AP Physics 1: Algebra-Based

The College Board

AP® Physics 1 Practice Exam

SECTION I: Multiple Choice

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
90 minutes
Number of Questions
50
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 50 multiple-choice questions. Pages containing equations and other information are also printed in this booklet. Calculators, rulers, and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work.

For questions 1 through 45, select the single best answer choice for each question. After you have decided which of the choices is best, fill in the appropriate letter in the corresponding space on the answer sheet.

For questions 46 through 50, select the two best answer choices for each question. After you have decided which two of the choices are best, enter both letters in the corresponding space on the answer sheet.

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on Section I is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

NO TEST MATERIAL ON THIS PAGE

AP® PHYSICS 1 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS			
Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	Coulomb's law constant,	$k = 1/4\pi\varepsilon_0 = 9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Speed of light,	$c = 3.00 \times 10^8$ m/s	Acceleration due to gravity at Earth's surface,	$g = 9.8\ \text{m/s}^2$

UNIT SYMBOLS								
	meter,	m	kelvin,	K	watt,	W	degree Celsius,	°C
	kilogram,	kg	hertz,	Hz	coulomb,	C		
	second,	s	newton,	N	volt,	V		
	ampere,	A	joule,	J	ohm,	Ω		

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. Assume air resistance is negligible unless otherwise stated.
III. In all situations, positive work is defined as work done on a system.
IV. The direction of current is conventional current: the direction in which positive charge would drift.
V. Assume all batteries and meters are ideal unless otherwise stated.

AP® PHYSICS 1 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

$|\vec{F}_f| \leq \mu |\vec{F}_n|$

$a_c = \frac{v^2}{r}$

$\vec{p} = m\vec{v}$

$\Delta \vec{p} = \vec{F} \Delta t$

$K = \frac{1}{2} m v^2$

$\Delta E = W = F_{\parallel} d = F d \cos\theta$

$P = \frac{\Delta E}{\Delta t}$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$

$\omega = \omega_0 + \alpha t$

$x = A \cos(2\pi f t)$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

$\tau = r_{\perp} F = r F \sin\theta$

$L = I\omega$

$\Delta L = \tau \Delta t$

$K = \frac{1}{2} I \omega^2$

$|\vec{F}_s| = k|\vec{x}|$

$U_s = \frac{1}{2} k x^2$

$\rho = \frac{m}{V}$

a = acceleration
A = amplitude
d = distance
E = energy
f = frequency
F = force
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
V = volume
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
ρ = density
τ = torque
ω = angular speed

$\Delta U_g = mg \Delta y$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi \sqrt{\frac{m}{k}}$

$T_p = 2\pi \sqrt{\frac{\ell}{g}}$

$|\vec{F}_g| = G \frac{m_1 m_2}{r^2}$

$\vec{g} = \frac{\vec{F}_g}{m}$

$U_G = -\frac{G m_1 m_2}{r}$

ELECTRICITY

$|\vec{F}_E| = k \left| \frac{q_1 q_2}{r^2} \right|$

$I = \frac{\Delta q}{\Delta t}$

$R = \frac{\rho \ell}{A}$

$I = \frac{\Delta V}{R}$

$P = I \Delta V$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

A = area
F = force
I = current
ℓ = length
P = power
q = charge
R = resistance
r = separation
t = time
V = electric potential
ρ = resistivity

WAVES

$\lambda = \frac{v}{f}$

f = frequency
v = speed
λ = wavelength

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2} bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

Rectangular solid
$V = \ell w h$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r \ell + 2\pi r^2$

Sphere
$V = \frac{4}{3} \pi r^3$
$S = 4\pi r^2$

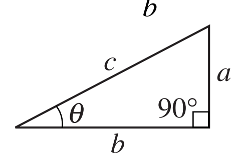
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

Right triangle
$c^2 = a^2 + b^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$

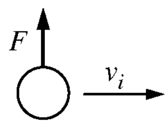


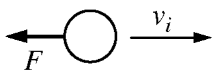
PHYSICS 1
Section I
50 Questions
Time—90 minutes

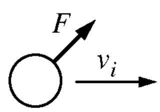
Note: To simplify calculations, you may use $g = 10 \text{ m/s}^2$ in all problems.

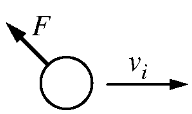
Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then enter the appropriate letter in the corresponding space on the answer sheet.

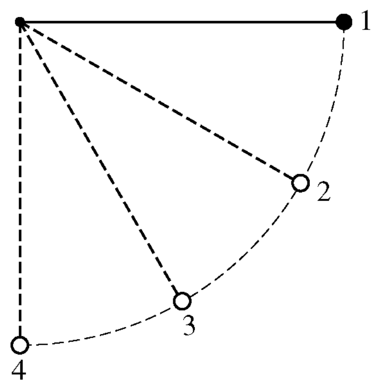
1. An object is moving to the right with speed v_i when a force of magnitude F is exerted on it. In which of the following situations is the object's direction of motion changing and kinetic energy decreasing at the instant shown?

(A) 

(B) 

(C) 

(D) 



2. A ball is suspended by a lightweight string, as shown in the figure above. The ball is displaced to position 1 and released. The four labeled positions are evenly spaced along the arc of the ball's motion. Between which adjacent pairs of positions is the change in kinetic energy of the ball greatest?

