spheres of mass $m_0 = 0.5$ kg are fixed to the rod at the positions shown in the side view figure. The rotational inertia I of each sphere about the vertical axle is $I = m_0 r^2$, where r is the distance of each sphere from the vertical axle. The rod-spheres system rotates with constant angular speed 10 rad/s about the vertical axle. What is the magnitude of the angular momentum of the system?

(A) 1.8 kg·m^2/s

(B) 3.4 kg·m^2/s

(C) 5.8 kg·m^2/s

(D) 6.8 kg·m^2/s

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7. A book of mass $2M$ rests on a table. A student exerts a horizontal force of magnitude F on the book, causing the book to accelerate across the table. The book is replaced by a block of mass M. The student exerts a horizontal force of magnitude F on the block, causing the block to accelerate across the table. Which of the following is a true statement regarding the magnitudes of the forces exerted on the student?

(A) The force exerted by the book on the student has twice the magnitude of the force exerted on the student by the block.

(B) The book and block exert forces of equal magnitude F on the student.

(C) The book and block exert forces of an equal magnitude less than F on the student.

(D) Neither the book nor the block exerts a force on the student.

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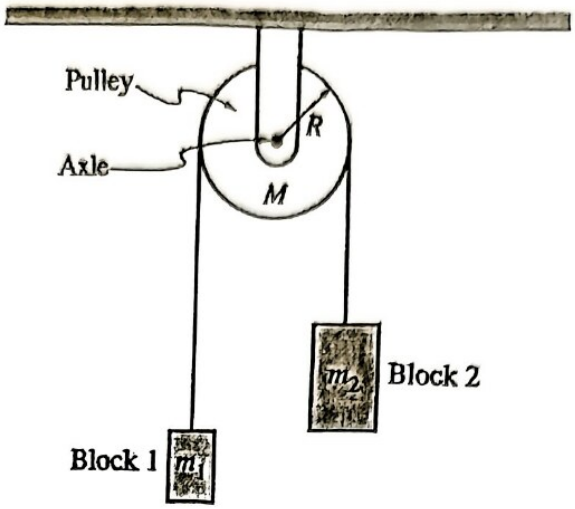
Questions 8 - 10 refer to the following material.



Block 1 of mass m_1 and Block 2 of mass m_2, where $m_1 < m_2$, are attached to either end of a string of negligible mass. The string passes over a pulley that is attached to a horizontal axle through its center, as shown, and the two blocks are held at rest. The pulley has radius R and mass M, where $M \gg m_2$, and the pulley is free to rotate about the axle with negligible friction. When the blocks are released from rest, the string does not slip as the pulley rotates and the blocks move.

8. As the pulley rotates and the blocks move, which of the following indicates the changes, if any, in the gravitational potential energy U_g of the system consisting of Block 1 and Earth and the system consisting of the two blocks and Earth?

	U_g of the Block 1-Earth System	U_g of the Two-Block-Earth System
A	Decreases	Constant
B	Decreases	Decreases
C	Increases	Constant
D	Increases	Decreases

(A) A
(B) B
(C) C
(D) D

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9. Which of the following best describes the motion of the center of mass of the two-block-pulley system as the pulley rotates and the blocks move?

(A) The speed of the center of mass of the system is constant and zero.

(B) The speed of the center of mass of the system is constant and in the upward direction.

(C) The speed of the center of mass of the system is constant and in the downward direction.

(D) The speed of the center of mass of the system is increasing and in the downward direction.

10. The magnitude of the tension in the left side of the string is T_1, and the magnitude of the tension in the right side of the string is T_2. Consider the clockwise direction to be positive. Which of the following is a correct expression for the net torque exerted on the pulley about its axle?

(A) $(T_2 + T_1)R$

(B) $(T_2 - T_1)R$

(C) $(T_2 + m_2 g + T_1 + m_1 g)R$

(D) $(T_2 + m_2 g - T_1 - m_1 g)R$

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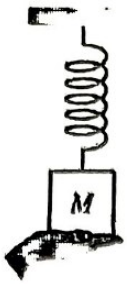


Figure 1

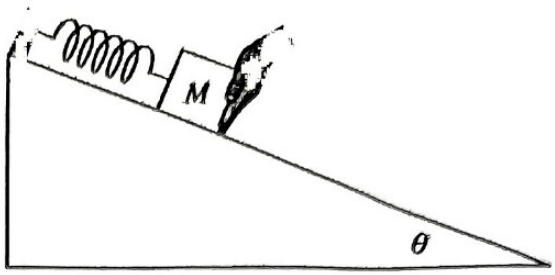


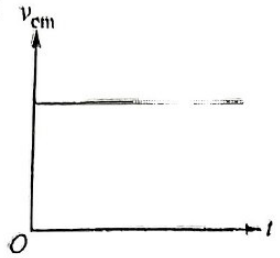
Figure 2

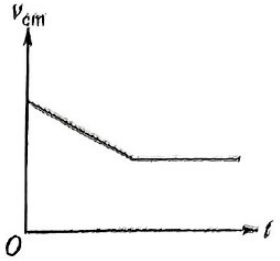
11. One end of a vertical spring is attached to a ceiling and the other end to a block of mass M. The block is held at rest when the spring is neither stretched nor compressed, as shown in Figure 1. The block is released, and the block-spring system oscillates with period T_0 and amplitude A_0. The block-spring system is then placed on a ramp inclined at angle θ above the horizontal, and the end of the spring is attached to the top of the ramp, as shown in Figure 2. The block is again held at rest when the spring is neither stretched nor compressed. The block is released and the system oscillates. All frictional forces are negligible. Which of the following represents the period and amplitude of oscillation for the system on the ramp?

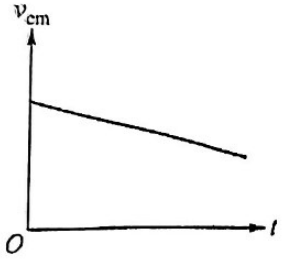
	Period	Amplitude
A	T_0	A_0
B	$T_0 \sin\theta$	A_0
C	T_0	$A_0 \sin\theta$
D	$T_0 \sin\theta$	$A_0 \sin\theta$

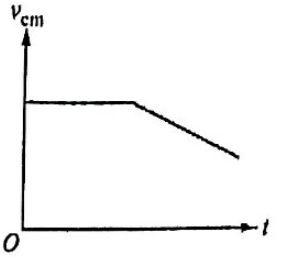
(A) A
(B) B
(C) C
(D) D

12. At time $t = 0$, Block 1 is released from rest at the top of a ramp and Block 2 has an initial velocity up the same ramp so that the blocks slide toward each other. All frictional forces are negligible. A short time later the blocks collide. The speed of the center of mass of the two-block system is v_{cm}. Which of the following graphs could represent v_{cm} as a function of t while the blocks are on the ramp?

(A)


(B)


(C)


(D)


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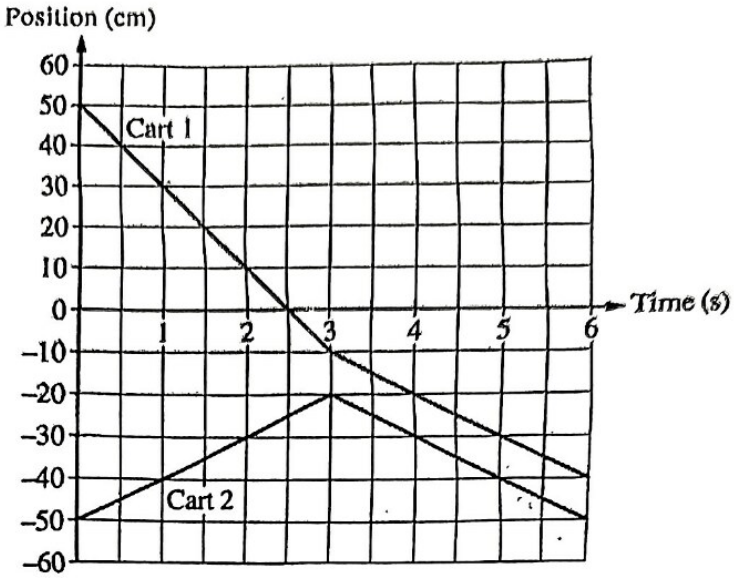

13. Carts 1 and 2 slide toward each other along a straight, horizontal track. There is negligible friction between the carts and the track. At time $t = 3$ s, the carts collide and stick together. The graph represents the positions of the centers of mass of each cart as functions of time, before and after the collision. If the mass of Cart 1 is 12 kg, what is the mass of Cart 2 ?

