

PHYSICS C: MECHANICS

SECTION I

Time—45 minutes

35 Questions

Directions: Each of the questions or incomplete statements below is followed by five 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 car traveling at 20 m/s along a straight road passes a road sign at time $t = 0$. At time $t = 1$ s, the car accelerates at -6 m/s^2 . Which of the following is closest to the speed of the car after it has traveled 50 m past the road sign?

- (A) 2 m/s
- (B) 6 m/s
- (C) 10 m/s
- (D) 14 m/s
- (E) The car comes to a stop before reaching a point 50 m past the road sign.

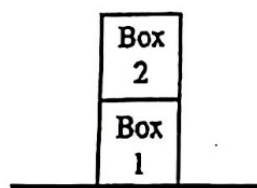


Figure 1

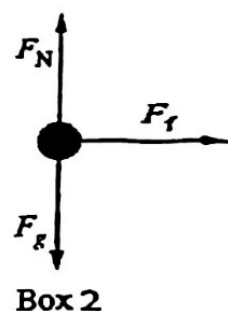


Figure 2

2. Box 1 is in contact with the ground and Box 2 is on top of Box 1. Boxes 1 and 2 are initially at rest, as shown in Figure 1. An external force is then exerted on Box 1. Figure 2 shows the free-body diagram for Box 2 while the external force is exerted on Box 1. The forces exerted on Box 1 are not shown. Which of the following could describe the motion of the boxes?
- (A) The boxes move together to the left with the same acceleration.
 - (B) The boxes move together to the right with the same acceleration.
 - (C) The boxes move together to the left with the same constant speed.
 - (D) The boxes move together to the right with the same constant speed.
 - (E) Box 1 is accelerating to the right while Box 2 is accelerating to the left.

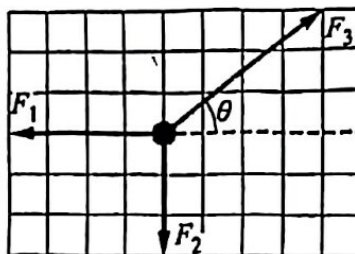
3. A 0.9 kg cart is at position $x = 0$ and moves with initial velocity 1.5 m/s. A force exerted on the cart is given by

$F(x) = (2.0 \text{ N/m}^3)x^3 + (1.2 \text{ N/m}^2)x^2$, where x is the position of the cart. What is the change in kinetic energy of the cart when the cart has moved from $x = 0$ to position $x = 1.0 \text{ m}$?

- (A) 0.11 J
- (B) 0.90 J
- (C) 1.0 J
- (D) 1.9 J
- (E) 3.2 J

4. A person jumps vertically upward. The floor exerts a force F_N on the person, and Earth exerts a force F_g on the person. Which of the following correctly compares F_N and F_g while the person is in contact with the floor and accelerating upward?

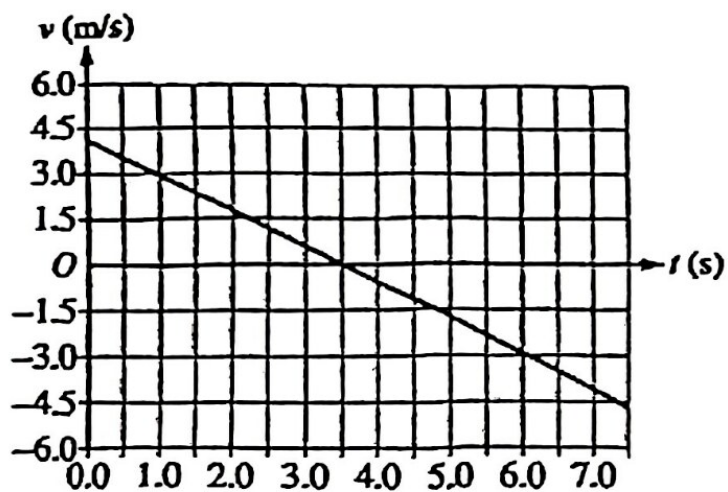
- (A) $F_N > F_g$ because the person is moving upward.
- (B) $F_N > F_g$ because the person is accelerating upward.
- (C) $F_N = F_g$ because the forces are a Newton's third law action-reaction pair.
- (D) $F_N = F_g$ because the force of gravity and the normal force acting on an object are always equal.
- (E) $F_N < F_g$ because the person will come back down after jumping.



5. Three forces are exerted on an object in equilibrium, as shown. The magnitudes of F_1 and F_2 and the angle θ can be changed. The magnitude of F_3 remains constant. Which of the following changes, if any, to F_1 and F_2 would keep the object in equilibrium as θ increases to 90° ?

	F_1	F_2
A	Increases	Increases
B	Decreases	Increases
C	Increases	Decreases
D	Remains constant	Increases
E	Decreases	Remains constant

- (A) A
(B) B
(C) C
(D) D
(E) E



6. The graph shows the velocity as a function of time for an object moving along the x -axis. Which of the following equations could correctly represent the motion of the object?

(A) $x = 4.0 - 0.57t$

(B) $x = -4.0t + 1.15t^2$

(C) $x = 4.0 - 1.15t$

(D) $x = 1.5 - 4.0t + 0.57t^2$

(E) $x = -1.5 + 4.0t - 0.57t^2$



Figure 1

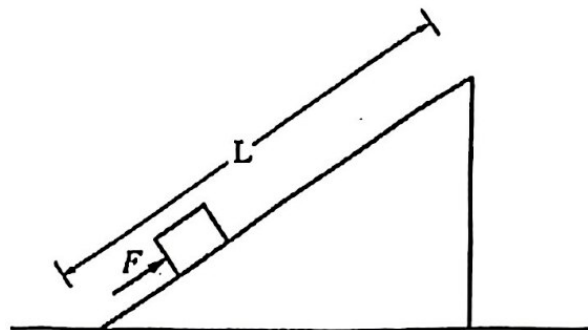
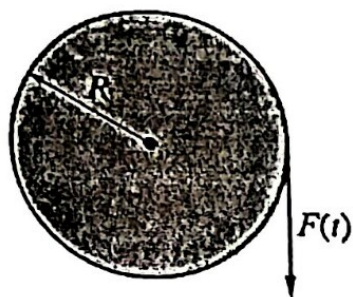


Figure 2

7. A block is pushed from rest by a force of magnitude F a distance L along an inclined ramp, as shown in Figure 1. The block leaves the end of the ramp and reaches the ground to the right of the ramp with speed v_1 .

The ramp is now raised to a greater angle with the horizontal, and the block is again pushed from rest by a force of magnitude F a distance L , as shown in Figure 2. The block leaves the end of the ramp and reaches the ground to the right of the ramp with speed v_2 . Frictional forces are negligible. Which of the following correctly compares v_1 and v_2 ?

- (A) $v_1 > v_2$
- (B) $v_1 = v_2$
- (C) $v_1 < v_2$
- (D) The speeds cannot be compared without knowing the angles of incline for the ramp.
- (E) The speeds cannot be compared without knowing the mass of the block.

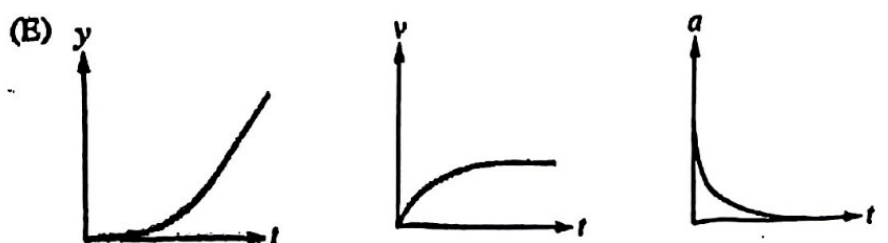
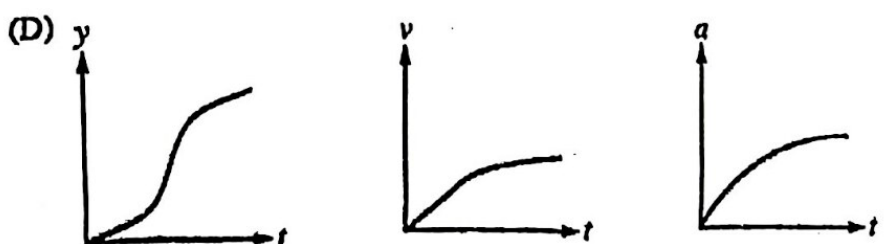
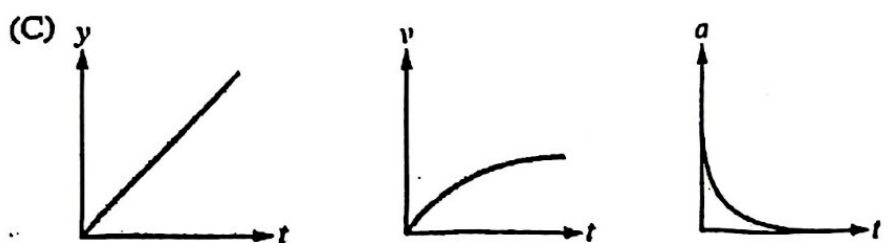
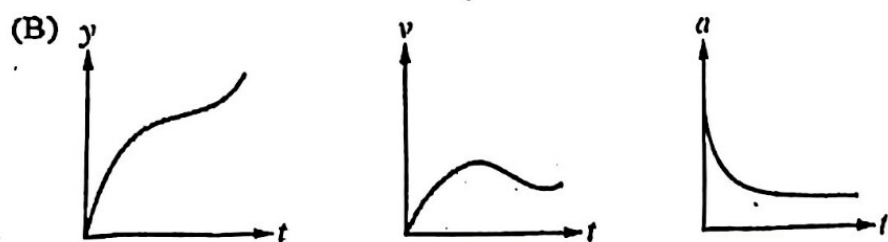
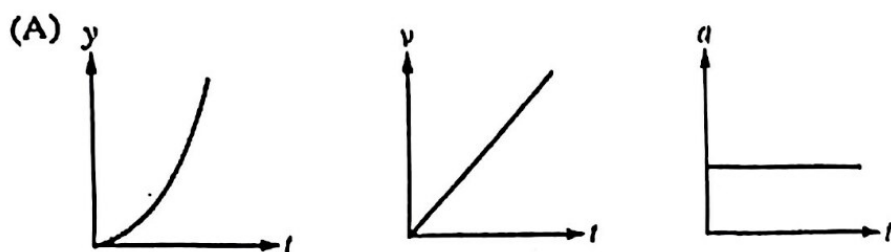


