



Mechanics Practice Exam for AP Physics C

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Below is a mechanics practice exam for AP Physics C exam. There are two sections in this practice exam. Section I has 35 multiple choice questions. Section II has 3 free response questions. For a thorough review of the concepts in this practice exam, refer to the information center on [AP Physics Notes](#).

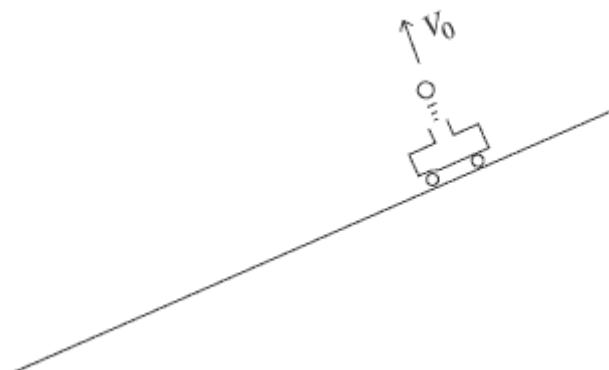
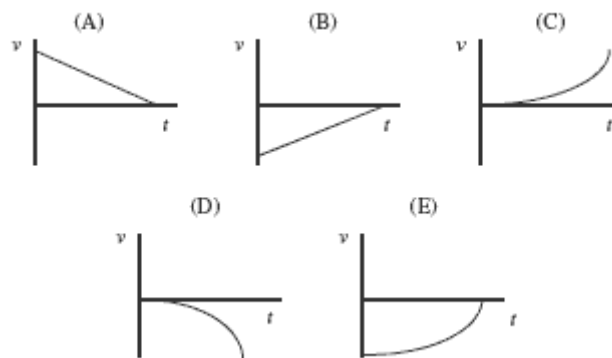
If you are taking both AP Physics C exams, the electricity and magnetism practice exam can be found at: [Electricity and Magnetism Practice Exam for AP Physics C](#)

Problems

Multiple Choice Questions

Time: 45 minutes. You may refer to the Constants sheet. However, you may not use the Equations sheet, and you may not use a calculator on this portion of the exam.

1. A cannon is mounted on a truck that moves forward at a speed of 5 m/s. The operator wants to launch a ball from a cannon so the ball goes as far as possible before hitting the level surface. The muzzle velocity of the cannon is 50 m/s. What angle from the horizontal should the operator point the cannon?
 - A. 5°
 - B. 41°
 - C. 45°
 - D. 49°
 - E. 85°
2. A car moving with speed v reaches the foot of an incline of angle θ . The car coasts up the incline without using the engine. Neglecting friction and air resistance, which of the following is correct about the magnitude of the car's horizontal acceleration a_x and vertical acceleration a_y ?
 - A. $a_x = 0$; $a_y < g$
 - B. $a_x = 0$; $a_y = g$
 - C. $a_x < g$; $a_y < g$
 - D. $a_x < g$; $a_y = g$
 - E. $a_x < g$; $a_y > g$
3. A bicycle slows down with an acceleration whose magnitude increases linearly with time. Which of the following velocity–time graphs could represent the motion of the bicycle?



4. A cart is sliding down a low friction incline. A device on the cart launches a ball, forcing the ball perpendicular to the incline, as shown above. Air resistance is negligible. Where will the ball land relative to the cart, and why?
- The ball will land in front of the cart, because the ball's acceleration component parallel to the plane is greater than the cart's acceleration component parallel to the plane.
 - The ball will land in front of the cart, because the ball has a greater magnitude of acceleration than the cart.
 - The ball will land in the cart, because both the ball and the cart have the same component of acceleration parallel to the plane.
 - The ball will land in the cart, because both the ball and the cart have the same magnitude of acceleration.
 - The ball will land behind the cart, because the ball slows down in the horizontal direction after it leaves the cart.
5. The quantity "jerk," j , is defined as the time derivative of an object's acceleration,

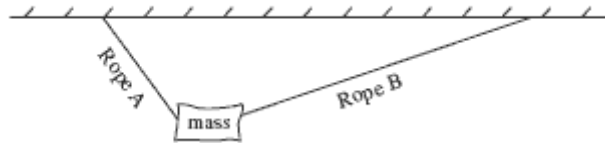
$$j = \frac{da}{dt} = \frac{d^3x}{dt^3}.$$

What is the physical meaning of the area under a graph of jerk vs. time?

- The area represents the object's acceleration.
 - The area represents the object's change in acceleration.
 - The area represents the object's change in velocity.
 - The area represents the object's velocity.
 - The area represents the object's change in position.
6. A particle moves along the x -axis with a position given by the equation $x(t) = 5 + 3t$, where x is in meters,

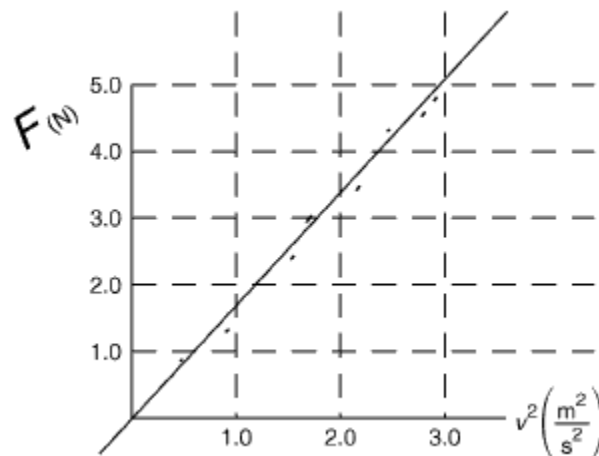
and t is in seconds. The positive direction is east. Which of the following statements about the particle is FALSE.

1. The particle is east of the origin at $t = 0$.
2. The particle is at rest at $t = 0$.
3. The particle's velocity is constant.
4. The particle's acceleration is constant.
5. The particle will never be west of position $x = 0$.



7. A mass hangs from two ropes at unequal angles, as shown above. Which of the following makes correct comparisons of the horizontal and vertical components of the tension in each rope?