(A) 6 kg
(B) 8 kg
(C) 18 kg
(D) 24 kg

14. Consider the following three collisions between two blocks on a horizontal surface where there is negligible friction between the blocks and the surface.

- Collision 1: A block of mass m_0 moving with speed v_0 collides elastically with a block of mass $4m_0$, which is initially at rest. The final kinetic energy of the two-block system is K_1.
- Collision 2: A block of mass m_0 moving with speed v_0 collides with and sticks to a block of mass $4m_0$, which is initially at rest. The final kinetic energy of the two-block system is K_2.
- Collision 3: A block of mass $4m_0$ moving with speed v_0 collides elastically with a block of mass m_0, which is initially at rest. The final kinetic energy of the two-block system is K_3.

Which of the following correctly compares K_1, K_2, and K_3 ?

(A) $K_1 = K_2 = K_3$

(B) $K_3 > (K_1 = K_2)$

(C) $(K_1 = K_3) > K_2$

(D) $K_3 > K_1 > K_2$

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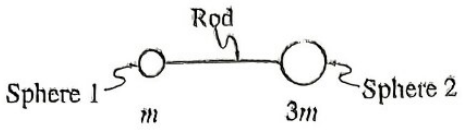
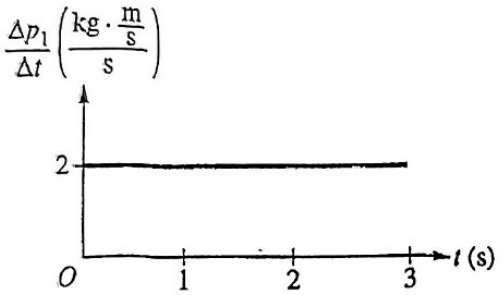


The figure shows a system that consists of two spheres, 1 and 2, connected by a rigid rod of negligible mass. The masses of spheres 1 and 2 are m and $3m$, respectively. The system is held at its center of mass such that the rod is horizontal, and at time $t = 0$ the system is released from rest near the surface of Earth.



15. The graph represents the rate of change of linear momentum $\frac{\Delta p_1}{\Delta t}$ of Sphere 1 as a function of time t while the system falls. What is the linear momentum of Sphere 1 after it has fallen for 3.0 s ?

(A) Zero
(B) 2 kg · m/s
(C) 3 kg · m/s
(D) 6 kg · m/s

16. Which of the following statements is true regarding the net torque about the center of mass of the two-sphere-rod system as the system falls?

(A) The net torque on the system causes the system to rotate counterclockwise.
(B) The net torque on the system causes the system to rotate clockwise.
(C) The net torque on the system is zero, and the system does not rotate.
(D) The net torque on the system cannot be determined without knowing the angular momentum of the system and the masses of the spheres.

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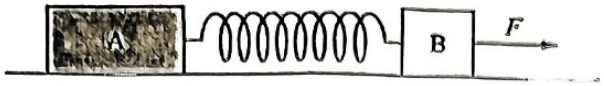


Scenario 1



Scenario 2

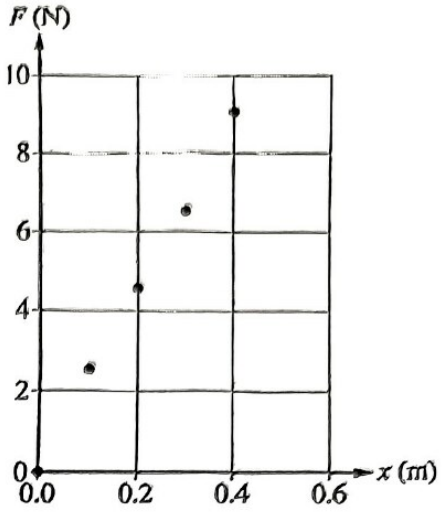
17. Blocks A and B are each attached to opposite ends of an ideal spring. The blocks are initially at rest on a horizontal surface. The mass of Block A is greater than the mass of Block B. The coefficient of kinetic friction between the surface and each block is the same and nonzero. In scenarios 1 and 2, the orientation of blocks A and B is reversed, as shown. In each scenario, a rightward force of magnitude F is exerted on the rightmost block so that the two-block-spring system moves at a constant speed. Which of the following correctly compares the spring potential energy U_1 in Scenario 1 with the spring potential energy U_2 in Scenario 2 ?

(A) $U_1 > U_2$

(B) $U_1 < U_2$

(C) $U_1 = U_2$

(D) U_1 and U_2 cannot be compared without knowing the masses of the blocks and the spring constant of the spring.



18. A box is attached to one end of an ideal spring that is initially at its relaxed length. The other end of the spring is attached to a wall. A student exerts a force of magnitude F on the box in the x-direction so that the spring stretches and the box is displaced 0.4 m. The graph shows data for F as a function of the position x of the box. Which of the following is most nearly the work done by the student on the box-spring system as the box moves from $x = 0$ m to $x = 0.4$ m ?

(A) 1.8 J

(B) 3.6 J

(C) 9.0 J

(D) 23 J

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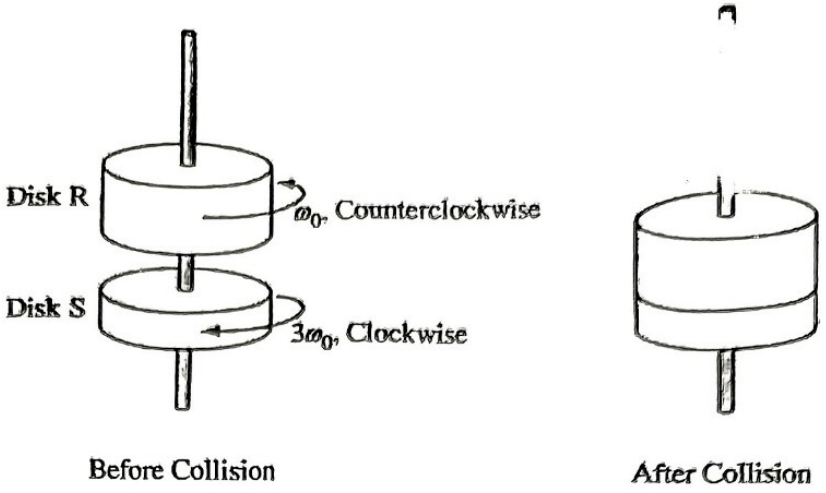

Before Collision

After Collision

19. Two solid, cylindrical disks, R and S, rotate with negligible friction about the same vertical axle. Disk R initially rotates above and apart from Disk S, as shown. Disk R, with rotational inertia $2I$, initially rotates counterclockwise, when viewed from above, with angular speed ω_0. Disk S, with rotational inertia I, initially rotates clockwise, when viewed from above, with angular speed $3\omega_0$. Disk R is released, falls, and collides with Disk S so that the two disks rotate together with negligible friction about the axle after the collision. Which of the following statements is true regarding the direction of rotation and the angular speed of the two-disk system after the collision?

(A) The disks rotate clockwise with an angular speed greater than $2\omega_0$.

(B) The disks rotate counterclockwise with an angular speed greater than $2\omega_0$.

(C) The disks rotate clockwise with an angular speed less than $2\omega_0$.

(D) The disks rotate counterclockwise with an angular speed less than $2\omega_0$.

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20. A 1 kg block is initially at rest on a horizontal surface. From time $t = 0$ to $t = 3$ s, the block experiences an acceleration of 2 m/s^2 to the right. From $t = 3$ s to $t = 6$ s, the block experiences an acceleration of 2 m/s^2 to the left. What is the displacement of the block from $t = 0$ to $t = 6$ s ?

(A) Zero
(B) 12 m
(C) 18 m
(D) 36 m

Time (s)	Position (cm)
1.0	59
2.0	46
3.0	35
4.0	26
5.0	19
6.0	14

21. A student collects data as a toy car moves along a straight, horizontal track in the $-x$-direction. The table shows the data of the position of the car at various times. Based on the data, which of the following describes the acceleration of the car during the time interval shown?

(A) The acceleration is positive and constant.
(B) The acceleration is negative and constant.
(C) The acceleration is positive and nonconstant.
(D) The acceleration is negative and nonconstant.

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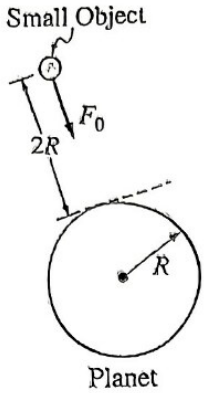
Questions 22 and 23 refer to the following material.



Note: Figure not drawn to scale.