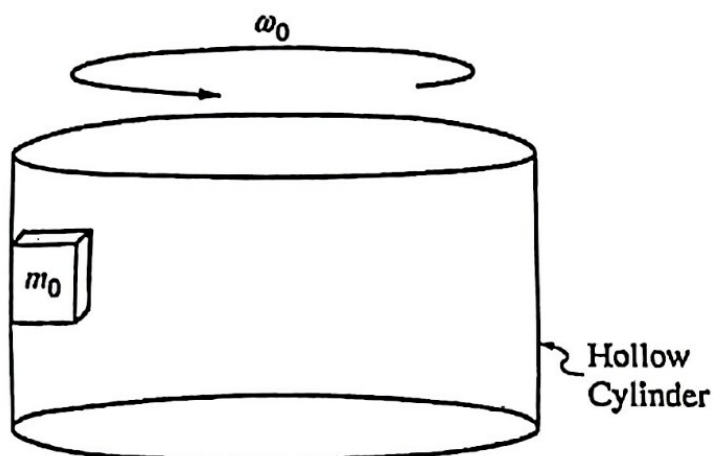
Top View

8. A disk of mass M and radius R is rotating clockwise about its center. At time $t = t_0$, the disk has angular momentum L_0 and a force is applied tangent to the edge of the disk, as shown in the top view. The magnitude of the force is modeled by $F(t) = At^2$, where A is a positive constant with appropriate units. What is the magnitude of the angular momentum of the disk at a later time $t = t_1$?

- (A) $A\left(\frac{t_1^3}{3}\right) - L_0$
- (B) $A\left(\frac{t_1^3 - t_0^3}{3}\right) + L_0$
- (C) $AR\left(\frac{t_1^3 - t_0^3}{3}\right)$
- (D) $AR\left(\frac{t_1^3}{3}\right) - L_0$
- (E) $AR\left(\frac{t_1^3 - t_0^3}{3}\right) + L_0$

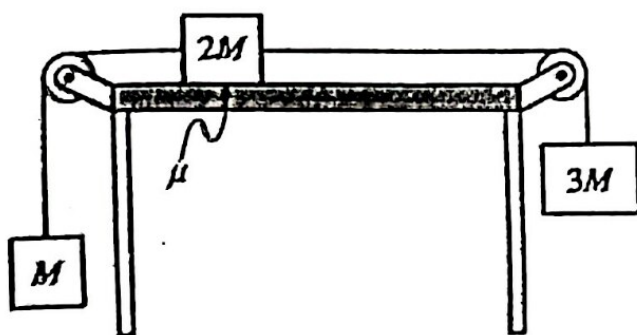
9. A sphere is dropped near the surface of Earth. While falling, the sphere reaches terminal velocity. Which of the following sets of graphs correctly shows the magnitudes of the position y , velocity v , and acceleration a of the sphere as functions of time t as the sphere is falling?





10. A block of mass m_0 is in contact with the inner wall of a hollow cylinder and does not slip as the cylinder rotates with angular speed ω_0 , as shown. The minimum coefficient of static friction necessary to prevent the block from slipping is μ_0 . What minimum coefficient of static friction μ is necessary to prevent a block of mass $2m_0$ from slipping when the cylinder rotates with angular speed $2\omega_0$?

- (A) $\mu = \frac{1}{4}\mu_0$
- (B) $\mu = \frac{1}{2}\mu_0$
- (C) $\mu = \mu_0$
- (D) $\mu = 2\mu_0$
- (E) $\mu = 4\mu_0$



11. Three blocks of masses M , $2M$, and $3M$ are connected by strings across two pulleys, as shown. The strings and pulleys have negligible mass. The $2M$ block is at rest on a rough horizontal surface. The coefficient of kinetic friction between the $2M$ block and the surface is μ . The blocks are released from rest and then accelerate. Which of the following equations represents the acceleration a of the blocks?

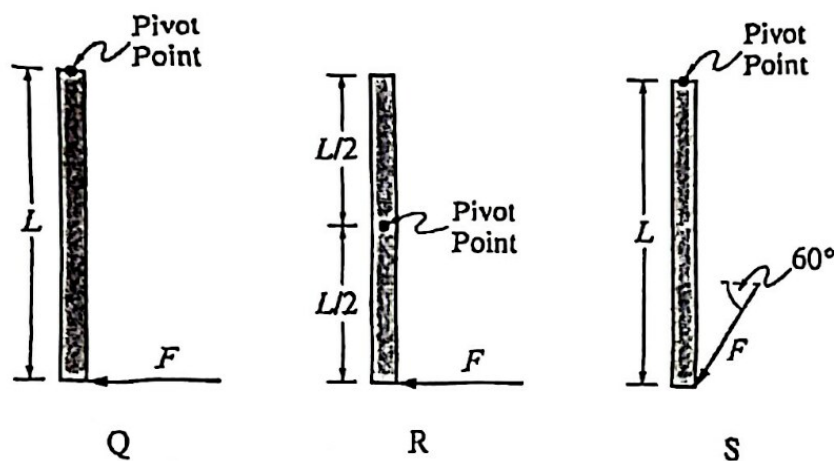
(A) $a = \frac{(2 - \mu)}{3} g$

(B) $a = \frac{(1 - \mu)}{6} g$

(C) $a = \frac{(2 - \mu)}{6} g$

(D) $a = \frac{(1 - \mu)}{3} g$

(E) $a = (1 - \mu)g$



12. Uniform bars Q, R, and S, each of mass M and length L , can rotate with negligible friction about the fixed pivot points shown in the figure. At time $t = t_0$, a force of magnitude F is exerted on each bar at the angle and point of contact shown. The torques exerted on the bars Q, R, and S are τ_Q , τ_R , and τ_S , respectively. The angular accelerations of bars Q, R, and S are α_Q , α_R , and α_S , respectively. Which of the following correctly ranks the magnitudes of these quantities at $t = t_0$?

	Torque (τ)	Angular Acceleration (α)
A	$\tau_Q = \tau_R = \tau_S$	$\alpha_Q = \alpha_R = \alpha_S$
B	$\tau_Q > \tau_R > \tau_S$	$\alpha_Q > \alpha_R > \alpha_S$
C	$\tau_Q > (\tau_R = \tau_S)$	$\alpha_Q > (\alpha_R = \alpha_S)$
D	$\tau_Q > (\tau_R = \tau_S)$	$\alpha_R > \alpha_Q > \alpha_S$
E	$\tau_Q > \tau_R > \tau_S$	$\alpha_R > \alpha_Q > \alpha_S$

- (A) A
(B) B
(C) C
(D) D
(E) E

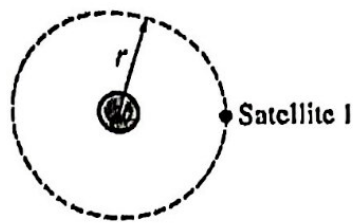


Figure 1

Note: Figure 1 not drawn to scale.