<u>Horizontal Tension</u>	<u>Vertical Tension</u>
(A) greater in rope B	greater in rope B
(B) equal in both ropes	greater in rope A
(C) greater in rope A	greater in rope A
(D) equal in both ropes	equal in both ropes
(E) greater in rope B	equal in both ropes



8. The force of air resistance F on a mass is found to obey the equation $F = bv^2$, where v is the speed of the mass, for the range of speeds investigated in an experiment. A graph of F_N vs. v^2 is shown above. What is the value of b ?
- A. 0.83 kg/m
 - B. 1.7 kg/m
 - C. 3.0 kg/m
 - D. 5.0 kg/m
 - E. 1.0 kg/m
 - F. zero
9. A box sits on an inclined plane without sliding. As the angle of the plane (measured from the horizontal)

increases, the normal force

- A. increases linearly
- B. decreases linearly
- C. does not change
- D. decreases nonlinearly
- E. increases nonlinearly

10. Which of the following conditions are necessary for an object to be in static equilibrium?

- I. The vector sum of all torques on the object must equal zero.
 - II. The vector sum of all forces on the object must equal zero.
 - III. The sum of the object's potential and kinetic energies must be zero.
- A. I only
 - B. II only
 - C. III only
 - D. I and II only
 - E. I, II, and III

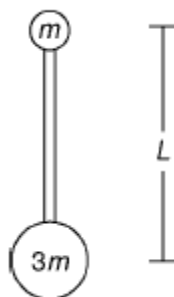


11. A student pushes a big 16-kg box across the floor at constant speed. He pushes with a force of 50 N angled 35° from the horizontal, as shown in the diagram above. If the student pulls rather than pushes the box at the same angle, while maintaining a constant speed, what will happen to the force of friction?

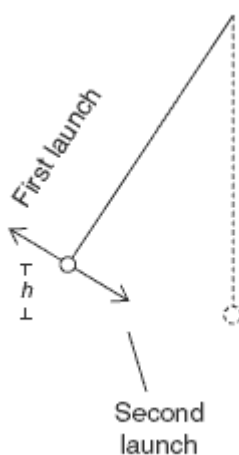
- A. It must increase.
- B. It must decrease.
- C. It must remain the same.
- D. It will increase only if the speed is greater than 3.1 m/s.
- E. It will increase only if the speed is less than 3.1 m/s.

12. Consider a system consisting only of the Earth and a bowling ball, which moves upward in a parabola above Earth's surface. The downward force of Earth's gravity on the ball, and the upward force of the ball's gravity on the Earth, form a Newton's third law force pair. Which of the following statements about the ball is correct?

- A. The ball must be in equilibrium since the upward forces must cancel downward forces.
- B. The ball accelerates toward the Earth because the force of gravity on the ball is greater than the force of the ball on the Earth.
- C. The ball accelerates toward the Earth because the force of gravity on the ball is the only force acting on the ball.
- D. The ball accelerates away from Earth because the force causing the ball to move upward is greater than the force of gravity on the ball.
- E. The ball accelerates away from Earth because the force causing the ball to move upward plus the force of the ball on the Earth are together greater than the force of gravity on the ball.



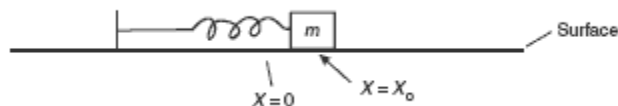
13. A mass m is attached to a mass $3m$ by a rigid bar of negligible mass and length L . Initially, the smaller mass is located directly above the larger mass, as shown above. How much work is necessary to flip the rod 180° so that the larger mass is directly above the smaller mass?
- $4mgL$
 - $2mgL$
 - mgL
 - $4pmgL$
 - $2pmgL$
14. A ball rolls horizontally with speed v off of a table a height h above the ground. Just before the ball hits the ground, what is its speed?
- $\sqrt{2gh}$
 - $v\sqrt{2gh}$
 - $\sqrt{v^2 + 2gh}$
 - v
 - $v + \sqrt{2gh}$



15. A pendulum is launched into simple harmonic motion in two different ways, as shown above, from a point that is a height h above its lowest point. During both launches, the bob is given an initial speed of 3.0 m/s. On the first launch, the initial velocity of the bob is directed upward along the pendulum's path, and on the second launch it is directed downward along the pendulum's path. Which launch will cause the

pendulum to swing with the larger amplitude?

- A. the first launch
- B. the second launch
- C. Both launches produce the same amplitude.
- D. The answer depends on the initial height h .
- E. The answer depends on the length of the supporting rope.

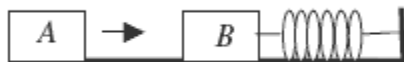


16. The mass M is moving to the right with velocity v_0 at position $x = x_0$. Neglect friction. The spring has force constant k . What is the total mechanical energy of the block at this position?

- (A) $\frac{1}{2}mv_0^2$
- (B) $\frac{1}{2}mv_0^2 + \frac{1}{2}kx_0^2$
- (C) $\frac{1}{2}mv_0^2 + \frac{1}{2}kx_0^2 + mgx_0$
- (D) $mgx_0 + \frac{1}{2}mv_0^2$
- (E) $mgx_0 + \frac{1}{2}kx_0^2$

17. A sphere, a cube, and a cylinder, all of equal mass, are released from rest from the top of a short incline. The surface of the incline is extremely slick, so much so that the objects do not rotate when released, but rather slide with negligible friction. Which reaches the base of the incline first?

- A. the sphere
- B. the cube
- C. the cylinder
- D. All reach the base at the same time.
- E. The answer depends on the relative sizes of the objects.



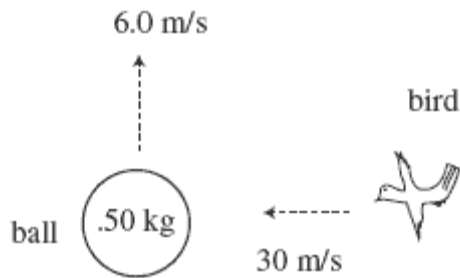
18. Block B is at rest on a smooth tabletop. It is attached to a long spring, which is in turn anchored to the wall. Block A slides toward and collides with block B. Consider two possible collisions:

Collision I: Block A bounces back off of block B.

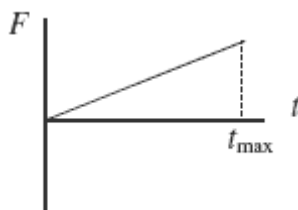
Collision II: Block A sticks to block B.

Which of the following is correct about the speed of block B immediately after the collision?