(A) 1 and 2
(B) 2 and 3
(C) 3 and 4
(D) The change is the same for all adjacent pairs.

GO ON TO THE NEXT PAGE.

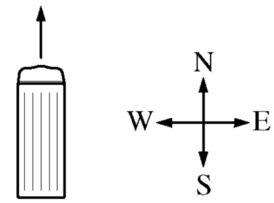
3. A newly discovered planet is found to have density $\frac{2}{3}\rho_E$ and radius $2R_E$, where ρ_E and R_E are the density and radius of Earth, respectively. The surface gravitational field of the planet is most nearly

(A) 1.7 N/kg

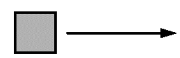
(B) 3.3 N/kg

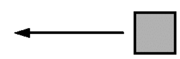
(C) 6.7 N/kg

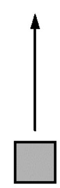
(D) 13 N/kg

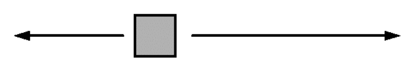


4. A bus is initially traveling north at a constant speed, as shown in the figure above. As the bus starts to make a left turn without changing speed, a passenger notices that a box on the floor starts sliding toward the right side of the bus. Which of the following top views of the box, when correctly labeled, would best represent all of the horizontal forces exerted on the box as it starts sliding?

(A) 

(B) 

(C) 

(D) 

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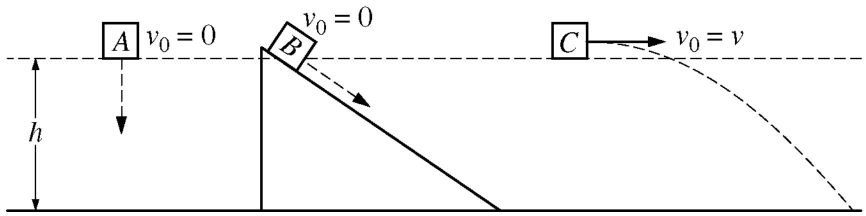
Questions 5-6 refer to the following material.



Three identical blocks each take a different path from a height h to the ground. Block A is released from rest and falls vertically. Block B is released from rest and slides down a frictionless incline. Block C is projected horizontally with an initial speed v.

5. Which block takes the longest time to reach the ground?

   (A) A
   (B) B
   (C) C
   (D) The blocks take the same time to reach the ground.

6. Which block has the greatest speed just before hitting the ground?

   (A) A
   (B) B
   (C) C
   (D) The blocks reach the ground with the same speed.

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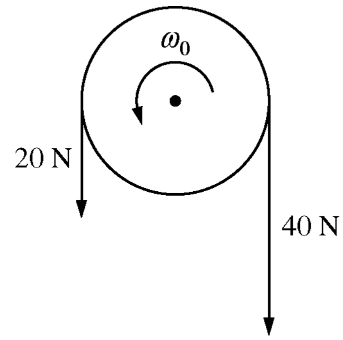
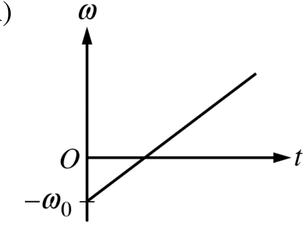
7. A ball is dropped from rest and falls to the floor. The initial gravitational potential energy of the ball-Earth-floor system is 10 J. The ball then bounces back up to a height where the gravitational potential energy is 7 J. What was the mechanical energy of the ball-Earth-floor system the instant the ball left the floor?

(A) 0 J
(B) 3 J
(C) 7 J
(D) 10 J



8. A disk is initially rotating counterclockwise around a fixed axis with angular speed ω_0. At time $t = 0$, the two forces shown in the figure above are exerted on the disk. If counterclockwise is positive, which of the following could show the angular velocity of the disk as a function of time?

(A)


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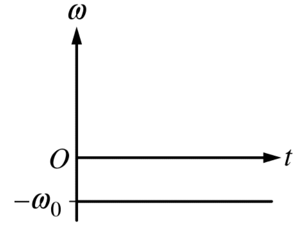

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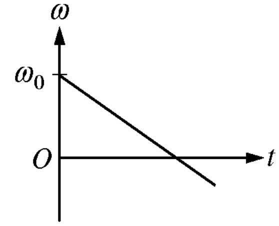

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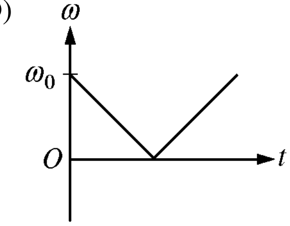

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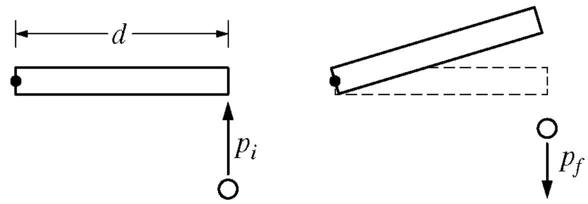
9. A 50.0 N box is at rest on a horizontal surface. The coefficient of static friction between the box and the surface is 0.50, and the coefficient of kinetic friction is 0.30. A horizontal 20.0 N force is then exerted on the box. The magnitude of the acceleration of the box is most nearly

(A) 0 m/s^2
(B) 0.5 m/s^2
(C) 1.0 m/s^2
(D) 4.0 m/s^2



Top View

10. A thin rod of length d on a frictionless surface is pivoted about one end, as shown above, and can rotate freely. The rod is at rest when it is struck by a sphere with linear momentum of magnitude p_i perpendicular to the rod. The sphere rebounds along its original line of motion with momentum of magnitude p_f. What is the magnitude of the angular momentum of the rod immediately after the collision?