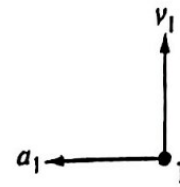
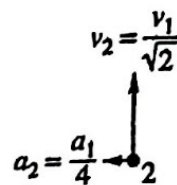
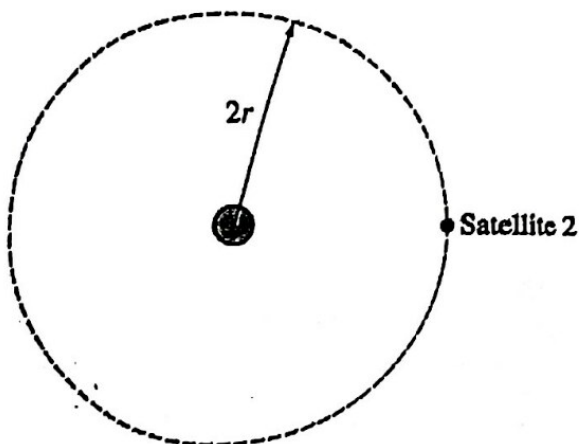


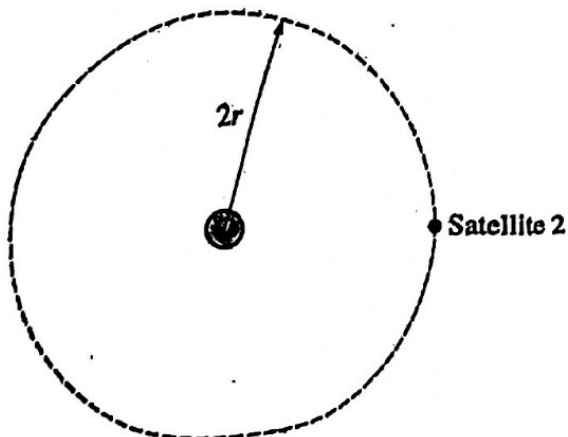
Figure 2

13. Satellite 1 is at the position shown in Figure 1 while traveling in a circular orbit of radius r around a planet. The velocity and acceleration of Satellite 1 are represented by the vectors v_1 and a_1 , respectively, shown in Figure 2. Satellite 2 is in a circular orbit around the same planet with velocity and acceleration vectors v_2 and a_2 , respectively. Which of the following shows a correct pair of orbital and vector diagrams for Satellite 2?

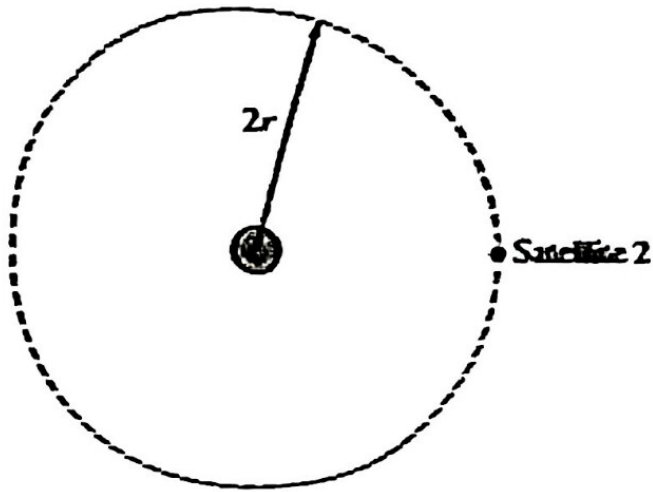
(A)



(B)



9



$$r_2 = \sqrt{2}r_1$$

$$a_2 = \frac{a_1}{4}$$

(D)



$$r_2 = \frac{r_1}{\sqrt{2}}$$

$$a_2 = \frac{a_1}{4}$$

(E)



$$r_2 = 2r_1$$

$$a_2 = 2a_1$$

14. A pendulum is made of a sphere attached to a thin rod of length L . The pendulum is suspended from a pivot point opposite the sphere. The diameter of the sphere is small in comparison with L . The pendulum is released and oscillates.

Which of the following could explain why the measured period of the pendulum is smaller

than $2\pi\sqrt{\frac{L}{g}}$?

- (A) The density of the rod decreases from the pivot point to the free end of the rod.
- (B) The rod was given an initial velocity when released.
- (C) Air resistance acting on the pendulum is nonnegligible.
- (D) Friction at the pivot point is nonnegligible.
- (E) The experiment is done at a high altitude.

Time	Position (x, y)
0 s	(4 m, 10 m)
1 s	(6 m, 6 m)
2 s	(8 m, 3 m)
3 s	(10 m, 1 m)
4 s	(12 m, 0 m)

15. The table shows the position of an object on an xy -coordinate plane at each second during the time interval $0 \leq t \leq 4$ s. Which of the following is a correct claim about the x - or y -component of the object's acceleration, a_x or a_y , respectively, and provides correct justification using the object's position?

	Claim	Justification
A	$a_x > 0$	The x -position is always positive.
B	$a_x > 0$	The x -position is always positive and always increasing.
C	$a_y < 0$	The y -position is always decreasing.
D	$a_y > 0$	The y -position is always positive.
E	$a_y > 0$	The y -position is positive and decreases at a decreasing rate.

- (A) A
(B) B
(C) C
(D) D
(E) E

16. A pendulum is made by attaching Sphere A of mass m to a rigid rod of length L and negligible mass. The pendulum is held at rest horizontally. The pendulum is released from rest. At the bottom of the swing, Sphere A collides with an identical Sphere B. Spheres A and B stick together and continue to move upward. Which of the following is a correct expression for the velocity of the spheres immediately after the collision?

- (A) $\sqrt{2gL}$
- (B) $\frac{\sqrt{2gL}}{2}$
- (C) $2\sqrt{gL}$
- (D) $\frac{gL}{4}$
- (E) $2gL$

17. A block of mass M rests on a horizontal surface. Frictional forces between the block and the surface are negligible. The block is attached to a spring that exerts a force of magnitude $F(x) = kx^2$, where k is a positive constant with appropriate units and x is the displacement from equilibrium. The block reaches a maximum speed v when released from a compression distance $x = D$. What is the maximum speed of the block if $x = 2D$?

- (A) $\sqrt{2}v$
- (B) $2v$
- (C) $4v$
- (D) $\sqrt{8}v$
- (E) $8v$

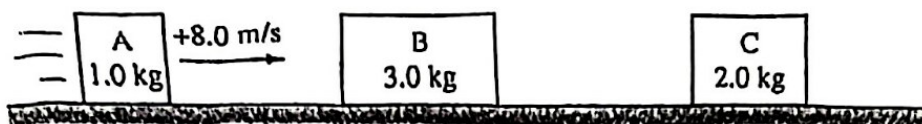


Figure 1

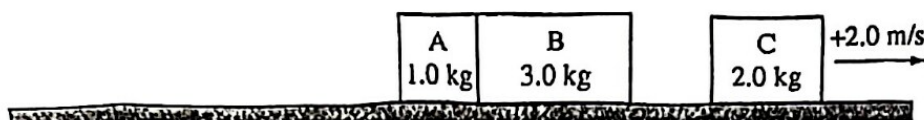
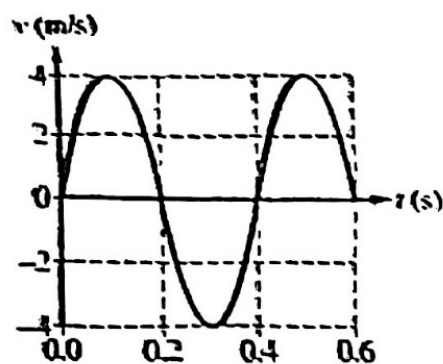


Figure 2

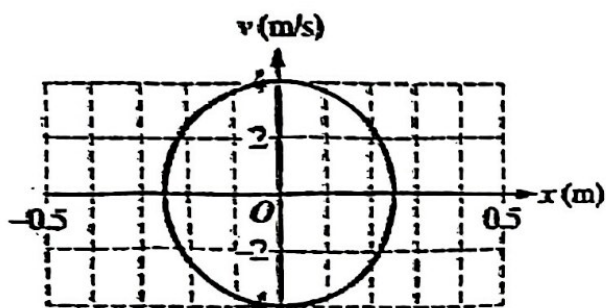
18. Blocks A, B, and C with masses 1.0 kg, 3.0 kg, and 2.0 kg, respectively, are on a level floor. There is negligible friction between the blocks and the floor. Block A moves at +8.0 m/s, while blocks B and C are at rest, as shown in Figure 1. Block A collides with and sticks to Block B. Blocks A and B then collide with but do not stick to Block C. After the collision, Block C moves at +2.0 m/s, as shown in Figure 2. What is the velocity of blocks A and B after they collide with Block C?

- (A) -3.7 m/s
- (B) -1.4 m/s
- (C) -1.0 m/s
- (D) $+1.0 \text{ m/s}$
- (E) $+1.4 \text{ m/s}$

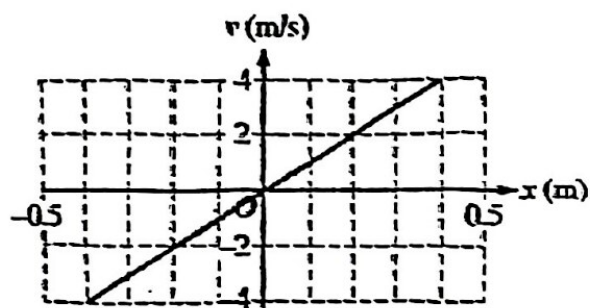


19. An ideal spring-block system oscillates in one-dimensional motion. A motion sensor records the velocity v of the block as a function of time t , as shown. Which of the following graphs best illustrates how the velocity v of the block varies as a function of position x ?