- A. It is faster in case II than in case I ONLY if block B is heavier.
- B. It is faster in case I than in case II ONLY if block B is heavier.
- C. It is faster in case II than in case I regardless of the mass of each block.
- D. It is faster in case I than in case II regardless of the mass of each block.
- E. It is the same in either case regardless of the mass of each block.

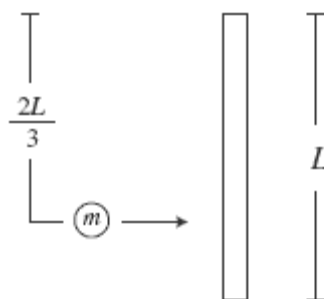


19. A 0.30-kg bird is flying from right to left at 30 m/s. The bird collides with and sticks to a 0.50-kg ball which is moving straight up with speed 6.0 m/s. What is the magnitude of the momentum of the ball/bird combination immediately after collision?
- 12.0 N•s
 - 9.5 N•s
 - 9.0 N•s
 - 6.0 N•s
 - 3.0 N•s



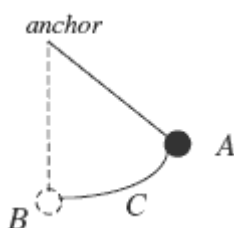
20. The force F on a mass is shown above as a function of time t . Which of the following methods can be used to determine the impulse experienced by the mass?
- multiplying the average force by t_{\max}
 - calculating the area under the line on the graph
 - taking the integral $\int_0^{t_{\max}} F \cdot dt$
- II only
 - III only
 - II and III only
 - I and II only
 - I, II, and III
21. A projectile is launched on level ground in a parabolic path so that its range would normally be 500 m. When the projectile is at the peak of its flight, the projectile breaks into two pieces of equal mass. One of these pieces falls straight down, with no further horizontal motion. How far away from the launch point does the other piece land?
- 250 m
 - 375 m
 - 500 m
 - 750 m
 - 1000 m

Questions 22 and 23



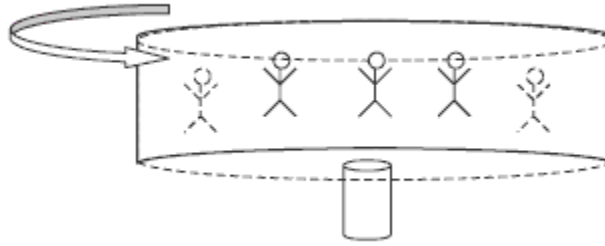
A rigid rod of length L and mass M is floating at rest in space far from a gravitational field. A small blob of putty of mass $m < M$ is moving to the right, as shown above. The putty hits and sticks to the rod a distance $2L/3$ from the top end.

22. How will the rod/putty contraption move after the collision?
- The contraption will have no translational motion, but will rotate about the rod's center of mass.
 - The contraption will have no translational motion, but will rotate about the center of mass of the rod and putty combined.
 - The contraption will move to the right and rotate about the position of the putty.
 - The contraption will move to the right and rotate about the center of mass of the rod and putty combined.
 - The contraption will move to the right and rotate about the rod's center of mass.
23. What quantities are conserved in this collision?
- linear and angular momentum, but not kinetic energy
 - linear momentum only
 - angular momentum only
 - linear and angular momentum, and linear but not rotational kinetic energy
 - linear and angular momentum, and linear and rotational kinetic energy
24. A car rounds a banked curve of uniform radius. Three forces act on the car: a friction force between the tires and the road, the normal force from the road, and the weight of the car. Which provides the centripetal force which keeps the car in circular motion?
- the friction force alone
 - the normal force alone
 - the weight alone
 - a combination of the normal force and the friction force
 - a combination of the friction force and the weight



25. A ball of mass m anchored to a string swings back and forth to a maximum position A , as shown above. Point C is partway back to the vertical position. What is the direction of the mass's acceleration at point C ?
- along the mass's path toward point B

- B. toward the anchor
- C. away from the anchor
- D. between a line toward the anchor and a line along the mass's path
- E. along the mass's path toward point A



26. In a carnival ride, people of mass m are whirled in a horizontal circle by a floorless cylindrical room of radius r , as shown in the diagram above. If the coefficient of friction between the people and the tube surface is μ , what minimum speed is necessary to keep the people from sliding down the walls?

(A) $\sqrt{\mu rg}$

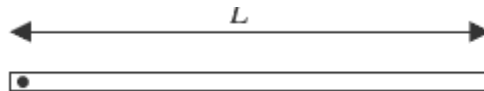
(B) $\sqrt{\frac{rg}{\mu}}$

(C) $\sqrt{\frac{\mu}{rg}}$

(D) $\sqrt{\frac{1}{\mu rg}}$

(E) $\sqrt{\mu mg}$

Questions 27 and 28



The uniform, rigid rod of mass m , length L , and rotational inertia I shown above is pivoted at its left-hand end. The rod is released from rest from a horizontal position.

27. What is the linear acceleration of the rod's center of mass the moment after the rod is released?

(A) $\frac{mgL^2}{2I}$

(B) $\frac{mgL^2}{4I}$

(C) $\frac{mgL^2}{I}$

(D) $\frac{mgL}{2I}$

(E) $\frac{2mgL^2}{I}$

28. What is the linear speed of the rod's center of mass when the mass passes through a vertical position?

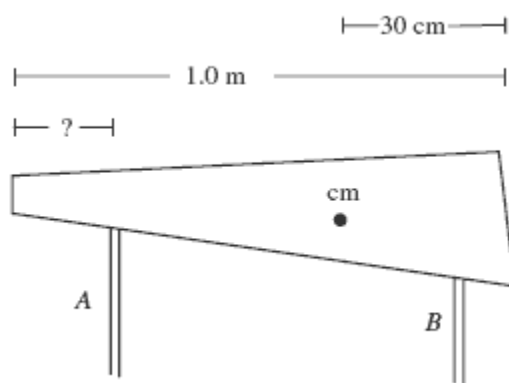
(A) $\sqrt{\frac{mgL^3}{8I}}$

(B) $\sqrt{\frac{mg\pi L^3}{4I}}$

(C) $\sqrt{\frac{mg\pi L^3}{8I}}$

(D) $\sqrt{\frac{mgL^3}{4I}}$

(E) $\sqrt{\frac{mgL^3}{2I}}$



29. The 1.0-m-long non-uniform plank, shown above, has weight 1000 N. It is to be supported by two rods, *A* and *B*, as shown above. The center of mass of the plank is 30 cm from the right edge. Each support

bears half the weight of the plank. If support B is 10 cm from the right-hand edge, how far from the left-hand edge should support A be?