(A) $p_f - p_i$
(B) $p_f + p_i$
(C) $(p_f - p_i)d$
(D) $(p_f + p_i)d$

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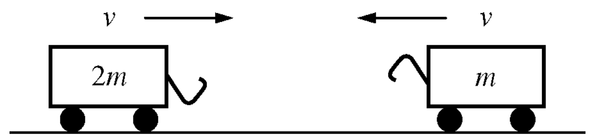
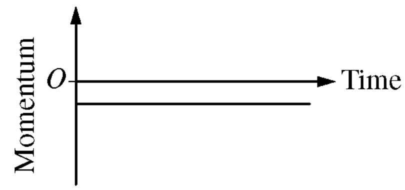
11. A spacecraft is placed in a circular orbit around a planet with mass 6.4×10^{23} kg. The spacecraft orbits at a height of 4.5×10^{7} m above the planet's surface. What additional information is needed to calculate the speed of the spacecraft in the orbit?

(A) No additional information
(B) The planet's radius only
(C) The spacecraft's mass only
(D) Both the planet's radius and the spacecraft's mass



12. Two carts, of mass 2*m* and *m*, approach each other head-on with the same speed *v*, as shown in the figure above. When the carts collide, they hook together. Assuming positive momentum is to the right, which of the following best represents the momentum of the cart of mass *m* as a function of time before and after the collision?

(A)


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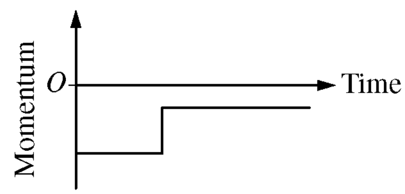

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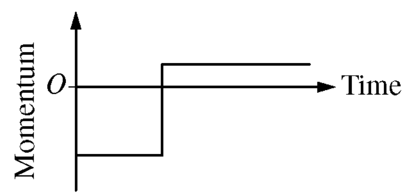

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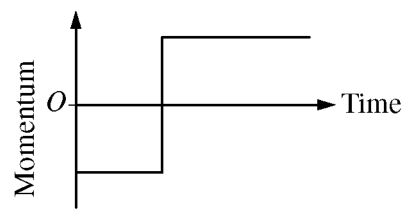

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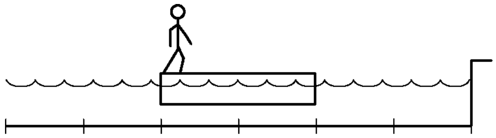
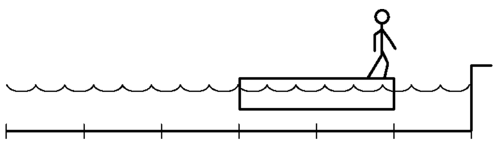


13. A student stands at one end of a raft floating in a pool with equally spaced marks along the bottom, as shown above. The student and the raft have the same mass. The student walks to the opposite end of the raft. Which of the following best shows the final locations of the raft and student relative to the marks at the bottom of the pool? Assume that there is no drag force between the raft and the water.

(A)



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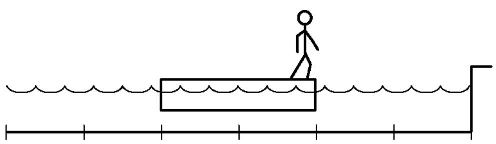
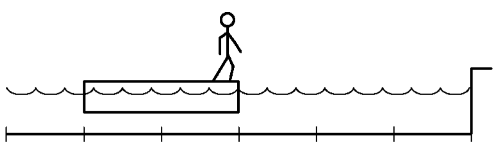
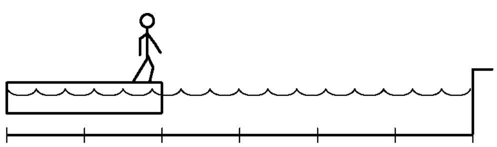
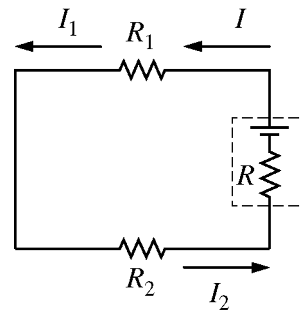


(C)



(D)





14. A circuit is designed with two resistors, $R_1 = 200\ \Omega$ and $R_2 = 400\ \Omega$, and a battery with internal resistance $R = 10\ \Omega$, as shown above. What is the relationship between the three labeled currents?

(A) $I_1 + I_2 = I$
(B) $I > I_1 > I_2$
(C) $I_2 > I_1 > I$
(D) $I_1 = I_2 = I$

No longer tested

GO ON TO THE NEXT PAGE.