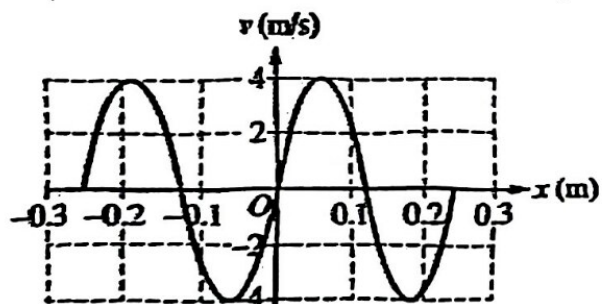
(A)



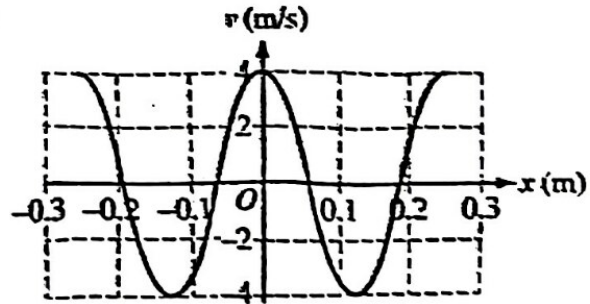
(B)



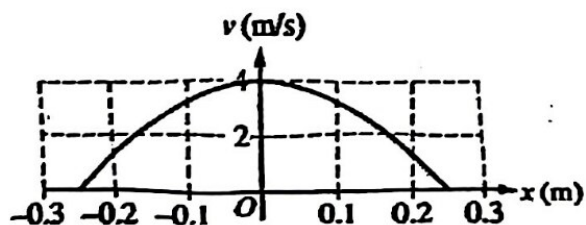
(C)



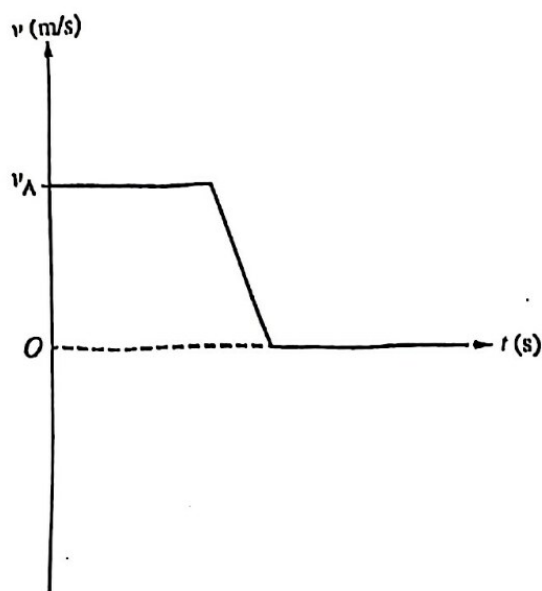
(D)



(E)



Velocity of Cart A



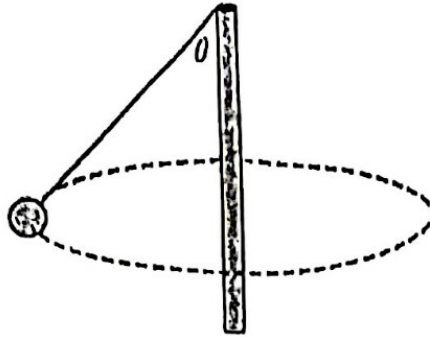
20. Cart A of mass m_A moves with an initial velocity v_A and then collides elastically with Cart B. The velocity of Cart A as a function of time is shown in the graph. Which of the following correctly describes the mass and initial velocity of Cart B, m_B and v_B , respectively?

	Mass	Velocity
A	$m_B < m_A$	$v_B = 0$
B	$m_B = m_A$	$v_B = 0$
C	$m_B > m_A$	$v_B = 0$
D	$m_B = m_A$	$v_B = -v_A$
E	$m_B > m_A$	$v_B = -v_A$

- (A) A
(B) B
(C) C
(D) D
(E) E

21. An object is launched at an angle of 45° above the horizontal with a speed of 10 m/s. Which of the following is most nearly the height of the object when the object is a horizontal distance of 10 m from the launch site? Air resistance is negligible.

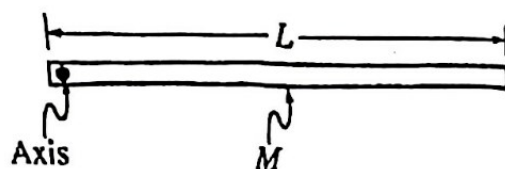
- (A) 0 m
(B) 5 m
(C) 10 m
(D) 15 m
(E) 20 m



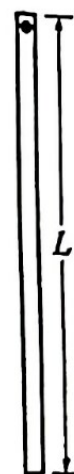
22. A sphere is connected to a vertical pole by a string of negligible mass, as shown. The sphere travels in a horizontal circular path around the pole. The angle between the string and the pole is initially θ . A resistive force is exerted on the sphere that opposes the motion of the sphere. Which of the following correctly predicts and justifies the effect of the resistive force on θ ?

	Effect on θ	Justification
A	θ increases	The tension in the string increases.
B	θ increases	The speed of the sphere decreases.
C	θ decreases	The tension in the string increases.
D	θ decreases	The speed of the sphere decreases.
E	θ remains constant	There is no relationship between the resistive force and θ .

- (A) A
(B) B
(C) C
(D) D
(E) E



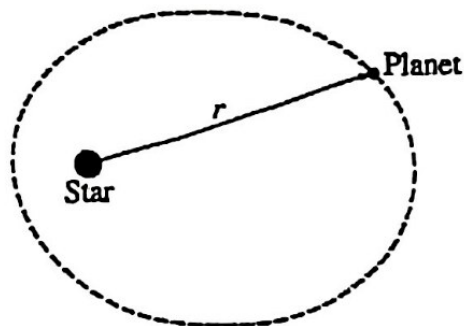
$t = t_1$
Figure 1



$t = t_2$
Figure 2

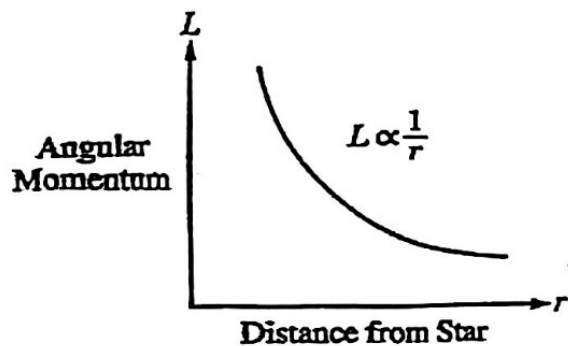
23. A uniform rod of mass M and length L is free to rotate about a fixed axis about one end. The rod is held horizontally, as shown in Figure 1, released, and swings in the vertical plane. Time t_1 is immediately after the rod is released, and time t_2 is the time when the rod passes through the vertical, as shown in Figure 2. If the procedure is repeated with a rod of the same mass but greater length, which of the following quantities decreases?

- (A) Torque exerted on the rod at t_1
- (B) Angular acceleration at t_1
- (C) Angular momentum of the rod at t_2
- (D) Rotational kinetic energy of the rod at t_2
- (E) Tangential speed of the free end of the rod at t_2

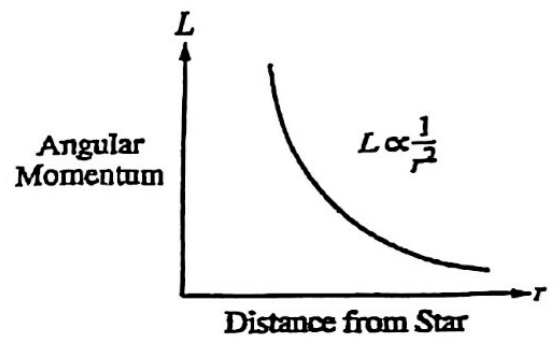


24. A planet orbits a star in an elliptical path, as shown. Which of the following correctly graphs the magnitude of the angular momentum L of the planet about the star as a function of the planet's distance r from the star?