- A. 0 cm
- B. 10 cm
- C. 30 cm
- D. 50 cm
- E. 70 cm

30. A mass m on a spring oscillates on a horizontal surface with period T . The total mechanical energy contained in this oscillation is E . Imagine that instead a new mass $4m$ oscillates on the same spring with the same amplitude. What is the new period and total mechanical energy?

	<u>Period</u>	<u>Total Mechanical Energy</u>
(A)	T	E
(B)	$2T$	E
(C)	$2T$	$2E$
(D)	T	$4E$
(E)	$2T$	$16E$

31. A mass m is attached to a horizontal spring of spring constant k . The spring oscillates in simple harmonic motion with amplitude A . What is the maximum speed of this simple harmonic oscillator?

(A) $2\pi\sqrt{\frac{m}{k}}$

(B) $2\pi A\sqrt{\frac{m}{k}}$

(C) $2\pi A\sqrt{\frac{k}{m}}$

(D) $A\sqrt{\frac{k}{m}}$

(E) $A\sqrt{\frac{m}{k}}$

32. An empty bottle goes up and down on the surface of the ocean, obeying the position function $x = A\cos(\omega t)$. How much time does this bottle take to travel once from its lowest position to its highest position?

(A) $\frac{2\pi}{\omega}$

(B) $\frac{\pi}{\omega}$

(C) $\frac{4\pi}{\omega}$

(D) $\frac{\pi}{2\omega}$

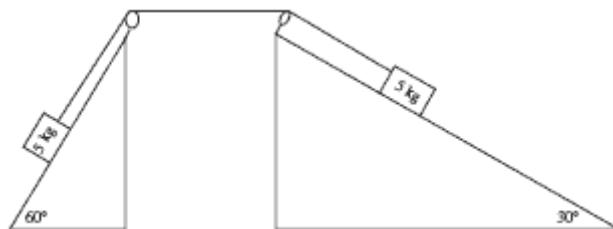
(E) $\frac{\pi}{4\omega}$

33. The Space Shuttle orbits 300 km above the Earth's surface; the Earth's radius is 6400 km. What is the acceleration due to Earth's gravity experienced by the Space Shuttle?
- A. 4.9 m/s^2
 - B. 8.9 m/s^2
 - C. 9.8 m/s^2
 - D. 0.8 m/s^2
 - E. zero
34. An artificial satellite orbits Earth just above the atmosphere in a circle with constant speed. A small meteor collides with the satellite at point P in its orbit, increasing its speed by 1%, but not changing the instantaneous direction of the satellite's velocity. Which of the following describes the satellite's new orbit?
- A. The satellite now orbits in an ellipse, with P as the farthest approach to Earth.
 - B. The satellite now orbits in an ellipse, with P as the closest approach to Earth.
 - C. The satellite now orbits in a circle of larger radius.
 - D. The satellite now orbits in a circle of smaller radius.
 - E. The satellite cannot maintain an orbit, so it flies off into space.
35. Mercury orbits the sun in about one-fifth of an Earth year. If 1 AU is defined as the distance from the Earth to the sun, what is the approximate distance between Mercury and the sun?
- A. $(1/25)$ AU
 - B. $(1/9)$ AU
 - C. $(1/5)$ AU
 - D. $(1/3)$ AU
 - E. $(1/2)$ AU

STOP. End of Physics C—Mechanics Practice Exam—Multiple-Choice Questions

Free Response

Time: 45 minutes. You may refer to the Constants sheet and Equations sheet in the Appendixes. You may also use a calculator on this portion of the exam.

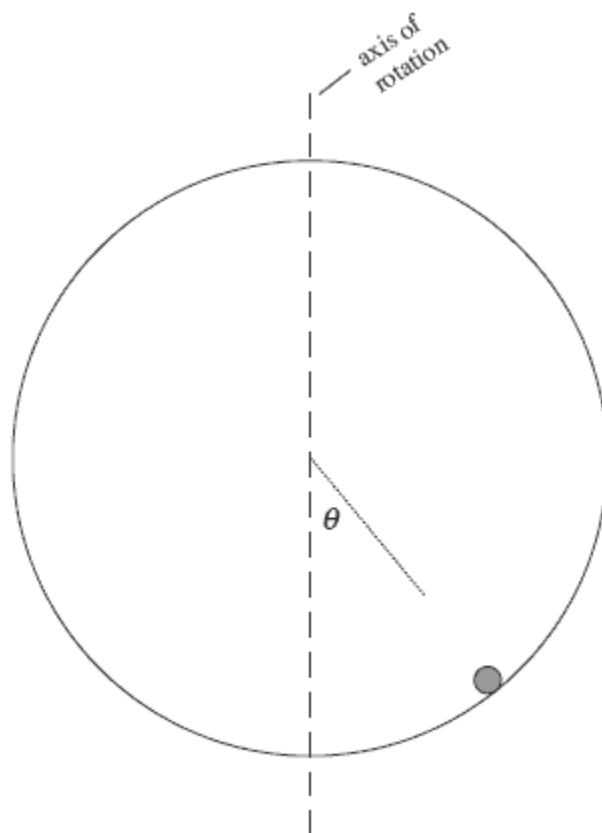
CM 1

Two 5-kg masses are connected by a light string over two massless, frictionless pulleys. Each block sits on a frictionless inclined plane, as shown above. The blocks are released from rest.

- Determine the magnitude of the acceleration of the blocks.
- Determine the tension in the string.

Now assume that the 30° incline is rough, so that the coefficient of friction between the block and the plane is 0.10. The 60° incline is still frictionless.

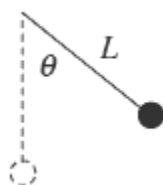
- Determine the magnitude of the acceleration of the blocks.
- Determine the tension in the string.

CM 2

A hollow glass sphere of radius 8.0 cm rotates about a vertical diameter with frequency 5 revolutions per second. A small wooden ball of mass 2.0 g rotates inside the sphere, as shown in the diagram above.