1X. When two charged, massive objects are placed a distance r apart, the gravitational force between them has magnitude F. When the distance between the objects is increased to $2r$, the magnitude of the gravitational force between them becomes $F/4$. Did the electrostatic force between the objects also decrease to one fourth its initial magnitude as a result of the change in position, and why?

(A) No, because the gravitational constant is much smaller than the electrostatic constant.
(B) No, because the gravitational force is only attractive, and the electrostatic force can also be repulsive.
(C) Yes, because both forces have the same $1/r^2$ dependence.
(D) Yes, because the gravitational force always equals the electrostatic force at any given distance.

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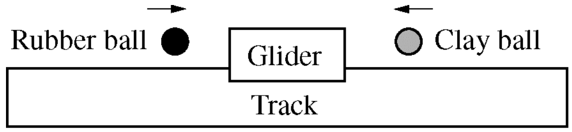

16. A clay ball and a rubber ball of the same mass are moving toward a glider that is at rest on a frictionless air track. The balls have the same speed, with the rubber ball moving toward the right and the clay ball moving toward the left, as shown above. The balls strike the glider at the same time. The clay ball sticks to the glider, and the rubber ball bounces off it. Which of the following indicates the direction of motion of the glider after the collisions and explains why it moves in that direction?

(A) The glider moves to the right because the magnitude of the change in momentum of the rubber ball is greater than the magnitude of the change in momentum of the clay ball.
(B) The glider moves to the right because the collision with the rubber ball is elastic and conserves energy.
(C) The glider moves to the left because the clay ball has more inertia when it sticks to the glider than the rubber ball does when it bounces off.
(D) The glider moves to the left because the clay ball exerts a force on the glider for a longer time than the rubber ball does.

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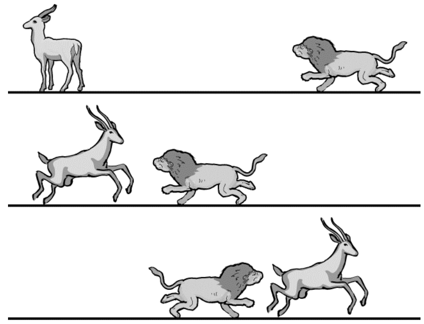
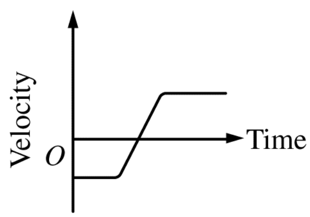
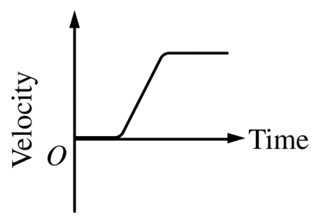


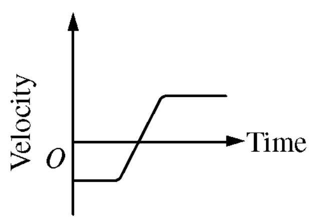
17. A lion is running at constant speed toward a gazelle that is standing still, as shown in the top figure above. After several seconds, the gazelle notices the lion and accelerates directly toward him, hoping to pass the lion and force him to reverse direction. As the gazelle accelerates toward and past the lion, the lion changes direction and accelerates in pursuit of the gazelle. The lion and the gazelle eventually each reach constant but different speeds. Which of the following sets of graphs shows a reasonable representation of the velocities of the lion and the gazelle as functions of time?

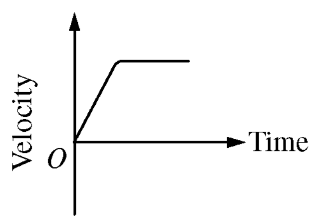
(A) LION GAZELLE



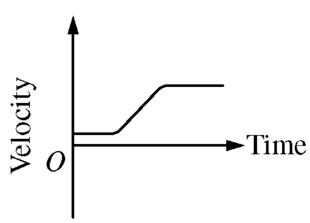


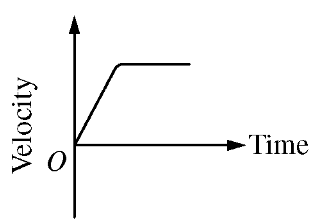
(B) LION GAZELLE



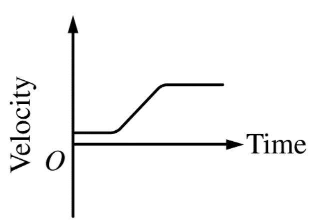


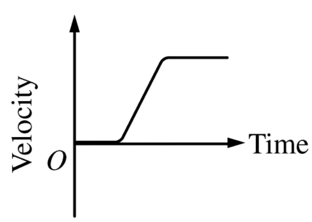
(C) LION GAZELLE





(D) LION GAZELLE





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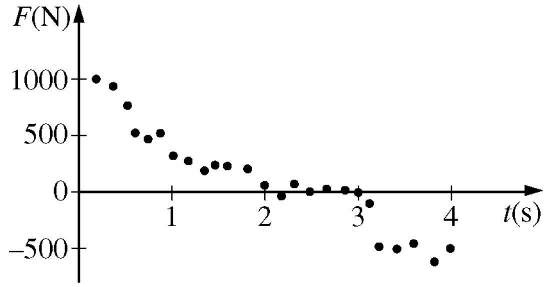

18. A spacecraft of mass 4000 kg is traveling in a straight line in the positive direction. Engines can be fired so that the force exerted on the spacecraft is in the positive or negative direction. The graph above shows data for the force during one interval. Which of the following is the best estimate of the net change in the speed of the spacecraft from time $t = 0$ to time $t = 4$ s ?