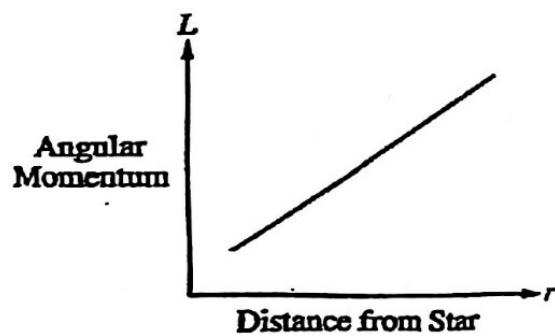
(A)



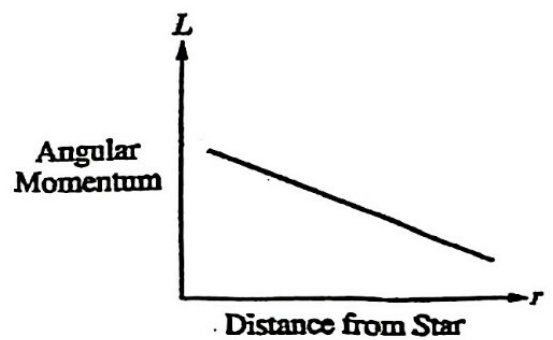
(B)



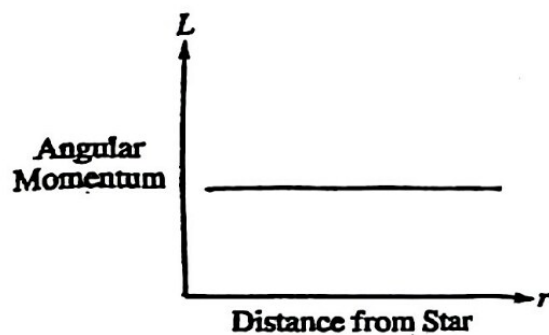
(C)

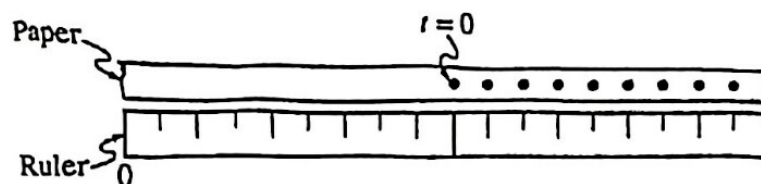


(D)

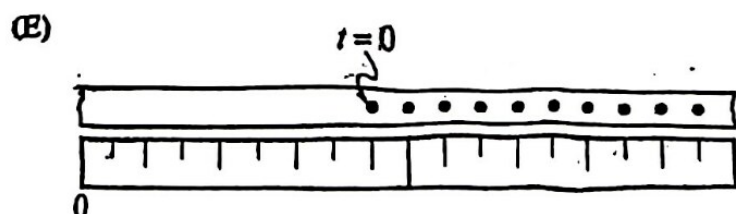
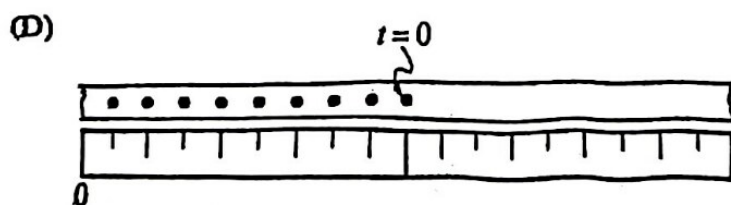
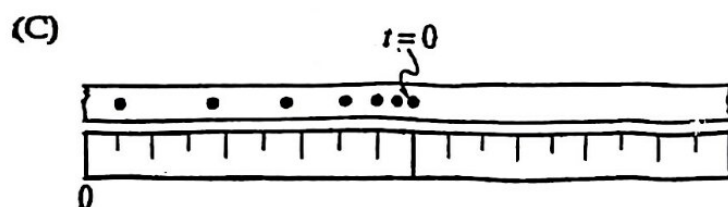
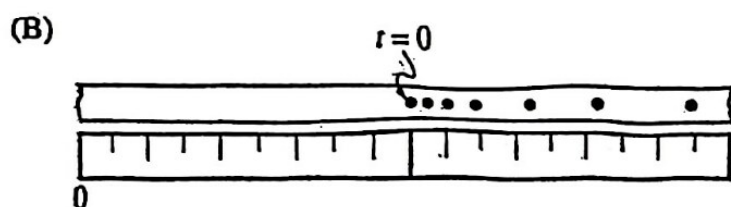
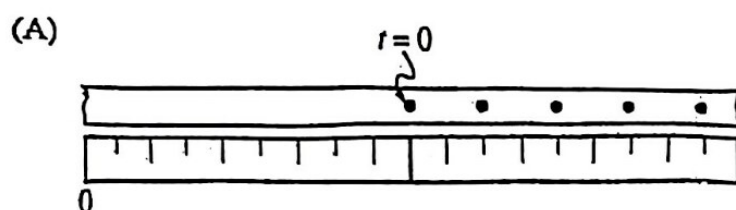


(E)



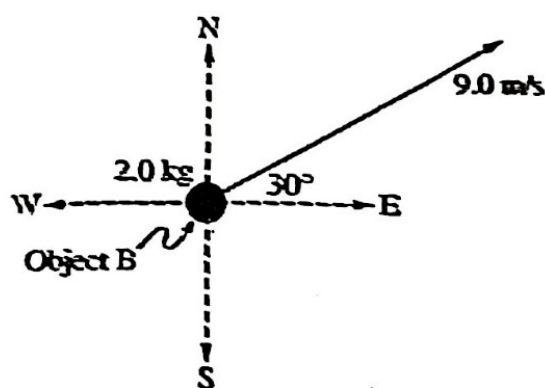
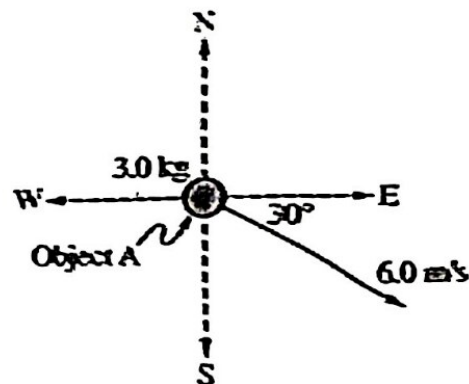


25. The position of an object is marked at regular time intervals on a thin strip of paper, which is then placed above a ruler, as shown. The position of the object is modeled by the equation $x = A + Bt + Ct^2$, where A , B , and C are constants with appropriate units. The positive direction is to the right. If the motion of the object is changed such that the position of the object is modeled by the equation $x = A - Bt + Ct^2$, which of the following could represent the position of the object at regular time intervals?



26. A student is performing an experiment to determine the power delivered to a block that is pulled at a constant speed across a surface by an external force. There is friction between the block and surface. Which of the following sets of equipment and corresponding measurements would allow the student to determine the power delivered to the block by the external force?

- (A) A force sensor to measure the applied force, a stopwatch to measure time, and a scale to measure the mass of the block
- (B) A stopwatch to measure time and a motion sensor to measure speed
- (C) A motion sensor to measure speed, a stopwatch to measure time, and a meterstick to measure distance
- (D) A force sensor to measure the applied force and a motion sensor to measure speed
- (E) A force sensor to measure the applied force, a scale to measure the mass of the block, and a meterstick to measure distance



Note: Figures not drawn to scale.

27. Object A of mass 3.0 kg moves with velocity 6.0 m/s directed 30° south of east, as shown. In the same plane, Object B of mass 2.0 kg moves with velocity 9.0 m/s directed 30° north of east, as shown. The objects then collide and stick together. Which of the following best approximates the velocity of the objects after the collision?

- (A) Zero
- (B) 6.2 m/s directed east
- (C) 7.2 m/s directed east
- (D) 13 m/s directed 7° north of east
- (E) 31 m/s directed east

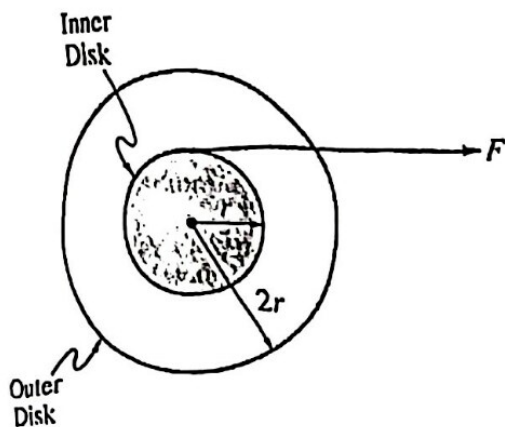


Figure 1

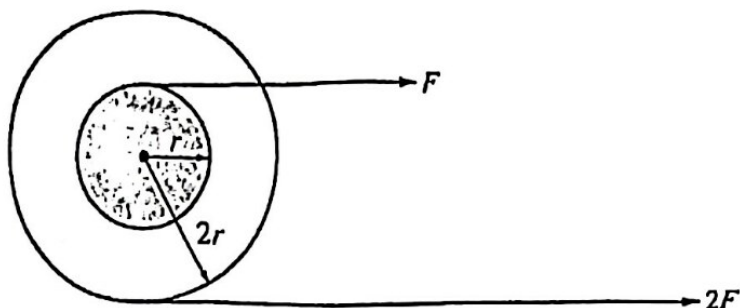
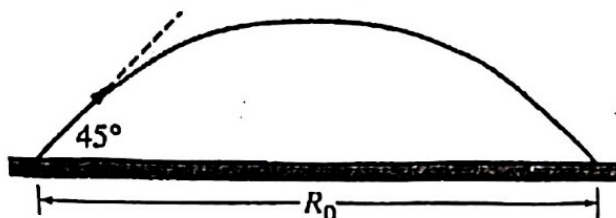


Figure 2

28. A pulley consists of an inner disk of radius r and an outer disk of radius $2r$. The pulley can rotate about an axle perpendicular to the plane of the page. In an experiment, a force of magnitude F is exerted tangent to the edge of the inner disk, as shown in Figure 1, for a time Δt . The experiment is repeated but an additional force of magnitude $2F$ is exerted tangent to the edge of the outer disk, as shown in Figure 2, for the same time Δt . The magnitudes of the changes in the angular momentum of the pulley in figures 1 and 2 are ΔL_1 and ΔL_2 , respectively. Which of the following correctly relates ΔL_2 and ΔL_1 ?