- Draw a free-body diagram indicating the forces acting on the wooden ball when it is at the position shown in the picture above.
- Calculate the angle θ , shown in the diagram above, to which the ball rises.
- Calculate the linear speed of the wooden ball as it rotates.
- The wooden ball is replaced with a steel ball of mass 20 g. Describe how the angle θ to which the ball rises will be affected. Justify your answer.

CM 3

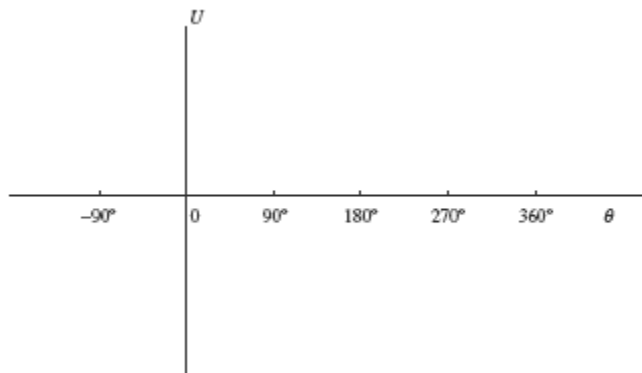


A heavy ball of mass m is attached to a light but rigid rod of length L . The rod is pivoted at the top and is free to rotate in a circle in the plane of the page, as shown above.

- The mass oscillates to a maximum angle θ . On the picture of the mass m below, draw a vector representing the direction of the NET force on the mass while it is at angle θ . Justify your choice of direction.



- Is the magnitude of the net force at the maximum displacement equal to $mg \sin\theta$ or $mg \cos\theta$? Choose one and justify your choice.
- Derive an expression for the ball's potential energy U as a function of the angle θ . Assume that a negative angle represents displacement from the vertical in the clockwise direction.
- On the axes below, sketch a graph of the mass's potential energy U as a function of the angle θ for angles between -90° and $+360^\circ$. Label maximum and minimum values on the vertical axis.



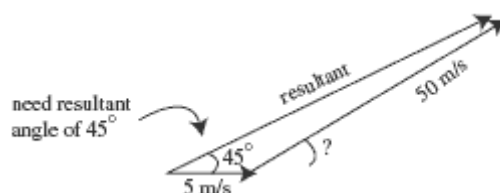
- The pendulum is considered a classic example of simple harmonic motion when it undergoes small-amplitude oscillation. With specific reference to the graph you made in part (d), explain why the assumption of simple harmonic motion is valid.

STOP. End of Physics C—Mechanics Practice Exam—Free-Response Questions

Solutions

Multiple-Choice Solutions

1. **D**—A projectile has its maximum range when it is shot at an angle of 45° relative to the ground. The cannon's initial velocity relative to the ground in this problem is given by the vector sum of the man's 5 m/s forward motion and the cannon's 50 m/s muzzle velocity. To get a resultant velocity of 45° , the man must shoot the cannon at only a slightly higher angle, as shown in the diagram below.



2. **C**—The car stays on the plane, and slows down as it goes up the plane. Thus, the net acceleration is in the direction down the plane, which has both a nonzero horizontal and vertical component. The car is not in free fall, so its vertical acceleration is less than g .
3. **E**—Acceleration is the slope of the $v-t$ graph. Because acceleration increases, the slope of the $v-t$ graph must get steeper, eliminating choices A and B. The bike slows down, so the speed must get closer to zero as time goes on, eliminating choices C and D.
4. **C**—The cart's acceleration is $g \sin\theta$, down the plane, the ball's acceleration is g , straight down. (So the magnitudes of acceleration are different and choice D is wrong.) The component of the ball's acceleration along an axis parallel to the plane is also $g \sin\theta$, equal to the ball's acceleration component.
5. **B**—The area under a jerk–time graph is the quantity $\int j dt$. The derivative

$$j = \frac{da}{dt}$$

can be interpreted as a change in acceleration over a time interval,

$$j = \frac{\Delta a}{\Delta t}$$

Solving algebraically, $j\Delta t$ is Δa , meaning the change in acceleration.

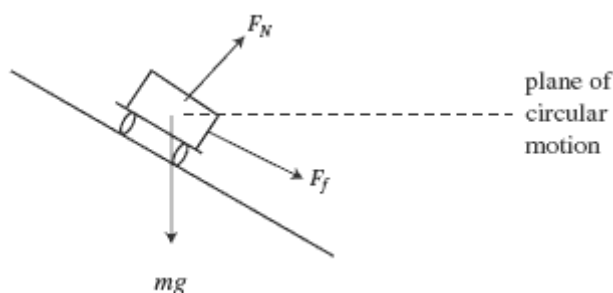
6. **B**—At $t = 0$, $x = +5$ m, so the particle is east of the origin to start with. The velocity is given by the derivative of the position function, $v(t) = 3$ m/s. This is a constant velocity; the acceleration is thus zero (and constant), but at $t = 0$ the velocity is also 3 m/s, so choice B is false.
7. **B**—Consider the horizontal and vertical forces separately. The only horizontal forces are the horizontal components of the tensions. Because the block is in equilibrium, these horizontal tensions must be *equal*, meaning only choices B and D can be right. But the ropes can't have equal horizontal AND vertical tensions, otherwise they'd hang at equal angles. So D can't be the right choice, and B must be right.
8. **B**—The equation $F = bv^2$ is of the form $y = mx$, the equation of a line. Here F is the vertical axis, v^2 is

the horizontal axis, so b is the slope of the line. Looking at the graph, the slope is $5.0 \text{ N}/3.0 \text{ m}^2/\text{s}^2 = 1.7 \text{ kg/m}$.