A small object falls directly toward the center of mass of a planet that has approximately the same radius R as the radius of Earth but has approximately twice the mass of Earth. At time $t = t_1$, shown in the figure, the small object is a distance $2R$ above the surface of the planet and the planet exerts a force with magnitude F_0 on the small object.

22. Which of the following best approximates the magnitude of the gravitational field on the surface of the planet?

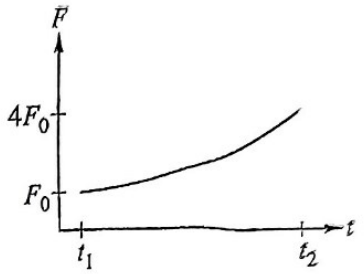
(A) 2.5 N/kg
(B) 5.0 N/kg
(C) 14 N/kg
(D) 20 N/kg

23. Which of the following graphs best represents the magnitude of the force F exerted by the planet on the small object as a function of time t, from $t = t_1$ until just before the small object strikes the planet at time $t = t_2$?

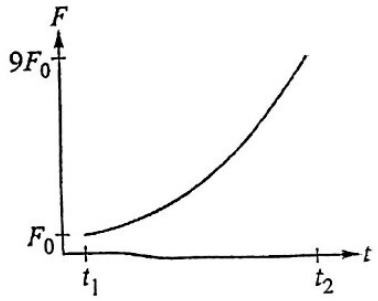
(A)



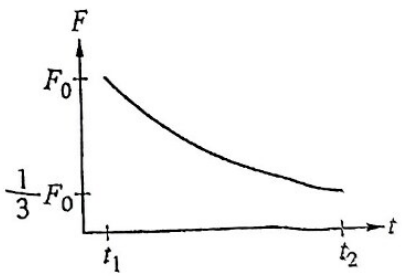
(B)



(C)



(D)



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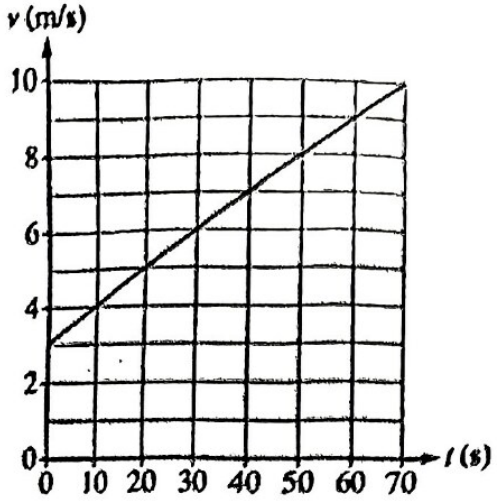


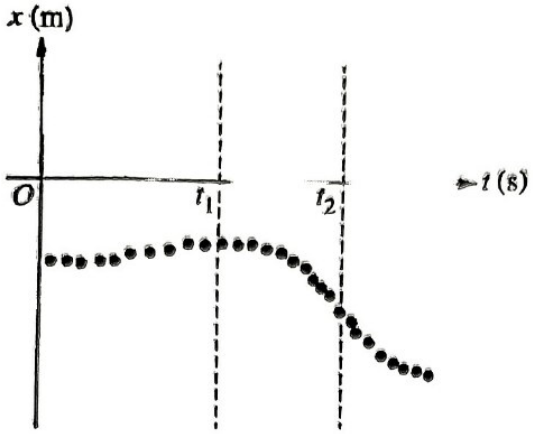
24. A car travels along a straight, horizontal track. The graph represents the velocity v of the car as a function of time t. Which of the following is most nearly the distance the car travels between $t = 0$ and $t = 70$ s ?

(A) 30 m

(B) 210 m

(C) 460 m

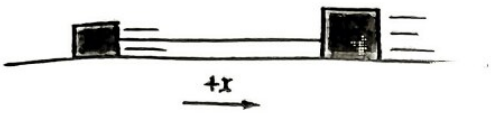
(D) 780 m



25. The graph shows data of the position x of a block as a function of time t as the block moves along a straight, horizontal track. Which of the following best describes the displacement Δx and change in velocity Δv of the block during time interval $t_1 \le t \le t_2$?

	Displacement	Change in Velocity
A	$\Delta x < 0$	$\Delta v < 0$
B	$\Delta x > 0$	$\Delta v = 0$
C	$\Delta x > 0$	$\Delta v < 0$
D	$\Delta x < 0$	$\Delta v = 0$

(A) A
(B) B
(C) C
(D) D



26. Two blocks with different masses are connected by a string of negligible mass. The two-block system slides along a horizontal surface in the $-x$-direction, as shown. At time $t = 0$, the center of mass of the system is located at a position $x_0 > 0$, and the system experiences a constant acceleration in the $+x$-direction. Which of the following best describes the motion of the center of mass of the system at $t = 0$?

(A) The center of mass of the system is speeding up and sliding away from $x = 0$.

(B) The center of mass of the system is slowing down and sliding away from $x = 0$.

(C) The center of mass of the system is speeding up and sliding toward $x = 0$.

(D) The center of mass of the system is slowing down and sliding toward $x = 0$.

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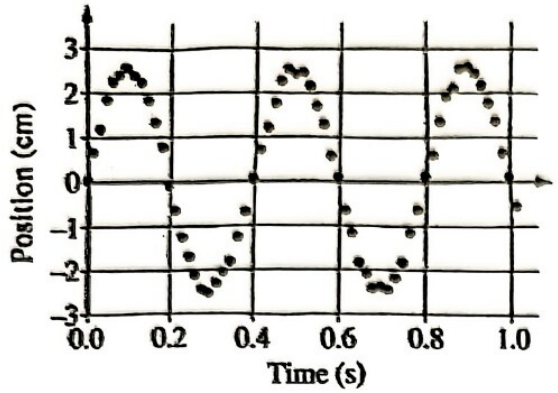
Questions 27 - 29 refer to the following material.



A system that consists of a block and spring is oscillating on a horizontal surface. The graph shows data collected by a motion sensor for the position of the block as a function of time.

27. During the first 0.4 s, at what time or times is the magnitude of the force exerted on the block by the spring at a maximum?

(A) 0.1 s only
(B) 0.2 s only
(C) 0.1 s and 0.3 s
(D) 0 s, 0.2 s, and 0.4 s

28. The original block is replaced by a new block with a greater mass, and the new block-spring system is made to oscillate with the same amplitude as the original block-spring system. Which of the following claims is correct regarding how the period T_{new} of the new block-spring system compares to the period T_{orig} of the original block-spring system?

(A) $T_{new} > T_{orig}$
(B) $T_{new} < T_{orig}$
(C) $T_{new} = T_{orig}$
(D) T_{new} and T_{orig} cannot be compared without knowing the masses of the blocks.

29. At a particular instant, the elastic potential energy of the system is 0.005 J and the kinetic energy of the system is 0.005 J. What are the minimum and maximum values of the kinetic energy of the system during one full oscillation?

	Minimum Kinetic Energy	Maximum Kinetic Energy
A	−0.010 J	0.010 J
B	−0.005 J	0.005 J
C	0 J	0.005 J
D	0 J	0.010 J

(A) A
(B) B
(C) C
(D) D

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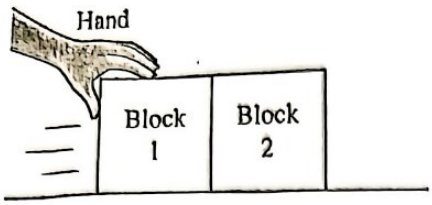
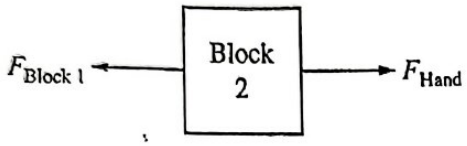


30. The figure shows a hand pushing two identical blocks, 1 and 2, across a horizontal surface with constant velocity. There is friction between the blocks and the surface. Which of the following correctly indicates all <u>horizontal</u> forces that are exerted on Block 2 ?