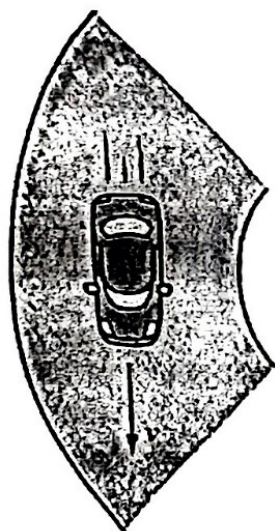
- (A) $\Delta L_2 = \frac{1}{3} \Delta L_1$
- (B) $\Delta L_2 = \frac{1}{2} \Delta L_1$
- (C) $\Delta L_2 = \Delta L_1$
- (D) $\Delta L_2 = 2\Delta L_1$
- (E) $\Delta L_2 = 3\Delta L_1$



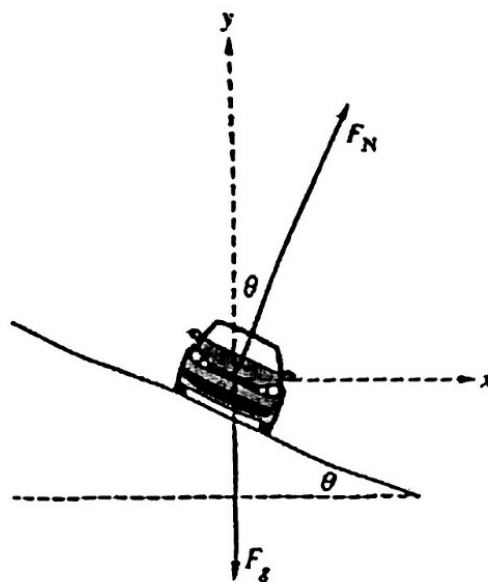
29. An object is launched at an angle of 45° above the horizontal across level ground. The horizontal displacement R_0 of the object is measured, as shown. Air resistance is negligible. The launch angle is increased, and the object is launched again with the same initial speed. The new horizontal displacement R_{new} of the object is measured. Which of the following correctly compares R_0 and R_{new} and provides valid justification?

	Displacement	Supporting Claim
A	$R_0 > R_{\text{new}}$	The object would hit the ground after a shorter time.
B	$R_0 > R_{\text{new}}$	The horizontal component of the object's initial speed would be smaller.
C	$R_0 < R_{\text{new}}$	The object would hit the ground after a longer time.
D	$R_0 < R_{\text{new}}$	The initial kinetic energy of the object would be greater.
E	$R_0 = R_{\text{new}}$	The initial kinetic energy of the object would be unchanged.

- (A) A
(B) B
(C) C
(D) D
(E) E



Top View



Front View

30. A car travels with a constant speed v along a circular road, as shown in the Top View. The circular road has radius r . The road is banked at an angle θ with respect to the x -axis. The normal force F_N and the gravitational force F_g exerted on the car are shown in the Front View. At what angle θ should the road be banked so that no frictional force between the car and road is required to keep the car from slipping?

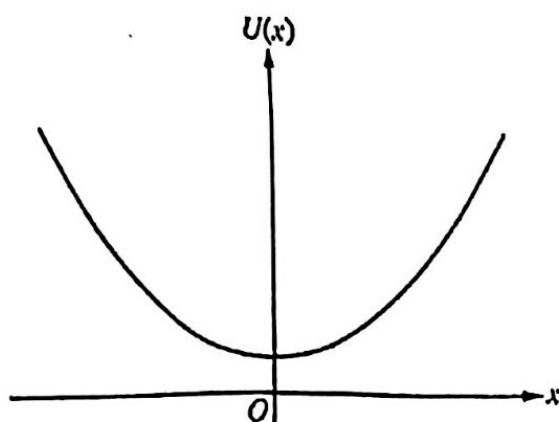
(A) $\sin^{-1}\left(\frac{v^2}{rg}\right)$

(B) $\sin^{-1}\left(\frac{rg}{v^2}\right)$

(C) $\tan^{-1}\left(\frac{v^2}{rg}\right)$

(D) $\tan^{-1}\left(\frac{rg}{v^2}\right)$

(E) $\tan^{-1}\left(\frac{v}{\sqrt{rg}}\right)$



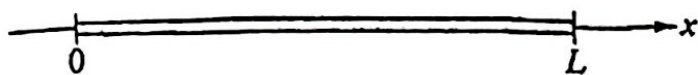
31. The potential energy $U(x)$ of a system varies with the position x of an object in the system. The potential energy, as shown in the graph, is described by $U(x) = Ax^2 + B$, where A and B are positive constants with appropriate units. There are no external forces acting on the system. Which of the following gives the correct magnitude and direction of the x -component of the net force on the object when it is at position x_0 , where $x_0 > 0$?

32. The magnitude of the gravitational force between two planets is $F = \frac{A}{r^2}$, where $A = 3.2 \times 10^{37} \text{ N}\cdot\text{m}^2$. How much work would be done by the gravitational force if the planets moved from $r = 4.0 \times 10^9 \text{ m}$ apart to $r = 3.0 \times 10^9 \text{ m}$ apart?

- (A) $1.6 \times 10^{18} \text{ J}$
 (B) $2.0 \times 10^{27} \text{ J}$
 (C) $2.7 \times 10^{27} \text{ J}$
 (D) $3.6 \times 10^{27} \text{ J}$
 (E) $1.9 \times 10^{28} \text{ J}$

	Magnitude	Direction
A	$\frac{1}{3}Ax_0^3 + Bx_0$	$+x$
B	$\frac{1}{3}Ax_0^3 + Bx_0$	$-x$
C	$Ax_0^2 + B$	$-x$
D	$2Ax_0$	$+x$
E	$2Ax_0$	$-x$

- (A) A
 (B) B
 (C) C
 (D) D
 (E) E



33. A thin rod of length L is positioned on the x -axis, as shown. The rod has a linear mass density of $\lambda(x) = Ax^2$, where x is position and A is a positive constant with appropriate units. At what position is the center of mass of the rod located?

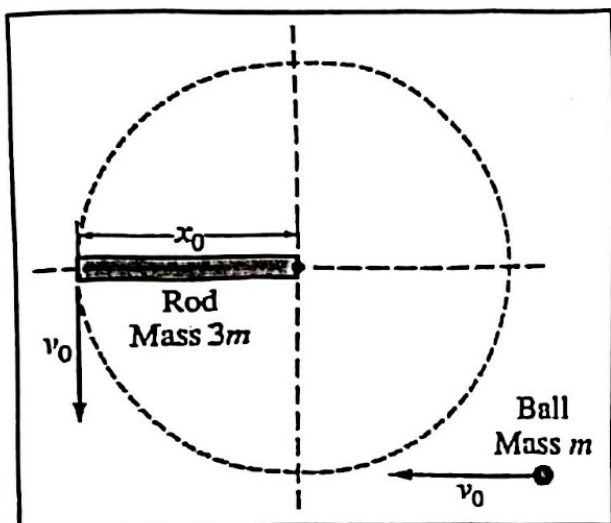
(A) $x = \frac{1}{4}L$

(B) $x = \frac{1}{2}L$

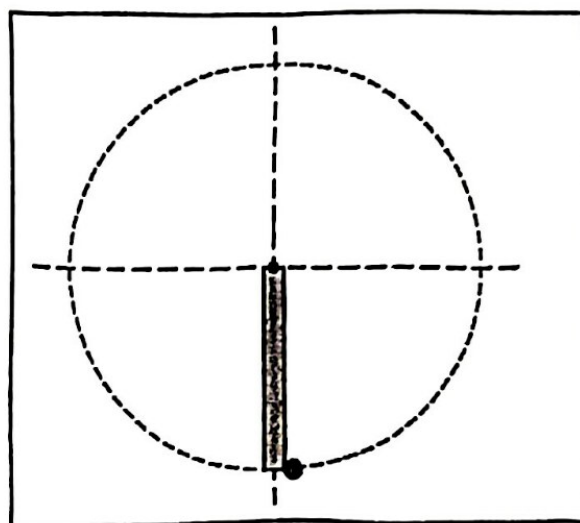
(C) $x = \frac{2}{3}L$

(D) $x = \frac{3}{4}L$

(E) $x = \frac{4}{5}L$



Top View
Figure 1



Top View
Figure 2

34. A uniform rod of mass $M = 3m$ and length $L = x_0$ is rotating in the counterclockwise direction on a horizontal table about a pivot at one end. The free end of the rod has speed v_0 . A ball of mass m slides across the table with speed v_0 , as shown in Figure 1. The ball collides with and sticks to the free end of the rod when the rod is at the position shown in Figure 2. The rotational inertia of a rod about its end is given by $\frac{1}{3}ML^2$. Frictional forces are negligible. Positive values of angular momentum correspond to counterclockwise rotation. Which of the following indicates the change in angular momentum of the rod after the collision?