9. **D**—Because no forces act perpendicular to the incline except for the normal force and the perpendicular component of weight, and there is no acceleration perpendicular to the incline, the normal force is equal to the perpendicular component of weight, which is $mg \cos\theta$. As the angle increases, the cosine of the angle decreases. This decrease is nonlinear because a graph of F_N vs. θ would show a curve, not a line.
10. **D**—In equilibrium, the net force and the net torque must both be zero. Static equilibrium means the object is stationary, so kinetic energy must be zero. However, potential energy can take on any value—a sign suspended above a roadway is in static equilibrium, yet has potential energy relative to Earth's surface.
11. **B**—The friction force is equal to the coefficient of friction times the normal force. The coefficient of friction is a property of the surfaces in contact, and thus will not change here. However, the normal force decreases when the cart is pulled rather than pushed—the surface must apply more force to the box when there is a downward component to the applied force than when there is an upward component. Speed is irrelevant because equilibrium in the vertical direction is maintained regardless.
12. **C**—The ball accelerates toward the Earth because, although it is moving upward, it must be slowing down. The only force acting on the ball is Earth's gravity. Yes, the ball exerts a force on the Earth, but that force acts on the Earth, not the ball. According to Newton's 3rd law, force pairs always act on different objects, and thus can never cancel.
13. **B**—The work done on an object by gravity is independent of the path taken by the object and is equal to the object's weight times its vertical displacement. Gravity must do $3mgL$ of work to raise the large mass, but must do $mg(-L)$ of work to lower the small mass. The net work done is thus $2mgL$.
14. **C**—Use conservation of energy. Position 1 will be the top of the table; position 2 will be the ground. $PE_1 + KE_1 = PE_2 + KE_2$. Take the PE at the ground to be zero. Then $\frac{1}{2}mv_2^2 = \frac{1}{2}mv_1^2 + mgh$. The ms cancel. Solving for v_2 , you get choice C. (Choice E is wrong because it's illegal algebra to take a squared term out of a square root when it is added to another term.)
15. **C**—Consider the conservation of energy. At the launch point, the potential energy is the same regardless of launch direction. The kinetic energy is also the same because KE depends on speed alone and not direction. So, both balls have the same amount of kinetic energy to convert to potential energy, bringing the ball to the same height in every cycle.
16. **B**—Total mechanical energy is defined as kinetic energy plus potential energy. The KE here is $\frac{1}{2}mv_0^2$. The potential energy is provided entirely by the spring—gravitational potential energy requires a *vertical* displacement, which doesn't occur here. The PE of the spring is $\frac{1}{2}kx_0^2$.
17. **D**—When an object rotates, some of its potential energy is converted to rotational rather than linear kinetic energy, and thus it moves more slowly than a non-rotating object when it reaches the bottom of the plane. However, here none of the objects rotate! The acceleration does not depend on mass or size.
18. **D**—Momentum must be conserved in the collision. If block *A* bounces, it changes its momentum by a larger amount than if it sticks. This means that block *B* picks up more momentum (and thus more speed) when block *A* bounces. The mass of the blocks is irrelevant because the comparison here is just between bouncing and not bouncing. So *B* goes faster in collision I regardless of mass.
19. **B**—The momentum of the bird before collision is 9 N·s to the left; the momentum of the ball is initially 3 N·s up. The momentum after collision is the *vector* sum of these two initial momentums. With a calculator you would use the Pythagorean theorem to get 9.5 N·s; without a calculator you should just notice that the resultant vector must have magnitude less than 12 N·s (the algebraic sum) and more than 9 N·s.
20. **E**—Impulse is defined on the equation sheet as the integral of force with respect to time, so III is right.

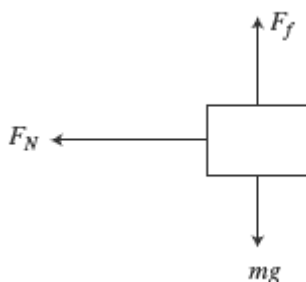
The meaning of this integral is to take the area under a F vs. t graph, so II is right. Because the force is increasing linearly, the average force will be halfway between zero and the maximum force, and the rectangle formed by this average force will have the same area as the triangle on the graph as shown, so I is right.

21. **D**—The center of mass of the projectile must maintain the projectile path and land 500 m from the launch point. The first half of the projectile fell straight down from the peak of its flight, which is halfway to the maximum range, or 250 m from the launch point. So the second half of equal mass must be 250 m beyond the center of mass upon hitting the ground, or 750 m from the launch point.
22. **D**—By conservation of linear momentum, there is momentum to the right before collision, so there must be momentum to the right after collision as well. A free-floating object rotates about its center of mass; because the putty is attached to the rod, the combination will rotate about its combined center of mass.
23. **A**—Linear and angular momentum are conserved in *all* collisions (though often angular momentum conservation is irrelevant). Kinetic energy, though, is only conserved in an elastic collision. Because the putty sticks to the rod, this collision cannot be elastic. Some of the kinetic energy must be dissipated as heat.
24. **D**



The centripetal force must act toward the center of the car's circular path. This direction is NOT down the plane, but rather is purely horizontal. The friction force acts down the plane and thus has a horizontal component; the normal force acts perpendicular to the plane and has a horizontal component. So BOTH F_N and F_f contribute to the centripetal force.

25. **D**—The mass's acceleration has two components here. Some acceleration must be centripetal (i.e., toward the anchor) because the mass's path is circular. But the mass is also speeding up, so it must have a tangential component of acceleration toward point B . The vector sum of these two components must be in between the anchor and point B .
26. **B**—The free-body diagram for a person includes F_N toward the center of the circle, mg down and the force of friction up:



Because the person is not sliding down, $mg = F_f$. And because the motion of the person is circular, the

normal force is a centripetal force, so $F_N = mv^2/r$. The force of friction by definition is μF_N . Combining these equations, we have $mg = \mu mv^2/r$; solve for v to get answer choice B. Note: Without any calculation, you could recognize that only choices A and B have units of speed, so you would have had a good chance at getting the answer right just by guessing one of these two!

27. **B**—Use Newton's second law for rotation, $\tau_{\text{net}} = I\alpha$. The only torque about the pivot is the rod's weight, acting at the rod's center; this torque is thus $mgL/2$. So the angular acceleration, α , of the rod is $mgL/2I$. But the question asks for a linear acceleration, $a = r\alpha$, where r is the distance to the center of rotation. That distance here is $L/2$. So combining, you get $a = (L/2)(mgL/2I) = mgL^2/4I$.
28. **D**—We cannot use rotational kinematics here because the net torque, and thus the angular acceleration, is not constant. Use conservation of energy instead. The potential energy at the release point is $mg(L/2)$ ($L/2$ because the rod's center of mass is that far vertically above its lowest point). This potential energy is converted entirely into rotational kinetic energy $\frac{1}{2}I\omega^2$. The rod's angular velocity ω is equal to $v/(L/2)$, where v is the linear speed of the center of mass that we're solving for. Plugging in, you get $mgL/2 = \frac{1}{2}I(v^2/[L/2]^2)$. Solving for v , choice D emerges from the mathematics.
29. **D**—Choose any point at all as the fulcrum; say, the center of mass. Rod B supports 500 N, and is located 20 cm from the fulcrum, producing a total counterclockwise torque of 10,000 N·cm. Rod A also supports 500 N; call its distance from the fulcrum "x". So $10,000 = 500x$, and $x = 20$ cm. This means Rod A is located 20 cm left of the center of mass, or 50 cm from the left edge.
30. **B**—The period of a mass on a spring is

$$2\pi\sqrt{\frac{m}{k}},$$

with the mass under the square root. So when the mass is quadrupled, the period is only multiplied by two. The total mechanical energy is the sum of potential plus kinetic energy. At the greatest displacement from equilibrium (i.e., at the amplitude), the mass's speed is zero and all energy is potential; potential energy of a spring is $\frac{1}{2}kx^2$ and does not depend on mass. So, because the amplitude of oscillation remains the same, the total mechanical energy does not change.