(A)



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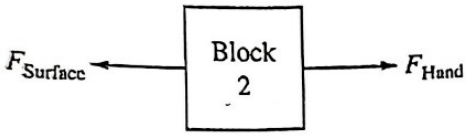

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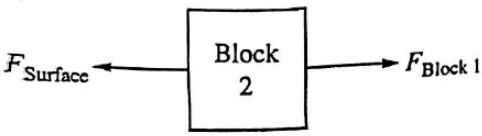

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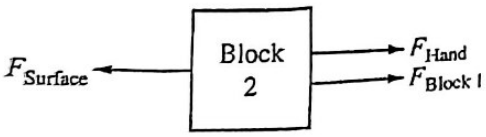

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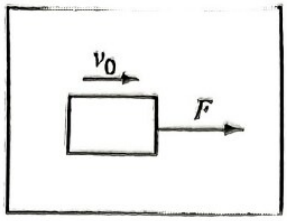
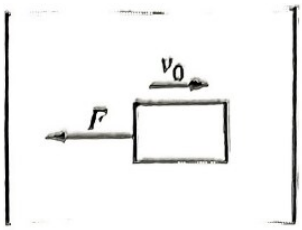


Scenario 1

Top View



Scenario 2

Top View

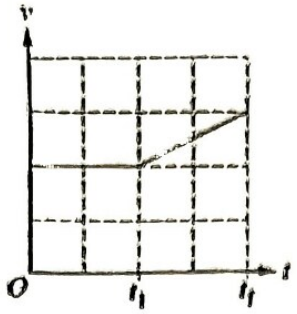
31. The figure shows scenarios 1 and 2, in which identical blocks initially move to the right along a horizontal surface, each with speed v_0. In both scenarios, all frictional forces are negligible. In both scenarios, a force of magnitude F is exerted on each block, in the directions shown, for the same time interval Δt. The blocks do not come to rest. The changes in kinetic energy for scenarios 1 and 2 are ΔK_1 and ΔK_2, respectively. Which of the following correctly compares the magnitudes of ΔK_1 and ΔK_2 ?

(A) $|\Delta K_1| > |\Delta K_2|$

(B) $|\Delta K_1| < |\Delta K_2|$

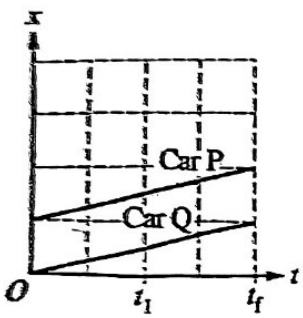
(C) $\left(|\Delta K_1| = |\Delta K_2|\right) > 0$

(D) $|\Delta K_1| = |\Delta K_2| = 0$

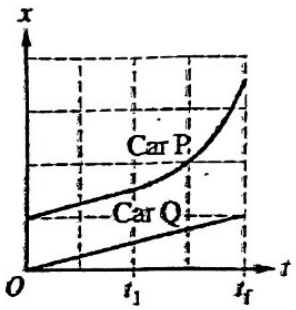


22. The graph shows the velocity v of the center of mass of two identical cars, P and Q, as a function of time t for time interval $0 \le t \le t_f$. Which of the following graphs could correctly represent the positions x of cars P and Q as functions of time t for the same time interval $0 \le t \le t_f$?

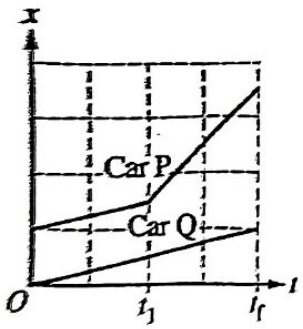
(A)



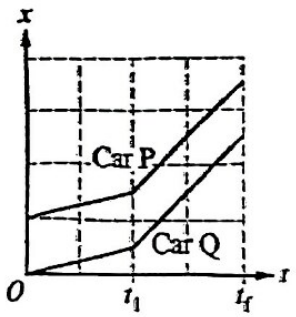
(B)

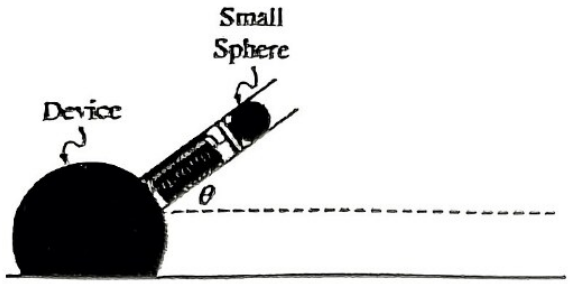


(C)



(D)





33. A small sphere is loaded into a device that has an ideal spring that can be compressed and released to launch objects, as shown. The spring is compressed from its relaxed length until the device-sphere system has elastic potential energy ΔU_s. The spring is released and launches the sphere at an angle $0 < \theta < 90°$ above the horizontal. The change in the gravitational potential energy of the sphere-Earth system from the launch height of the sphere to the highest point in the path of the sphere is ΔU_g. How does the magnitude of ΔU_g compare with the magnitude of ΔU_s ?

(A) $|\Delta U_g| = |\Delta U_s|$

(B) $|\Delta U_g| < |\Delta U_s|$

(C) $|\Delta U_g| > |\Delta U_s|$

(D) The magnitude of ΔU_g cannot be compared with the magnitude of ΔU_s without knowing the mass of the sphere.

34. A disk with rotational inertia $0.15\ \text{kg}\cdot\text{m}^2$ initially rotates clockwise about an axle with angular speed 3.0 rad / s. Friction between the disk and the axle is negligible. Starting at time $t = 0$, a counterclockwise torque of magnitude 0.3 N·m is exerted on the disk. In addition to $t = 0$, at which of the following times, if any, will the disk have an angular speed of 3.0 rad / s ?

(A) 1.5 s

(B) 3.0 s

(C) 4.5 s

(D) There is no other time at which the disk will have an angular speed of 3.0 rad / s.

35. At time $t = 0$, a block rests on the ground. A student then picks up the block, and at $t = t_1$ the student holds the block at rest above the ground. Which of the following claims is true regarding the system that consists only of the block at times $t = 0$ and $t = t_1$?

(A) The total mechanical energy of the system is equal and zero at $t = t_1$ and $t = 0$.

(B) The total mechanical energy of the system is equal and nonzero at $t = t_1$ and $t = 0$.

(C) The kinetic energy of the system is greater at $t = t_1$ than at $t = 0$.

(D) The gravitational potential energy of the system is greater at $t = t_1$ than at $t = 0$.

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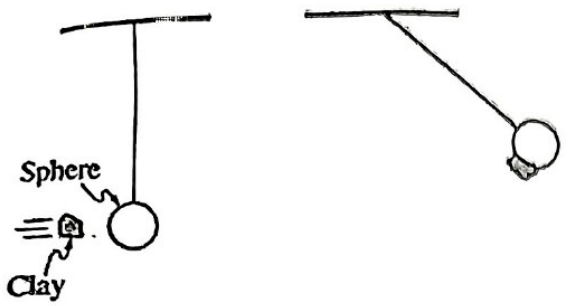


36. A piece of clay is launched so that it collides with and sticks to a sphere that hangs from a string with negligible mass, as shown in the figure.

- Time $t = t_1$ represents the instant immediately before the collision, when the clay is moving in the horizontal direction.
- $t = t_2$ represents the instant when the clay-sphere system has swung to its maximum height and momentarily comes to rest.

Which of the following quantities, if either, is the same for the system at $t = t_1$ and $t = t_2$?

(A) Only the linear momentum

(B) Only the mechanical energy

(C) Both the linear momentum and the mechanical energy

(D) Neither the linear momentum nor the mechanical energy

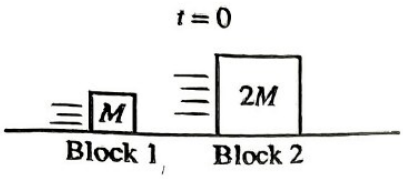


Figure 1

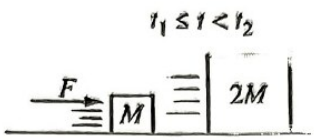


Figure 2

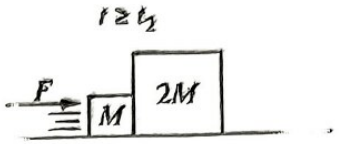
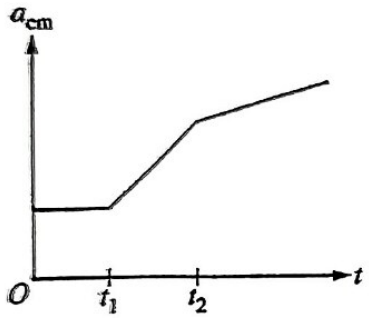


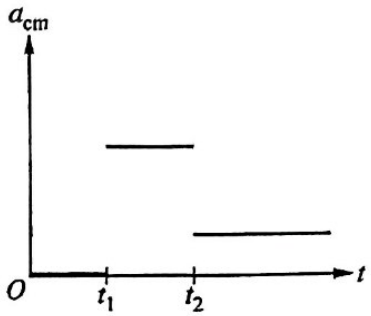
Figure 3

37. At time $t = 0$, blocks 1 and 2 with masses M and $2M$, respectively, slide to the right along a horizontal track at the same constant speed, as shown in Figure 1. All frictional forces are negligible. At $t = t_1$, a constant force of magnitude F is exerted on Block 1 in the rightward direction, as shown in Figure 2. Block 1 accelerates toward Block 2, and at $t = t_2$, the two blocks collide and stick together, and the two-block system continues sliding to the right as F continues to be exerted on Block 1, as shown in Figure 3. Which of the following graphs best represents the acceleration a_{cm} of the center of mass of the system as a function of t ?