(A) +0.4 m/s

(B) +0.1 m/s

(C) −0.1 m/s

(D) −0.4 m/s

19. A rocket is continuously firing its engines as it accelerates away from Earth. For the first kilometer of its ascent, the mass of fuel ejected is small compared to the mass of the rocket. For this distance, which of the following indicates the changes, if any, in the kinetic energy of the rocket, the gravitational potential energy of the Earth-rocket system, and the mechanical energy of the Earth-rocket system?

	Rocket Kinetic Energy	System Gravitational Potential Energy	System Mechanical Energy
(A)	Increasing	Increasing	Increasing
(B)	Increasing	Increasing	Constant
(C)	Increasing	Decreasing	Decreasing
(D)	Decreasing	Increasing	Constant

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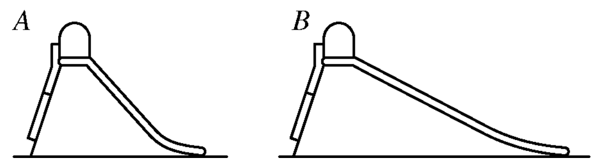
20. Block 1 is attached to a spring and oscillates on a horizontal frictionless surface. When block 1 is at a point of maximum displacement, block 2 is placed on top of it from directly above without interrupting the oscillation, and the two blocks stick together. How do the maximum kinetic energy and period of oscillation with both blocks compare to those of block 1 alone?

	Maximum Kinetic Energy	Period
(A)	Smaller	Smaller
(B)	Smaller	Greater
(C)	The same	Smaller
(D)	The same	Greater



21. A child slides from rest down slides A and B shown above. The slides are the same height, and the coefficient of friction between the slides and the child is the same. Which of the following compares the change ΔK in the kinetic energy of the child and the change ΔU in the potential energy of the child-Earth system for the two slides?

(A) $\Delta K_A = \Delta K_B$; $\Delta U_A = \Delta U_B$

(B) $\Delta K_A < \Delta K_B$; $\Delta U_A > \Delta U_B$

(C) $\Delta K_A > \Delta K_B$; $\Delta U_A = \Delta U_B$

(D) $\Delta K_A > \Delta K_B$; $\Delta U_A > \Delta U_B$

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Questions 22-24 refer to the following material.

A student is observing an object of unknown mass that is oscillating horizontally at the end of an ideal spring. The student measures the object's period of oscillation with a stopwatch.

22. The student wishes to determine the spring constant of the spring using the measurements of the period of oscillation. Which of the following pieces of equipment would provide another measured quantity that is sufficient information to complete the determination of the spring constant?

(A) Meterstick
(B) Motion sensor
(C) Balance
(D) Photogate

23. Using a number of measurements, the student determines the following.

Spring constant	$85\ \text{N/m}$
Mass of object	0.50 kg
Amplitude of oscillation	0.30 m
Maximum speed of object	$3.9\ \text{m/s}$

The total energy of the object-spring system is most nearly

(A) 0.98 J
(B) 3.8 J
(C) 7.6 J
(D) 12.8 J

24. While the object is continuously oscillating, the student determines the maximum speed of the object during two oscillations. The first speed is $3.5\ \text{m/s}$ and the second speed is $2.7\ \text{m/s}$. Which of the following could account for the decrease in the object's maximum kinetic energy?

(A) Energy was transferred from the object to the spring, which increased the maximum potential energy of the spring.
(B) Energy was transferred from the spring to the object, which decreased the maximum potential energy of the spring.
(C) As energy was transferred back and forth between the object and the spring, a greater average share of the energy became potential energy of the spring.
(D) The object-spring system lost energy to its surroundings.

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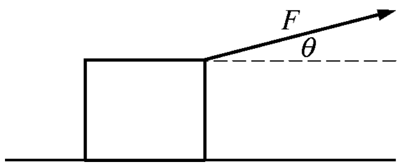
Questions 25-26 refer to the following material.



A crate is on a horizontal frictionless surface. A force of magnitude F is exerted on the crate at an angle θ to the horizontal, as shown in the figure above, causing the crate to slide to the right. The surface exerts a normal force of magnitude F_N on the crate. As the crate slides a distance d, it gains an amount of kinetic energy ΔK. While F is kept constant, the angle θ is now doubled but is still less than $90°$. Assume the crate remains in contact with the surface.

25. How does the new normal force exerted on the crate compare to F_N?

(A) The new normal force is greater than F_N.
(B) The new normal force is less than F_N.
(C) The new normal force is equal to F_N.
(D) The new normal force is greater or less than F_N depending on the value of θ.

26. As the crate slides a distance d, how does the new gain in kinetic energy compare to ΔK?

(A) The new gain is greater than ΔK.
(B) The new gain is less than ΔK.
(C) The new gain is equal to ΔK.
(D) The new gain is greater or less than ΔK depending on the value of θ.