- (A) 0
- (B) $-mx_0v_0$
- (C) $+mx_0v_0$
- (D) $-2mx_0v_0$
- (E) $+2mx_0v_0$

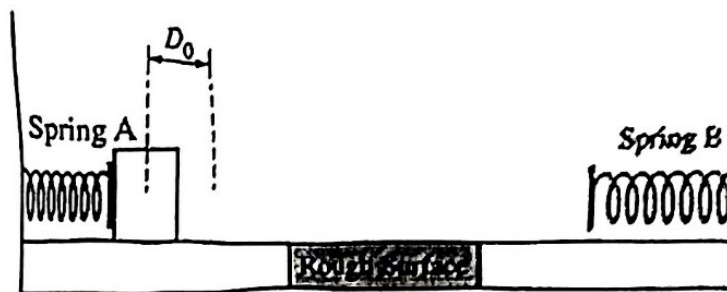


Figure 1

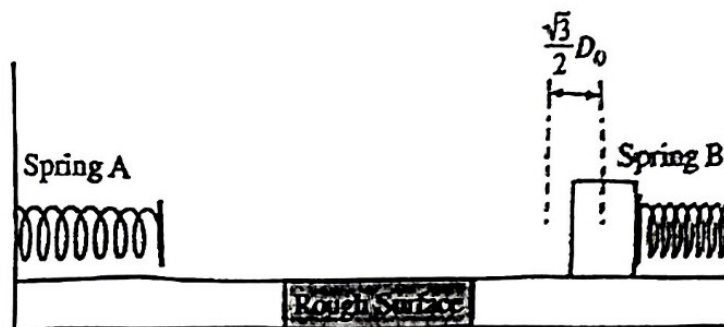


Figure 2

Note: Figures are not drawn to scale.

35. A block sits on a horizontal surface with a section of rough surface at its center. The block is pressed against Spring A, compressing the spring a distance D_0 , as shown in Figure 1. The block is then released and slides across the surface, compressing an identical spring, Spring B, a distance $\frac{\sqrt{3}}{2} D_0$, as shown in Figure 2. The block then moves back across the surface toward Spring A. Friction between the block and surface is negligible except when the block is on the rough surface. What is the maximum distance Spring A is compressed after the block leaves Spring B and passes over the rough surface again?

- (A) $\frac{1}{4} D_0$
- (B) $\frac{\sqrt{3}}{4} D_0$
- (C) $\frac{1}{2} D_0$
- (D) $\frac{1}{\sqrt{2}} D_0$
- (E) $\frac{3}{4} D_0$

Question 1

Begin your response to QUESTION 1 on this page.

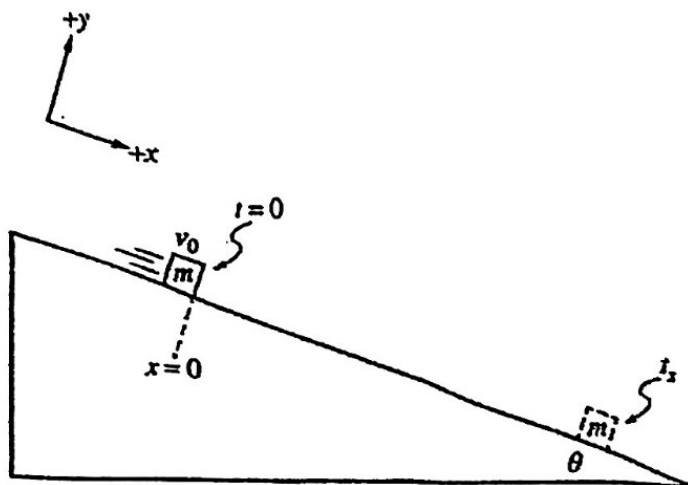
PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



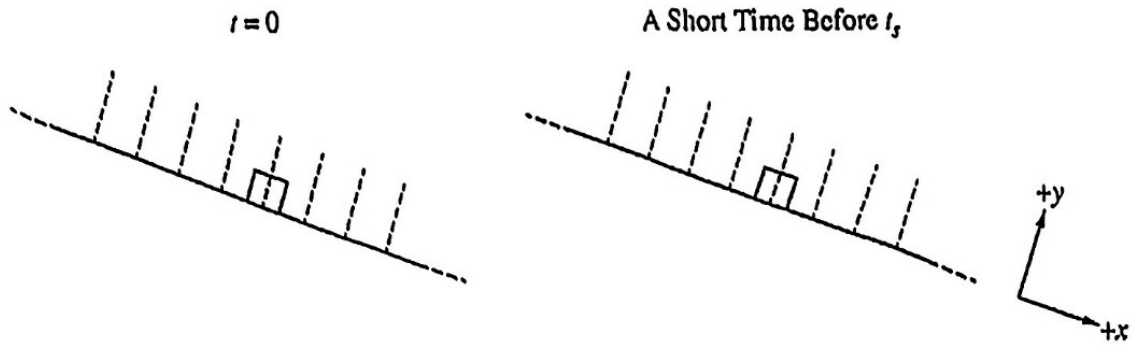
1. A block of mass m slides down a ramp that makes an angle θ with the horizontal. The $+x$ -direction is directed down the ramp. At time $t = 0$, the block is at position $x = 0$ and has speed v_0 down the ramp. A resistive force exerted on the block increases linearly with time as the block slides down the ramp. The resistive force at $x = 0$ is 0 N. The block comes to rest on the ramp at t_f , as shown.

Question 1

Continue your response to QUESTION 1 on this page.

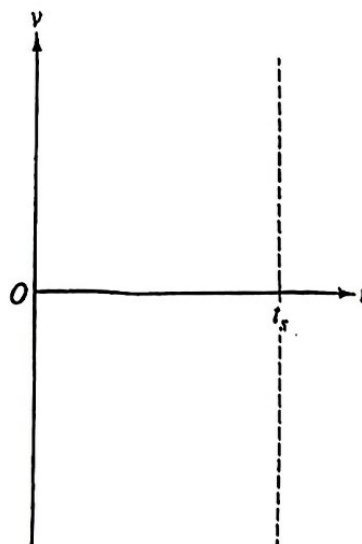
(a)

- i. The following diagrams represent the block at time $t = 0$ and a short time before t_s . In each figure, draw a single arrow that represents the velocity of the block. The lengths of each arrow should represent the relative magnitudes of the velocity at $t = 0$ and a short time before t_s .



- ii. A short time before t_s , is the acceleration vector of the block directed down the ramp (+ x -direction), directed up the ramp ($-x$ -direction), or zero? Briefly justify your reasoning.

- (b) On the following axes, sketch the velocity v of the block as a function of t during the interval $0 \leq t \leq t_s$.



Question 1

Continue your response to QUESTION 1 on this page.

- (c) During the time interval $0 \leq t \leq t_s$, the acceleration a of the block is described as a function of time by the equation $a = a_0 - bt$, where a_0 and b are positive constants with appropriate units. Derive an expression for the velocity v of the block as a function of time t for the time interval $0 \leq t \leq t_s$. Express your answer in terms of t , v_0 , a_0 , b , and physical constants, as appropriate.

In a new scenario, the block slides down a new ramp while a variable force is exerted on the block. At time $t = 0$, the block is at position $x = 0$ and has the same initial speed v_0 as in the original scenario. The block slides down the ramp and comes to rest at t_{s2} . While the block is moving, the position x of the block as a function of time t is modeled by $x = v_0 t + \frac{C}{6} t^3 - \frac{D}{12} t^4$, where C and D are positive constants. After the block has stopped moving, the block has traveled a vertical distance h .

- (d) Derive an expression for the kinetic energy K of the block as a function of time t for the time interval $0 \leq t \leq t_{s2}$. Express your answer in terms of t , m , C , D , v_0 , and physical constants, as appropriate.

Question 1

Continue your response to QUESTION 1 on this page.

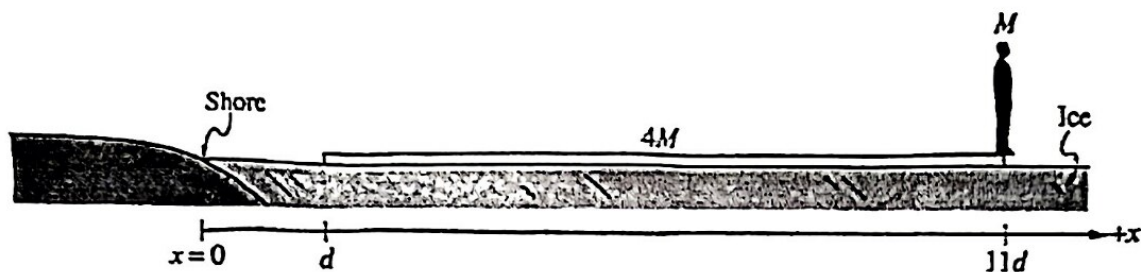
- (e) Derive an expression for the work W_{var} done by the variable force on the block after the block has traveled the vertical distance h . Express your answer in terms of m , v_0 , h , and physical constants, as appropriate.