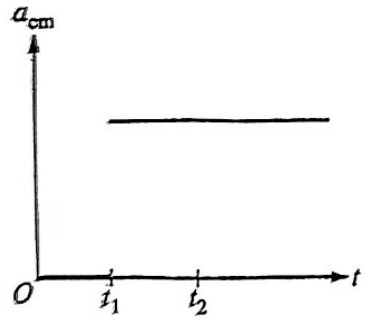
(A)



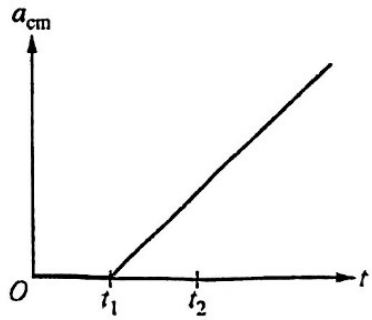
(B)



(C)



(D)



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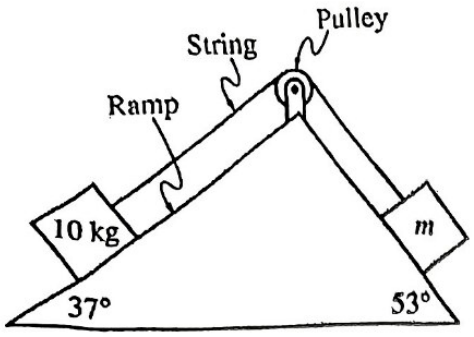
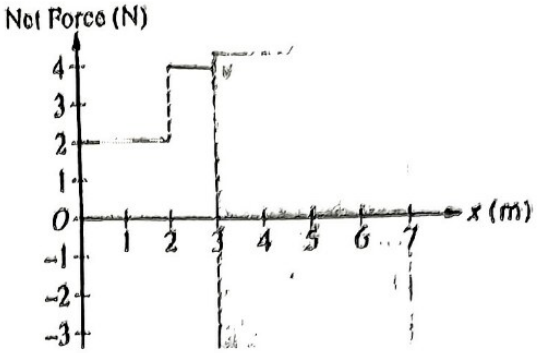


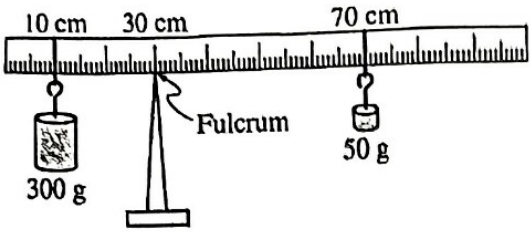
38. Two blocks are connected by a string of negligible mass that passes over a pulley. The blocks remain at rest on opposite sides of a ramp. All frictional forces are negligible. The mass of the block on the left and the angles of the inclines are shown in the figure. Which of the following is most nearly the mass m of the block on the right?

(A) 6.0 kg
(B) 7.5 kg
(C) 10 kg
(D) 13 kg



39. A block is at rest at the origin. A net force is then exerted on the block in the x-direction. The graph shows the net force exerted on the block as a function of the position x of the block for $0 \leq x < 3$ m. What constant net force must be exerted on the block in the gray region from $3\text{ m} \leq x \leq 7\text{ m}$, shown in the figure, in order for the block to come to rest at $x = 7$ m ?

(A) Zero
(B) −1 N
(C) −2 N
(D) −3 N



40. A meterstick of uniform density is horizontally balanced about a fulcrum when cylinders of mass 300 g and 50 g hang from the locations indicated in the figure. What is the mass of the meterstick?

(A) 150 g
(B) 200 g
(C) 250 g
(D) 350 g

Time (s)	Height of Ball (m)
1.0	85
2.0	60
3.0	26

41. At time $t = 0$, a ball is launched from a height of 100 m. The table shows the measured heights of the ball at three different times after the ball is launched. Which of the following best approximates the magnitude of the vertical component of the initial velocity of the ball?

(A) 0 m/s
(B) 5.0 m/s
(C) 10 m/s
(D) 15 m/s

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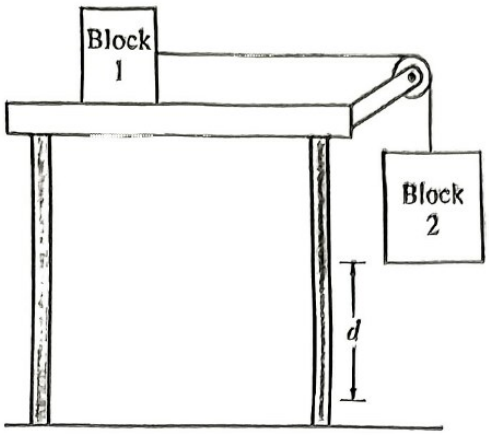
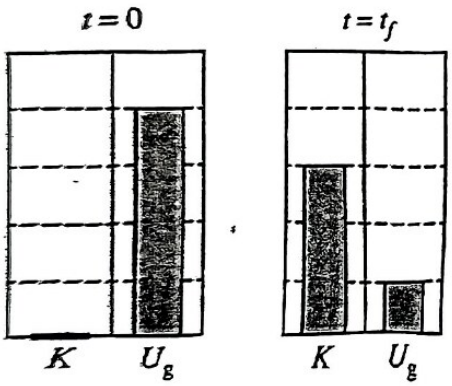
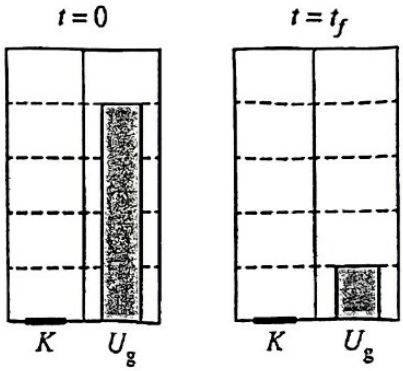


Blocks 1 and 2 are connected by a string with negligible mass that passes over a pulley. The pulley has negligible mass and negligible friction about its axle. Block 1 is held at rest on a table and Block 2 hangs from the string, as shown. There is friction between Block 1 and the table. At time $t = 0$, Block 1 is released from rest. At $t = t_f$, Block 2 has fallen a distance d but has not yet hit the ground and is still moving. The kinetic energy of the two-block system is K. The gravitational potential energy of the two-block-Earth system is U_g. Which of the following pairs of energy bar charts best represents K and U_g for times $t = 0$ and $t = t_f$?

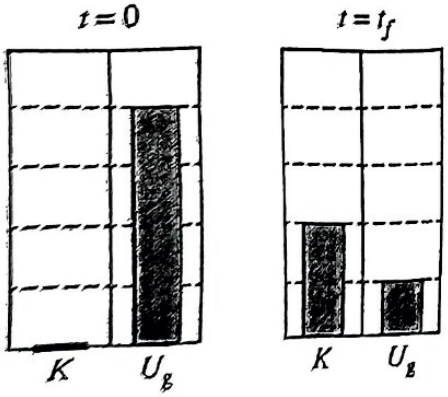
(A)



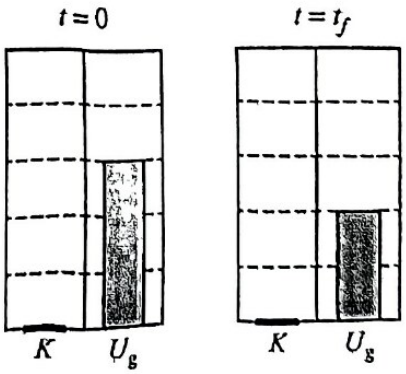
(B)



(C)



(D)



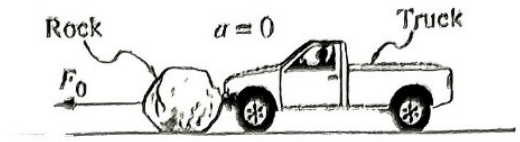
43. A student wants to determine the coefficient of kinetic friction μ_k between a block of known mass and a horizontal floor. Which of the following procedures and measurements could lead to a successful determination?

(A) Give the block a brief horizontal push. Measure the distance the block travels before coming to rest.