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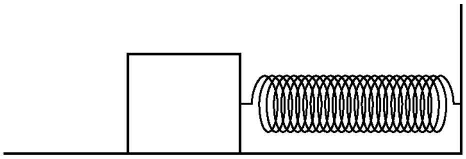
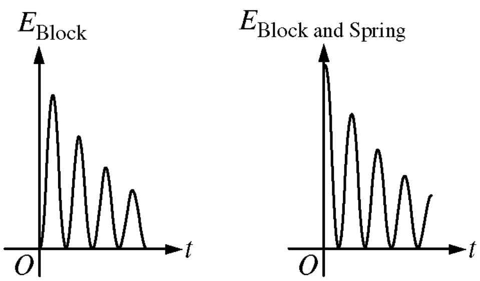
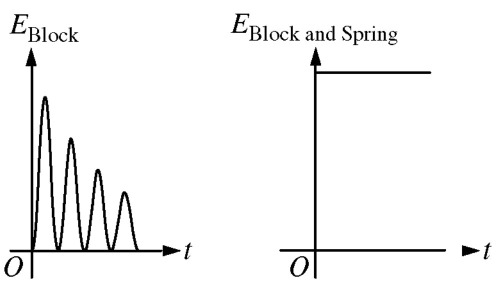
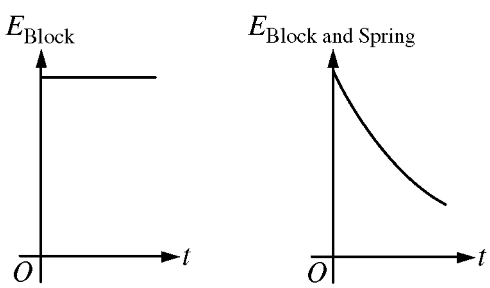
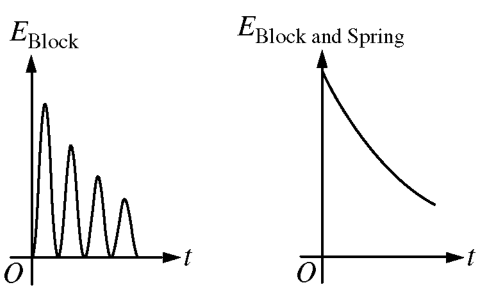


27. A block on a level surface is attached to one end of a spring, as shown in the figure above. The other end of the spring is attached to a wall. There is friction between the block and the surface. A person displaces the block from its equilibrium position and releases it. Which of the following shows the mechanical energy E as a function of time t for the system that includes only the block and the system that includes the block and spring?

(A) 

(B) 

(C) 

(D) 

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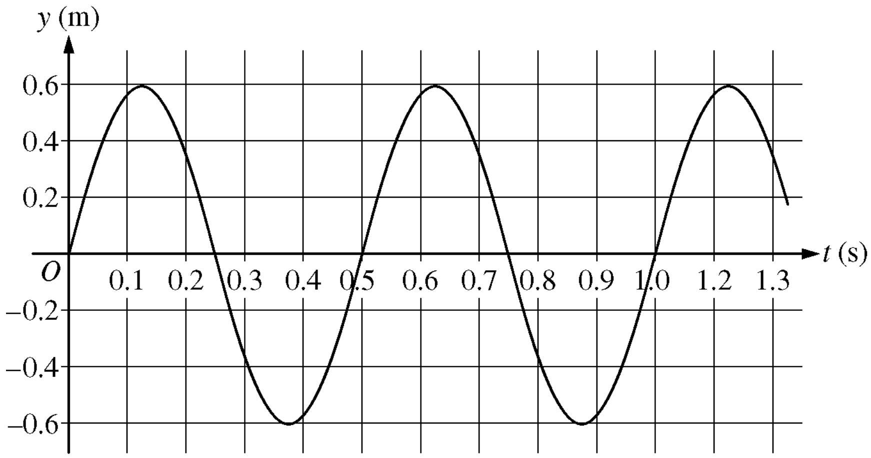

28. A transverse wave is traveling on a string. The graph above shows position as a function of time for a point on the string. If the frequency of the wave is doubled, what is the new average speed of the point?

(A) 0 m/s

(B) 2.4 m/s

(C) 4.8 m/s

(D) 9.6 m/s

Question 28 no longer tested

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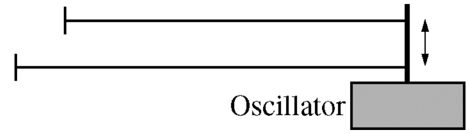
29. Alan and Beverly are on opposite sides of a large room when Alan says something to Beverly. Beverly does not hear him, so Alan repeats the message louder and Beverly now hears it. Which of the following could be different about the second sound wave compared to the first that allows Beverly to hear it?

(A) The second wave travels to Beverly more quickly, so less energy is dissipated by the time the wave reaches her.
(B) The second wave reflects more off the walls of the room.
(C) The air molecules disturbed by the second wave undergo a greater displacement from their equilibrium positions.
(D) The air molecules disturbed by the second wave are, on average, more closely spaced.

Not tested anymore



30. Two strings differing only in length are attached to the same oscillator, as shown in the figure above. Both are fixed at the other end and are under the same tension. The oscillator creates a transverse wave and is adjusted to the lowest frequency that creates a standing wave on the shorter string. Which of the following explains why there will not be a standing wave on the longer string?