31. **D**—The maximum potential energy of the mass is at the amplitude, and equal to $\frac{1}{2}kA^2$. This is entirely converted to kinetic energy at the equilibrium position, where the speed is maximum. So set $\frac{1}{2}kA^2 = \frac{1}{2}mv_{\text{max}}^2$. Solving for v_{max} , you get choice D. (Note: Only choices C and D have units of velocity! So guess between these if you have to!)
32. **B**—The bottle's lowest position is $x = -A$, and its highest position is $x = +A$. When $t = 0$, $\cos(0) = 1$ and the bottle is at $x = +A$. So, find the time when the cosine function goes to -1 . This is when $\omega t = \pi$, so $t = \pi/\omega$.
33. **B**—Don't try to calculate the answer by saying $mg = GMm/r^2$! Not only would you have had to memorize the mass of the Earth, but you have no calculator and you only have a minute or so, anyway. So think: the acceleration must be less than 9.8 m/s^2 , because that value is calculated at the surface of the Earth, and the Shuttle is farther from Earth's center than that. But the added height of 300 km is a small fraction (~5%) of the Earth's radius. So the gravitational acceleration will not be THAT much less. The best choice is thus 8.9 m/s^2 . (By the way, acceleration is not zero—if it were, the Shuttle would be moving in a straight line, and not orbiting.)
34. **B**—The orbit can no longer be circular—circular orbits demand a specific velocity. Because the satellite gains speed while at its original distance from the planet, the orbit is now elliptical. Because the direction

of the satellite's motion is still tangent to the former circular path, in the next instant the satellite will be farther from Earth than at point P , eliminating answer choice A. The satellite will not "fly off into space" unless it reaches escape velocity, which cannot be 1% greater than the speed necessary for a low circular orbit.

35. **D**—Kepler's third law states that for all planets in the same system, their period of orbit squared is proportional to the average distance from the sun cubed. Using units of years and AU, for Earth, $(1 \text{ year})^2 = (1 \text{ AU})^3$. For Mercury, we have $(\frac{1}{5} \text{ year})^2 = (? \text{ AU})^3$. Solving for the question mark, you find that the distance from Mercury to the sun is the cube root of $\frac{1}{25}$ AU, which is closest to $\frac{1}{3}$ AU.

Free-Response Solutions

For answers that are numerical, or in equation form:

*For each part of the problem, look to see if you got the right answer. If you did, and you showed any reasonable (and correct) work, give yourself full credit for that part. It's okay if you didn't explicitly show EVERY step, as long as some steps are indicated and you got the right answer. However:

*If you got the **WRONG** answer, then look to see if you earned partial credit. Give yourself points for each step toward the answer as indicated in the rubrics below. Without the correct answer, you must show each intermediate step explicitly in order to earn the point for that step. (See why it's so important to show your work?)

*If you're off by a decimal place or two, not to worry—you get credit anyway, as long as your approach to the problem was legitimate. This isn't a math test. You're not being evaluated on your rounding and calculator-use skills.

*You do not have to simplify expressions in variables all the way. Square roots in the denominator are fine; fractions in non-simplified form are fine. As long as you've solved properly for the requested variable, and as long as your answer is algebraically equivalent to the rubric's, you earn credit.

*Wrong, but consistent: Often you need to use the answer to part (a) in order to solve part (b). But you might have the answer to part (a) wrong. If you follow the correct procedure for part (b), plugging in your incorrect answer, then you will usually receive *full credit* for part (b). The major exceptions are when your answer to part (a) is unreasonable (say, a car moving at 105 m/s, or a distance between two cars equal to 10–100 meters), or when your answer to part (a) makes the rest of the problem trivial or irrelevant.

For answers that require justification:

*Obviously your answer will not match the rubric word-for-word. If the general gist is there, you get credit.

*But the reader is not allowed to interpret for the student. If your response is vague or ambiguous, you will **NOT** get credit.

*If your response consists of both correct and incorrect parts, you will usually not receive credit. It is not possible to try two answers, hoping that one of them is right. (See why it's so important to be concise?)

CM 1

a.

1 pt: Write Newton's second law for the direction along the plane for each block. Call the mass of each identical block m .

1 pt: For the right block, $T - mg \sin 30 = ma$.

1 pt: For the left block $mg \sin 60 - T = ma$.

1 pt: Here the directions chosen are consistent, so that forces that accelerate the system to the left are positive. (However, you earn this point as long as directions are consistent.)

1 pt: Solve these equations simultaneously (it's easiest just to add them together).

1 pt: $a = 1.8 \text{ m/s}^2$. (An answer of $a = -1.8 \text{ m/s}^2$ is incorrect because the magnitude of a vector can not be negative.) (Alternatively, you can just recognize that $mg \sin 60$ pulls left, while $mg \cos 60$ pulls right, and use Newton's second law directly on the combined system. Be careful, though, because the mass of the ENTIRE system is 10 kg, not 5 kg!)

b.

1 pt: Just plug the acceleration back into one of the original Newton's second law equations from part (a).

1 pt: You get $T = 34 \text{ N}$.

c.

For parts (c) and (d), points are awarded principally for showing the difference that friction makes in the solution. You earn credit for properly accounting for this difference, even if your overall solution is wrong, as long as you followed a similar process to parts (a) and (b).

1 pt: Following the solution for part (a), this time the right block's equation becomes $T - mg \sin 30 - \mu F_N$, where μ is the coefficient of friction, given as 0.10.

1 pt: The normal force is equal to $mg \cos 30$.