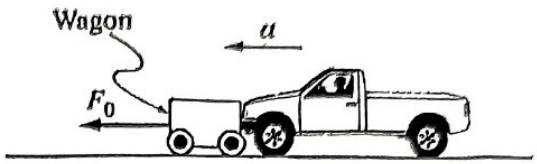
(B) Use a spring scale to pull on the block until the block just begins to move. Measure the maximum applied horizontal force.

(C) Place the block on a ramp of the same material as the floor and increase the angle of the ramp. Measure the angle at which the block begins to slide.

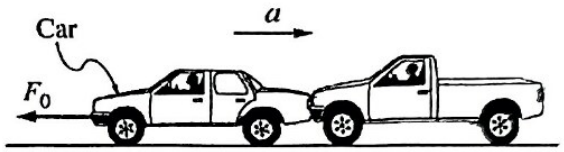
(D) Use a spring scale to pull the block at constant speed along a section of floor. Measure the required applied horizontal force.



Scenario 1



Scenario 2



Scenario 3

44. Scenarios 1, 2, and 3 show a truck pushing three different objects: a rock, a wagon, and a car, respectively. In each scenario, the truck exerts a constant leftward force of magnitude F_0 on the object. The direction of the acceleration a, if any, of the two-object system is indicated in each scenario.

- In Scenario 1, the magnitude of the force exerted on the truck by the rock is F_1.
- In Scenario 2, the magnitude of the force exerted on the truck by the wagon is F_2.
- In Scenario 3, the magnitude of the force exerted on the truck by the car is F_3.

Which of the following correctly compares F_1, F_2, and F_3 ?

(A) $F_1 = F_2 = F_3$

(B) $F_3 > F_1 > F_2$

(C) $F_1 > F_3 > F_2$

(D) $(F_1 = F_3) > F_2$

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Top View

35. Two disks with masses M and $2M$ initially slide directly toward each other along a horizontal surface, as shown in the top view figure, each with the same constant speed, before colliding elastically. Immediately after the collision, the velocity of the center of mass of the two-disk system is v_{cm}. Which of the following claims regarding v_{cm} is true?

(A) v_{cm} is to the right.
(B) v_{cm} is to the left.
(C) $v_{cm} = 0$
(D) The direction of v_{cm} cannot be determined without knowing the masses and the initial speeds of the disks.

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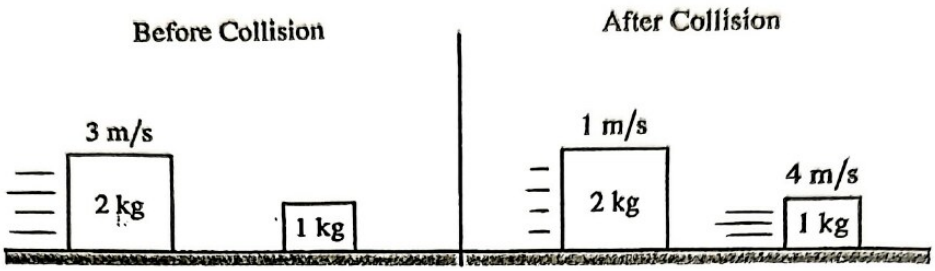
Directions: For each of the questions or incomplete statements below, two of the suggested answers will be correct. For each of these questions, you must select both correct choices to earn credit. No partial credit will be earned if only one correct choice is selected. Select the two that are best in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



131. A block of mass 2 kg initially slides to the right along a horizontal surface with a speed of 3 m/s before colliding with a block of mass 1 kg that is initially at rest, as shown. All frictional forces are negligible. After the collision, the 2 kg block slides to the right with a speed of 1 m/s and the 1 kg block slides to the right with a speed of 4 m/s. Which two of the following are true statements regarding the collision? Select two answers.

(A) The momentum of the two-block system is constant.
(B) The momentum of the two-block system is not constant.
(C) The kinetic energy of the two-block system is constant.
(D) The kinetic energy of the two-block system is not constant.

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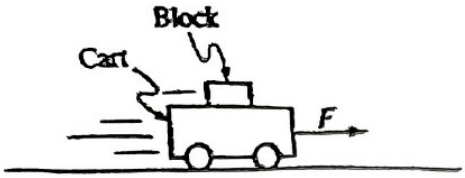


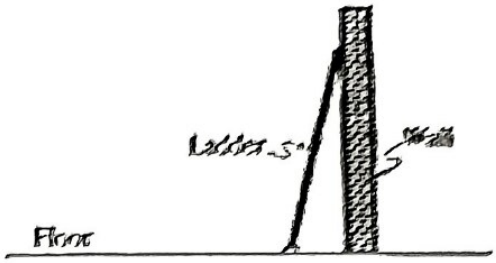
132. A cart is pulled to the right by a force of constant magnitude F, as shown. A block on top of the cart does not slip as the cart accelerates toward the right. Which two of the following forces are exerted on the block? Select two answers.

(A) A normal force directed toward the top of the page

(B) A frictional force directed toward the right

(C) A frictional force directed toward the left

(D) A pulling force of magnitude F directed toward the right



133. A ladder is placed on a floor so that it leans against a wall, as shown. There is negligible friction between the ladder and the wall but nonnegligible friction between the ladder and the floor. Which two of the following measurements can be used together to determine if the ladder will slip or remain at rest? Select two answers.

(A) The length of the ladder

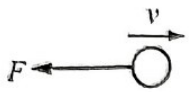
(B) The mass of the ladder

(C) The angle between the ladder and the floor

(D) The coefficient of static friction between the floor and the ladder

134. A disk is initially sliding to the right along a horizontal surface with speed v. All frictional forces are negligible. A force of magnitude F is then exerted on the disk for a short time interval in which the disk is always moving. Which two figures represent scenarios where the kinetic energy is always increasing while the force is being exerted? Select two answers.

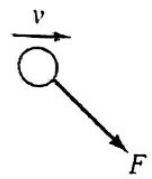
(A)



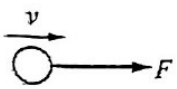
(B)

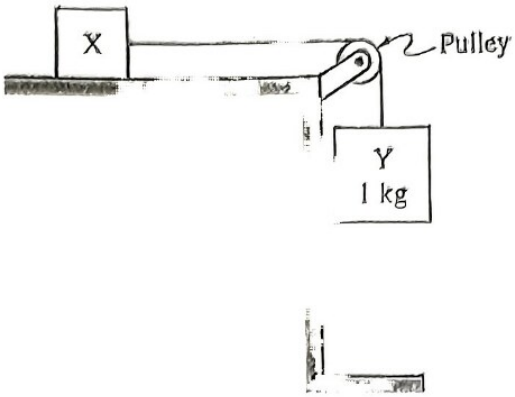


(C)



(D)





135. A student must use the setup shown in the figure to determine the inertial mass of Block X. Blocks X and Y are connected by a string of negligible mass that passes over a pulley with negligible mass. Block Y has mass 1 kg. All frictional forces are negligible. Which two of the following measuring devices could be used together in order for the student to determine the inertial mass of Block X ? Select two answers.

(A) Meterstick
(B) Protractor
(C) Digital scale
(D) Stopwatch

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Begin your response to **QUESTION 1** on this page.

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.

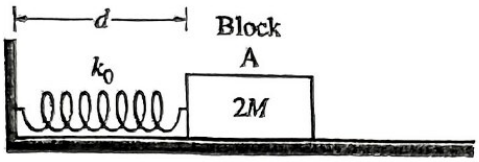

Figure 1

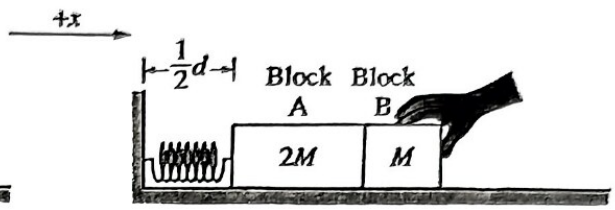

Figure 2

1. (7 points, suggested time 13 minutes)

Block A of mass $2M$ initially rests on a horizontal surface, as shown in Figure 1. One end of an ideal spring of relaxed length d and spring constant k_0 is attached to Block A. The other end of the spring is attached to a wall. Block B of mass M is pushed against Block A, compressing the spring a distance $\frac{1}{2}d$, as shown in Figure 2. The $+x$-direction is indicated above the figures, and all frictional forces are negligible.

- At time $t = t_0$, the two-block system is released from rest.
- At $t = t_1$, Block B loses contact with Block A and the spring is momentarily at relaxed length d.
- At $t = t_2$, Block A momentarily comes to rest before moving in the $-x$-direction while Block B continues to the right.
- At $t = t_3$, Block A momentarily comes to rest before moving again in the $+x$-direction while Block B continues to the right.