(A) The waves travel at slightly different speeds on the two strings.
(B) An oscillator frequency that results in a standing wave on a string of one length cannot result in a standing wave on a string with a different length.
(C) The amplitude of the wave does not match the boundary conditions for strings of different length at the same time.
(D) The wavelength associated with the given frequency does not match the boundary conditions set by the length of the longer string.

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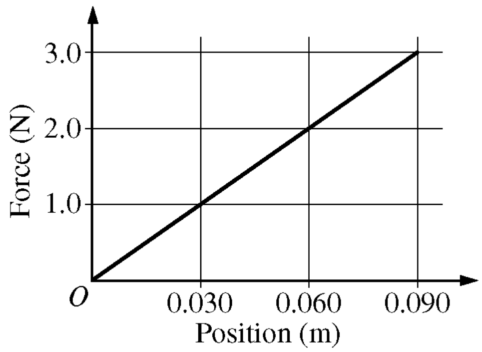
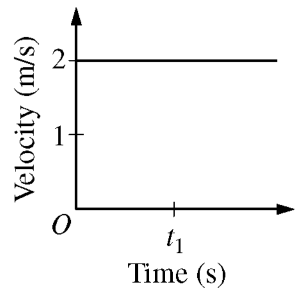


31. The figure above shows the net force exerted on an object as a function of the position of the object. The object starts from rest at position $x = 0$ m and acquires a speed of 3.0 m/s after traveling a distance of 0.090 m. What is the mass of the object?

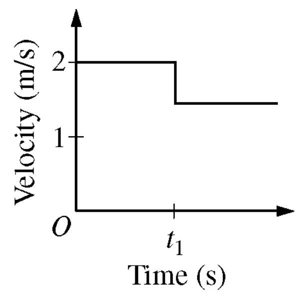
(A) 0.015 kg
(B) 0.030 kg
(C) 0.045 kg
(D) 0.060 kg

32. Two identical carts are free to move along a straight frictionless track. At time t_1, cart *X* is moving at 2.0 m/s when it collides with and sticks to cart *Y*, which is initially at rest. Which of the following graphs best shows the velocity of cart *X* before and after the collision?

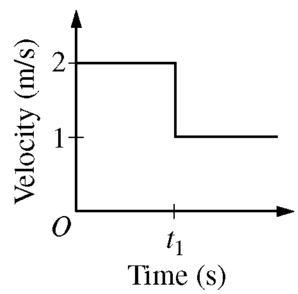
(A)



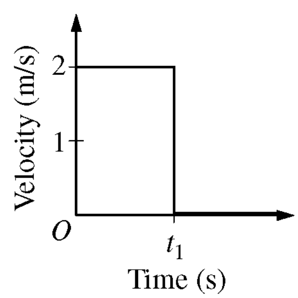
(B)



(C)



(D)



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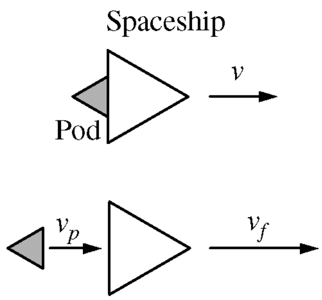
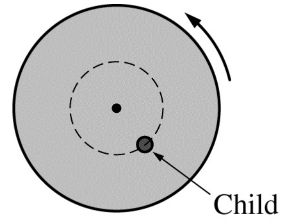


33. A spaceship and its shuttle pod are traveling to the right in a straight line with speed v, as shown in the top figure above. The mass of the pod is m, and the mass of the spaceship is $6m$. The pod is launched, and afterward the pod is moving to the right with speed v_p and the spaceship is moving to the right with speed v_f, where $v_f > v$, as shown in the bottom figure. Which of the following is true of the speed v_c of the center of mass of the system after the pod is launched?

(A) $v_c = v_f$
(B) $v < v_c < v_f$
(C) $v_c < v$
(D) $v_c = v$



Top View

34. The diagram above shows a top view of a child of mass M on a circular platform of mass $5M$ that is rotating counterclockwise. Assume the platform rotates without friction. Which of the following describes an action by the child that will result in an increase in the total angular momentum of the child-platform system?

(A) The child moves toward the center of the platform.
(B) The child moves away from the center of the platform.
(C) The child moves along a circle concentric with the platform (dashed line shown) opposite the direction of the platform's rotation.
(D) None of the actions described will change the total angular momentum of the child-platform system.

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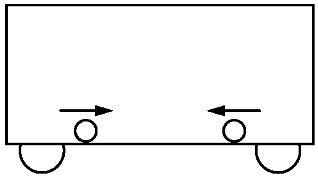

35. A train is traveling east with constant speed v_t. Two identical spheres are rolling on the floor of one train car. In the frame of reference of the train, the spheres are moving directly toward each other at one instant with the same speed v_p parallel to the train's motion, as shown in the figure above. What is the velocity of the center of mass of the spheres in the frame of reference of the train and in the frame of reference of a person standing at rest alongside the train?

	Train	Person
(A)	Zero	Zero
(B)	Zero	v_t east
(C)	v_t east	$v_p + v_t$ east
(D)	$v_p + v_t$ east	Zero

36. A satellite that is a spinning cylinder has initial rotational inertia I_0 and angular velocity ω_0. Solar panels unfold from the satellite and are extended outward. The satellite then has rotational inertia $I_f = aI_0$ and angular velocity $\omega_f = b\omega_0$, where a and b are constants. Which of the following is true about the constants a and b ?