1 pt: The left block's equation is the same as before, $mg \sin 60 - T = ma$.

1 pt: Eliminating T and solving, we get

1.4 m/s^2 . This is reasonable because we get a smaller acceleration when friction is included, as expected. [This answer point is awarded for ANY nonzero acceleration that is less than that calculated in part (a).]

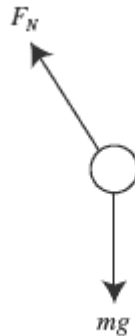
d.

1 pt: Plugging back into one of the equations in part (c), we find $T = 36 \text{ N}$ this time, or whatever tension is consistent with part (c).

1 pt: Awarded for ANY nonzero tension greater than that found in part (b).

1 pt: For proper units on at least one acceleration and one tension, and no incorrect units.

CM 2



a.

1 pt: The weight of the ball acts down.

1 pt: The normal force acts up and left, perpendicular to the surface of the glass.

1 pt: No other forces act.

b.

1 pt: The normal force can be broken into vertical and horizontal components, where the vertical is $F_N \cos\theta$ and the horizontal is $F_N \sin\theta$. (The vertical direction goes with cosine here because θ is measured from the vertical.)

1 pt: The net vertical force is zero because the ball doesn't rise or fall on the glass. Setting up forces equal to down, $F_N \cos\theta = mg$. 1 pt: The horizontal force is a centripetal force, so $F_N \sin\theta = mv^2/r \sin\theta$.

1 pt: For using $r \sin\theta$ and not just r . (Why? Because you need to use the radius of the actual circular motion, which is not the same as the radius of the sphere.)

1 pt: The tangential speed "v" is the circumference of the circular motion divided by the period. Since period is $1/f$, and because the radius of the circular motion is $r \sin\theta$, this speed $v = 2\pi r \sin\theta f$.

1 pt: Now divide the vertical and horizontal force equations to get rid of the FN term:

$$\sin\theta/\cos\theta = v^2/r \sin\theta g.$$

1 pt: Plug in the speed and the $\sin\theta$ terms cancel, leaving $\cos\theta = g/4\pi^2 r f^2$.

1 pt: Plugging in the given values (including $r = 0.08$ m), $\theta = 83^\circ$.

c.

1 pt: From part (a), the linear speed is $2\pi r \sin\theta f$.

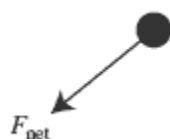
1 pt: Plugging in values, the speed is 2.5 m/s. (If you didn't get the point in part (a) for figuring out how to calculate linear speed, but you do it right here, then you can earn the point here.)

d.

1 pt: The angle will not be affected.

1 pt: Since the mass of the ball does not appear in the equation to calculate the angle in part (b), the mass does not affect the angle.

CM 3



a.

1 pt: The net force is at an angle down and to the left, perpendicular to the rod.

1 pt: Because the ball is instantaneously at rest, the direction of the velocity in the next instant must also be the direction of the acceleration; this direction is along the arc of the ball's motion.

b.

1 pt: The magnitude of the net force is $mg \sin\theta$.

1 pt: It's easiest to use a limiting argument: When $\theta = 90^\circ$, then the net force would be simply the weight of the ball, mg . $mg \sin 90^\circ = mg$, while $mg \cos 90^\circ = \text{zero}$; hence the correct answer.

c.

1 pt: The force on the mass is $-mg \sin\theta$, the negative arising because the force is always opposite the displacement.

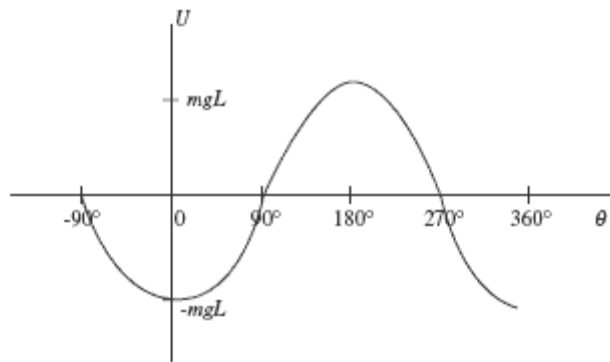
1 pt: Potential energy is derived from force by $U = \int F dx$.

1 pt: The distance displaced $x = L\theta$.

1 pt: The differential dx becomes $L d\theta$.

1 pt: The integral becomes $\int mgL \sin\theta d\theta$, which evaluates to $\int mgL \cos\theta$. (Here the constant of integration can be taken to be any value at all because the zero of potential energy can be chosen arbitrarily.)

[Alternate solution: Using geometry, it can be found that the height of the bob above the lowest point is $L - L\cos\theta$. Thus, the potential energy is $mgh = mg(L - L\cos\theta)$. This gives the same answer, but has defined the arbitrary constant of integration as mgL .]



d.

1 pt: The graph should look like some sort of sine or cosine function, oscillating smoothly. The graph may be shifted up or down and still receive full credit.

1 pt: The graph should have an amplitude of mgL , though the graph can be shifted arbitrarily up or down on the vertical axis.

1 pt: The graph should have a minimum at $\theta = 0$.

1 pt: The graph should have a maximum at $\theta = 180^\circ$.

e.

1 pt: For simple harmonic motion, the restoring force must be linearly proportional to the displacement, like $F = -kx$. This yields an energy function that is quadratic: $-(-kx) \cdot dx$ integrates to give $U = \frac{1}{2}kx^2$. The graph of the energy of a simple harmonic oscillator is, thus, parabolic.

1 pt: Near the $\theta = 0$ position, the graph in part (e) is shaped much like a parabola, only deviating from a parabolic shape at large angles; so the pendulum is a simple harmonic oscillator as long as the energy graph approximates a parabola.

AP Physics C—Mechanics Full Exam Scoring

Multiple Choice: Number Correct _____
 Number Wrong _____

Total = Right - ($1/4$) Wrong _____ 35 max

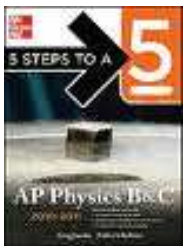
Free Response: Question 1 _____ 15 max
 Question 2 _____ 15 max
 Question 3 _____ 15 max

Total Free Response _____ 45 max

$1.286 \times$ Multiple Choice + Free Response = Raw Score _____ 90 max

56–90	5
40–55	4
29–39	3
15–28	2
0–14	1

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