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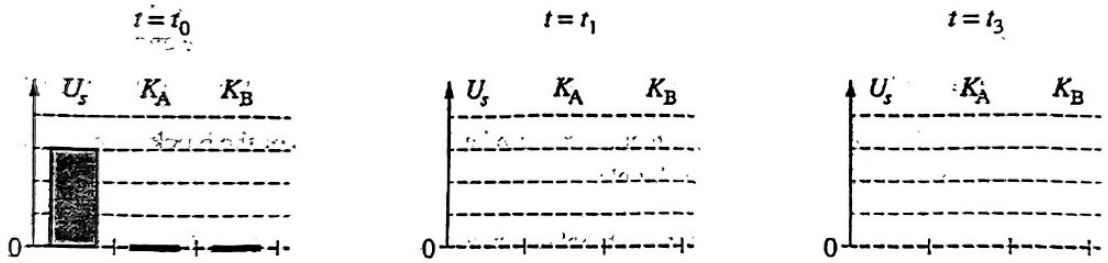
(a) Starting with Newton's second law, derive an expression for the initial acceleration of the two-block system at $t = t_0$. Express your answer in terms of M, d, k_0, and physical constants as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference book.

(b) The following energy bar charts represent the spring potential energy U_s, the kinetic energy K_A of Block A, and the kinetic energy K_B of Block B at $t = t_0$, $t = t_1$, and $t = t_3$. The energy bar chart at $t = t_0$ is complete. Draw shaded regions that represent U_s, K_A, and K_B to complete the energy bar charts for $t = t_1$ and $t = t_3$.

- Shaded regions should start at the dashed line that represents zero energy.
- Any energy that is equal to zero should be represented by a distinct line on the zero-energy line.
- The relative height of each shaded region should reflect the magnitude of the respective energy consistent with the scale shown for $t = t_0$.



(c) Will the distance the spring is compressed at $t = t_3$ be greater than, less than, or equal to the distance the spring is compressed at $t = t_0$? Briefly justify your response by referring to the energy bar charts drawn in part (b).

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Question 2

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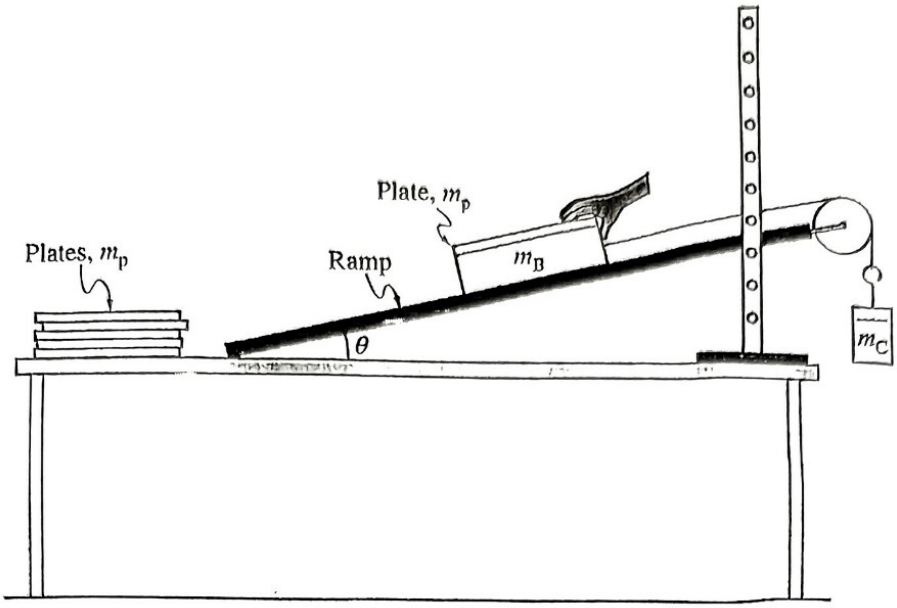

Figure 1

2. (12 points, suggested time 25 minutes)

A block of known mass m_B is held at rest on a ramp of adjustable angle θ above the horizontal, as shown in Figure 1. A string attached to the side of the block passes over a pulley that is attached to the end of the ramp. The other end of the string is attached to a cylinder of unknown mass m_C that is suspended vertically below the pulley.

A number n of rectangular plates, each of known mass m_p, can be fixed to the top of the block. The pulley has negligible mass, and all frictional forces are negligible.

One plate is attached to the top of the block, and the block-cylinder-plate system is released from rest.

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Question 2

Continue your response to **QUESTION 2** on this page.

(a) On the following dot, **draw** and label the forces (not components) exerted on the block-plate system immediately after the system has been released from rest. Each force must be represented by a distinct arrow starting on and pointing away from the dot. The dashed line indicates the same angle θ above the horizontal as that of the ramp.



(b) Starting with Newton's second law, **derive** an expression for the acceleration a of the cylinder as the block is released from rest with n plates attached and the cylinder falls toward the floor but before the cylinder hits the floor. Express your answer in terms of m_C, m_B, n, m_p, θ, and physical constants as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference book.

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Continue your response to **QUESTION 2** on this page.

(c) A student conducts an experiment using the setup shown to determine the mass m_C of the cylinder. The student has access to equipment found in a standard physics classroom but has no way (no scale or balance) to directly measure mass. Design a procedure that would allow the student to calculate m_C. During this experiment, the angle of the ramp θ is fixed at an unknown value between 0° and 45°.

In the first column of the following table, list the quantities that would be measured in your experiment. In the next two columns, define a symbol to represent each quantity, and list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them in the space just below the table.

In the space below the table, **describe** the overall procedure to determine m_C. 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 to Be Measured	Symbol for Quantity	Equipment for Measurement

Procedure (and diagram, if needed)

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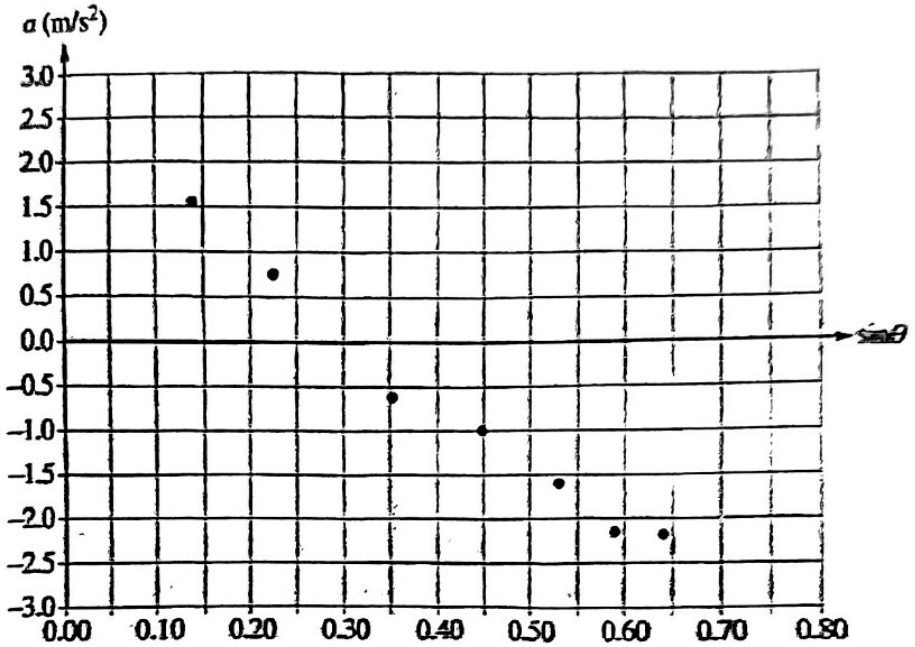
Continue your response to QUESTION 2 on this page.

(d) In a different experiment, a student is investigating how the angle of the ramp affects the acceleration of the cylinder when there are no plates on the block. The data the student collected for the acceleration a of the cylinder are plotted in the following graph as a function of $\sin\theta$.



i. On the graph, draw a best-fit line for the data.

ii. Calculate the slope of your best-fit line.

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Question 3

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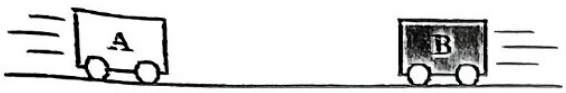

Figure 1



Figure 2

3. (12 points, suggested time 25 minutes)

Carts A and B initially move toward each other at constant speeds along a straight, horizontal track, as shown in Figure 1. Cart A is initially moving to the right, and Cart B is initially moving to the left. Cart A is initially moving more slowly than Cart B. The carts collide and stick together. After the collision, the carts move together to the right, as shown in Figure 2.