- (f) Derive an expression for the net force on the block at time $t = 0$. Express your answer in terms of t , m , C , D , v_0 , and physical constants, as appropriate.



Question 2

Begin your response to QUESTION 2 on this page.



Note: Figure not drawn to scale.

2. A board of uniform density, mass $4M$, and length $10d$ rests on the ice of a frozen lake. There is negligible friction between the board and the ice. One end of the board is at position $x = d$ from the shore of the lake. A student of mass M stands on the other end of the board at $x = 11d$, as shown.

(a) In Scenario 1, the student starts at $x = 11d$ and walks on the board toward the shore.

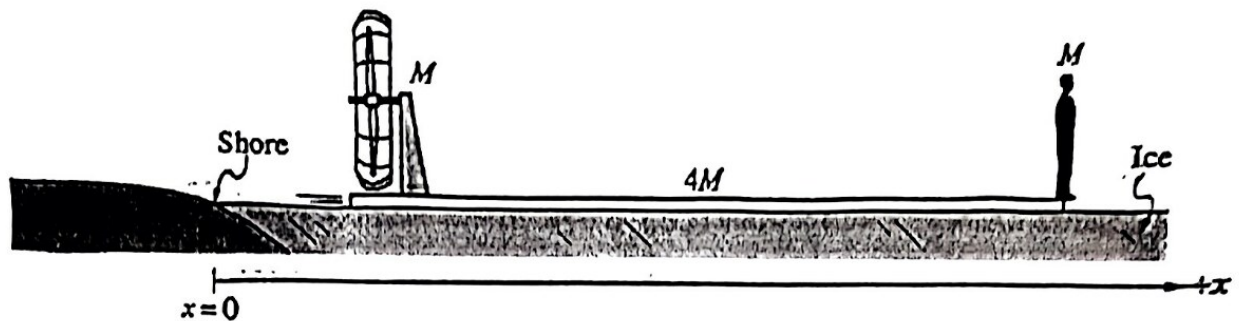
i. Briefly justify why the position of the center of mass of the system consisting of the board and the student does not change.

ii. Derive an expression for the position x_{CM} of the center of mass of the board-student system relative to the shore in terms of d , M , and physical constants, as appropriate.



Question 2

Continue your response to QUESTION 2 on this page.



Note: Figure not drawn to scale.

- (b) In Scenario 2, the student attaches a variable-speed fan of mass M to the board, as shown. The board-fan-student system is at rest when the fan is turned on at time $t = 0$. The force exerted on the system is modeled by the function $F = + Ct$, where C is a positive constant with appropriate units.

i. Derive an expression for the velocity v of the system as a function of time t in terms of M , C , t , and physical constants, as appropriate.

ii. The fan is turned off at $t = t_1$. On the following axes, sketch a graph of the momentum p of the system as a function of time for $0 < t < t_1$ and $t > t_1$.



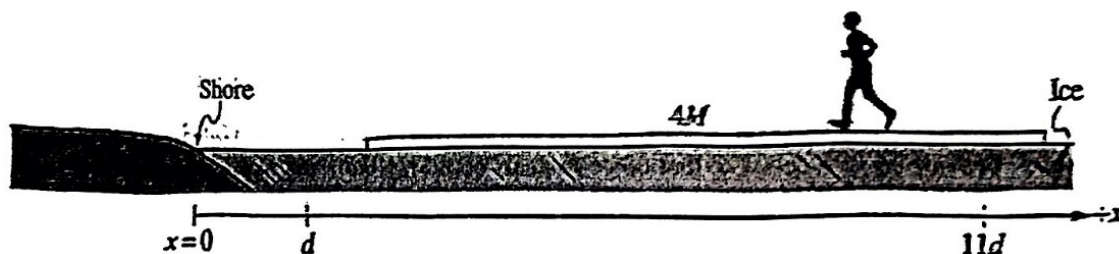
QUESTION 2

Continue your response to QUESTION 2 on this page.

(c) Consider the case where friction between the board and the ice is not negligible.

i. Describe how a feature of the graph you drew in part (b)(ii) would change when friction between the board and the ice is not negligible.

ii. Briefly justify your answer for part (c)(i) using physics principles.



Note: Figure not drawn to scale.

(d) In Scenario 3, the student has removed the fan from the board. Friction between the board and the ice is negligible. Starting at $t = 0$, the student runs on the board from $x = 11d$ toward the shore with a speed v_{sb} relative to the board. Derive an expression for the speed v_{bE} of the board relative to Earth. Express your answer in terms of v_{sb} and physical constants, as appropriate.

Question 3

Begin your response to QUESTION 3 on this page.



Figure 1

3. (a) A group of students plan an experiment to determine the rotational inertia I of a wheel. The wheel is released from rest at the top of a curved track, rolls down the track, and smoothly transitions to a flat, horizontal region as shown in Figure 1. At all times, the wheel rolls without slipping. The mass M_w and radius R of the wheel are known. The only measurement tools the students have access to are a meterstick and a stopwatch.

i. Describe a procedure to collect data that will be used to calculate an experimental value for I of the wheel. Provide enough detail so that other students could replicate the experiment, and include any steps necessary to reduce experimental uncertainty.

ii. Describe how the collected data can be used to calculate I .



QUESTION 3

Continue your response to QUESTION 3 on this page.

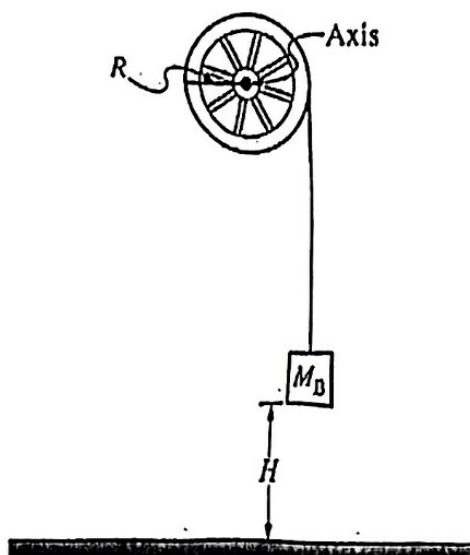


Figure 2

The students plan another experiment to determine I of the wheel. The students mount the wheel on an axis with negligible friction that is perpendicular to the plane of the page. A thin string is wound around the wheel, and the students attach the string to a hanging block of mass M_B , as shown in Figure 2. The students release the block from varying heights H and allow the block to fall to the floor. The speed of the block immediately before it reaches the floor is v . The string does not slip on the wheel as the block accelerates.

(b) Derive the relationship between I and v to show that $I = \frac{M_B(2gH - v^2)R^2}{v^2}$.

QUESTION 3

Continue your response to QUESTION 3 on this page.

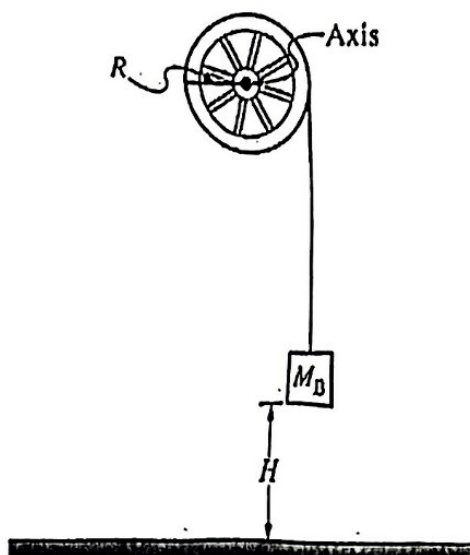


Figure 2

The students plan another experiment to determine I of the wheel. The students mount the wheel on an axis with negligible friction that is perpendicular to the plane of the page. A thin string is wound around the wheel, and the students attach the string to a hanging block of mass M_B , as shown in Figure 2. The students release the block from varying heights H and allow the block to fall to the floor. The speed of the block immediately before it reaches the floor is v . The string does not slip on the wheel as the block accelerates.

(b) Derive the relationship between I and v to show that $I = \frac{M_B(2gH - v^2)R^2}{v^2}$.

Question 3

Continue your response to QUESTION 3 on this page.

- (d) The students repeat the experiment with blocks of larger mass. The students observe that the string slips on the wheel as the block accelerates to the floor when the blocks with larger mass are used. Indicate whether the actual rotational inertia I of the wheel is greater than, less than, or equal to this new value calculated experimentally.

_____ Greater than _____ Less than _____ Equal to

Briefly justify your reasoning.

DO NOT WRITE ON THIS PAGE.

STOP

END OF EXAM

IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON THIS SECTION.

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THIS SECTION II: FREE
RESPONSE BOOKLET. MAKE SURE YOU HAVE DONE THE FOLLOWING:

- COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE
FRONT AND BACK COVERS OF THIS FREE RESPONSE BOOKLET
- CHECKED THAT YOUR AP ID LABEL IS IN THE BOX ON THE FRONT COVER