(a) Indicate which cart, if either, has the greater mass.

_____ Cart A _____ Cart B _____ The carts have the same mass.

Briefly justify your answer using qualitative reasoning beyond referencing equations.

(b) Cart A has mass m_A and initial speed v_A. Cart B has mass m_B and initial speed v_B. Starting with conservation of momentum, derive an equation for the velocity v_f of the two-cart system after the collision. Express your answer in terms of m_A, m_B, v_A, v_B, and physical constants as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference book.

(c) Indicate whether the equation you derived in part (b) agrees with your reasoning in part (a).

Explain your reasoning.

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Question 3

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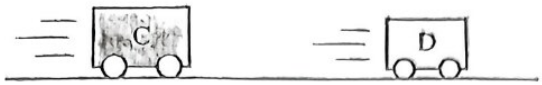
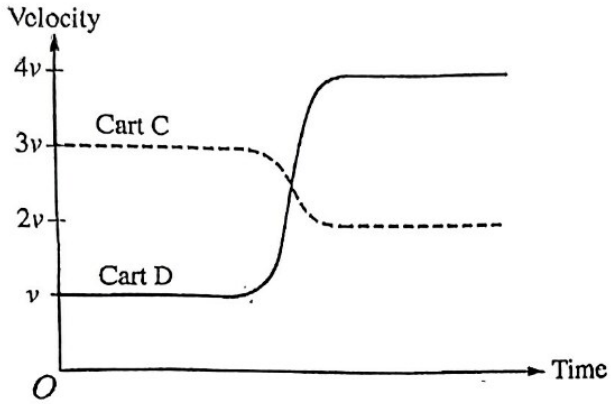


Figure 3

(d) In a different scenario, Cart C of mass $3M$ and initial velocity $3v$ moves along a straight, horizontal track toward Cart D of mass M and initial velocity v, as shown in Figure 3. The carts eventually collide. The following graph shows the velocity as a function of time for the two carts before and after the collision.



i. The sum of the kinetic energies of the two carts before the collision is K_i, and the sum of the kinetic energies of the two carts after the collision is K_f. **Indicate** whether K_f is greater than, less than, or equal to K_i.

_____ $K_f > K_i$ _____ $K_f < K_i$ _____ $K_f = K_i$

Calculate the initial and final kinetic energies, using evidence from the graph to support your answer.

ii. Briefly **justify** whether the collision is elastic or inelastic.

iii. Briefly **justify** why the magnitude of the impulse exerted on Cart C during the collision is the same as the magnitude of the impulse exerted on Cart D during the collision.

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Question 4

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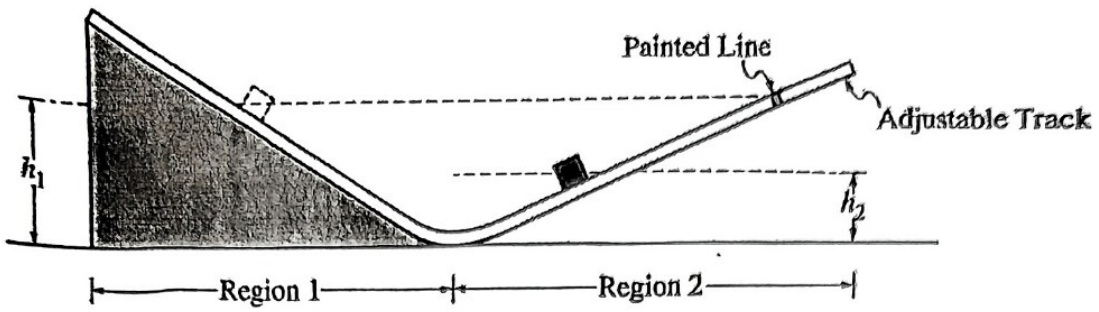

Figure 1

4. (7 points, suggested time 13 minutes)

Figure 1 shows a track with a rough surface on which a box can slide.

- In Region 1 the angle of incline of the track is fixed.
- In Region 2 the angle of incline of the track can be changed.

A box is released from rest in Region 1 at a height h_1 from the bottom of the track, as shown in Figure 1. The coefficient of kinetic friction between the box and the track is μ_k. The box slides down the track in Region 1, slides up the track in Region 2, and momentarily comes to rest at a height h_2, which is lower than h_1. There is a painted line on the track in Region 2. The painted line is initially at a height of h_1.

(a) **Explain** why the box does not reach the painted line.

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Question 4

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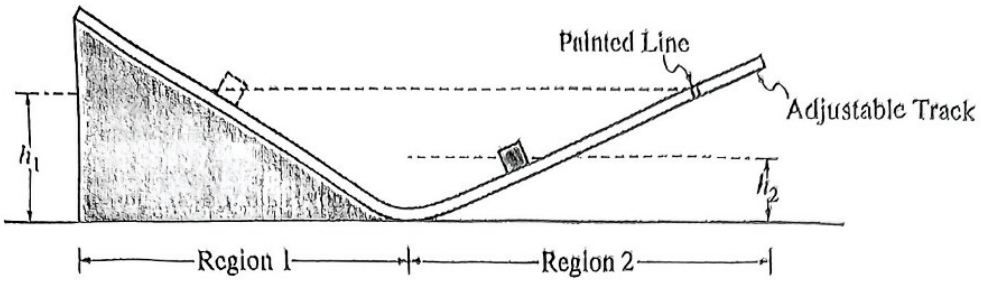

Figure 1

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(a) Explain why the box does not reach the painted line.

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Question 5

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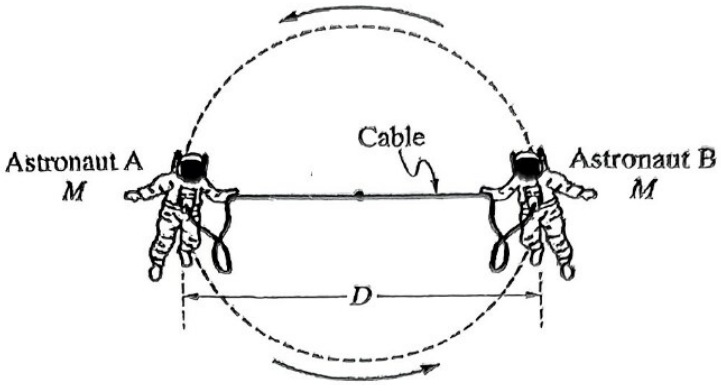

Figure 1

5. (7 points, suggested time 13 minutes)

Astronauts A and B, each of mass M, hold on to a lightweight cable, as shown in Figure 1. The centers of mass of the astronauts are separated by a distance D. The system consisting of the two astronauts and cable rotates counterclockwise about the center of mass of the system, as indicated by the curved arrows. At the instant shown, the astronauts are each moving with speed v. Gravitational forces are negligible.

(a) Starting with Newton's second law, **derive** an expression for the magnitude of the tension force exerted by the cable on each astronaut. Express your answer in terms of M, D, v, and physical constants as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference book.

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(b) The system initially has angular momentum L_i. The astronauts loosen their hold on the cable, causing the distance between their individual centers of mass to increase to $2D$. The final angular momentum of the system is L_f.

i. **Indicate** which of the following correctly relates L_f to L_i.

_____ $L_f > L_i$ _____ $L_f < L_i$ _____ $L_f = L_i$

Briefly **justify** your answer.

ii. The rotational inertia I of the two-astronaut system is $2Mr^2$, where r is the distance each astronaut is from the center of mass of the system. Initially, when the astronauts are distance D apart, the astronauts rotate with angular speed ω_i. **Derive** an expression for the final angular speed ω_f for when the astronauts are $2D$ apart. Express your answer in terms of the initial angular speed ω_i and physical constants as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference book.

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Question 5

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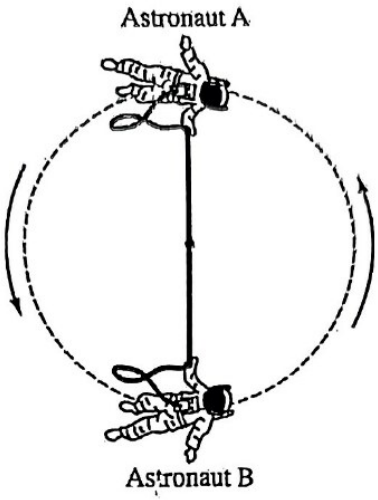

Figure 2

The astronauts consider what would happen if the cable between their respective hands were to break while the system continued to rotate counterclockwise about its center of mass.

(c) If the cable were to break at the instant shown in Figure 2, briefly **describe** the resulting motion of Astronaut A.

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