(A) $a = 1$ and $b = 1$
(B) $a > 1$ and $b < 1$
(C) $a > 1$ and $b = 1$
(D) $a < 1$ and $b < 1$

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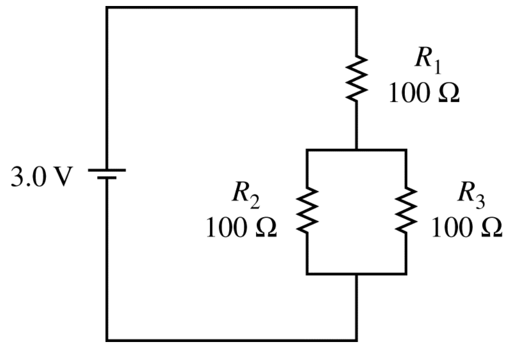
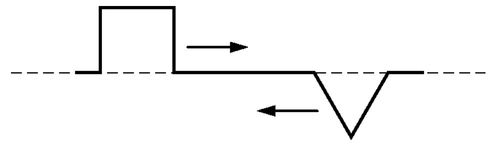


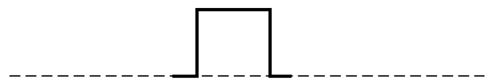
37. When the circuit shown above is set up, the potential difference across the battery is 3.0 V. By how much will the magnitude of the potential difference across R_2 change when R_3 is removed and its branch is left open?

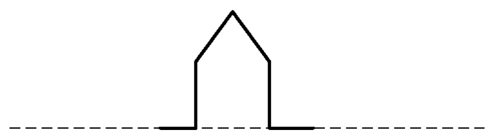
(A) The magnitude of the potential difference across R_2 does not change.
(B) The magnitude of the potential difference across R_2 decreases by 0.5 V.
(C) The magnitude of the potential difference across R_2 increases by 0.5 V.
(D) The magnitude of the potential difference across R_2 increases by 1.0 V.

Not tested anymore

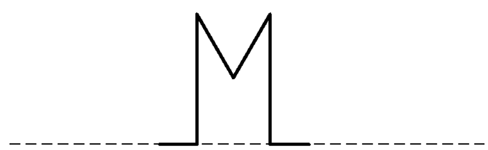


38. Two wave pulses are propagating along a straight line toward each other as shown above. Which of the following is the resultant when the centers of the pulses align?

(A) 

(B) 

(C) 

(D) 

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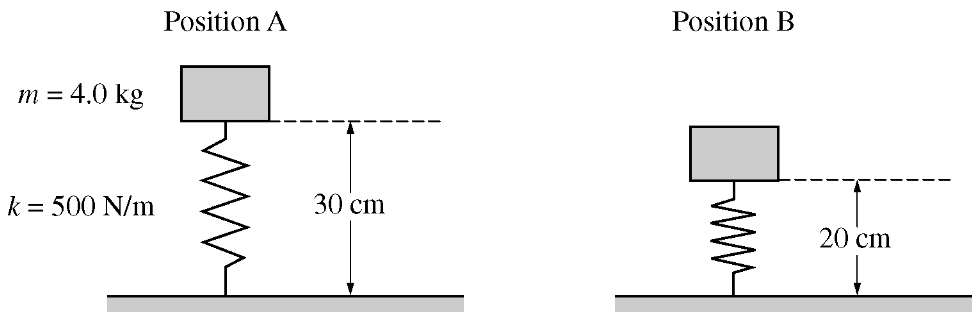

39. A person holds a 4.0 kg block at position A shown above on the left, in contact with an uncompressed vertical spring with a spring constant of 500 N/m. The person gently lowers the block from rest at position A to rest at position B. Which of the following describes the change in the energy of the block-spring-Earth system as a result of the block being lowered?

(A) The energy decreases by approximately 1.5 J.
(B) The energy decreases by approximately 2.5 J.
(C) The energy increases by approximately 4.0 J.
(D) The energy of the system does not change.

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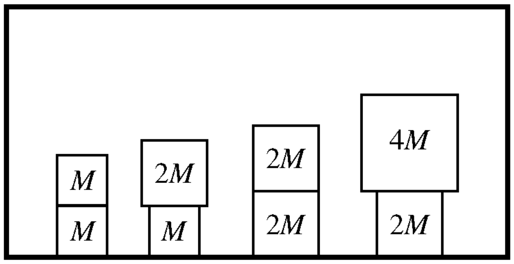
Questions 40-42 refer to the following material.



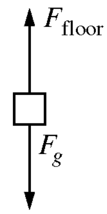
The stacks of boxes shown in the figure above are inside an elevator that is moving upward. The masses of the boxes are given in terms of the mass M of the lightest box.

40. How does the magnitude of the force exerted by the top box on the bottom box compare with the magnitude of the force exerted by the bottom box on the top box for each of the stacks?

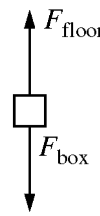
(A) The two magnitudes are always equal in each of the stacks.
(B) The two magnitudes are always different in each of the stacks.
(C) The two magnitudes are equal when the boxes have equal mass and different when the boxes have different masses.
(D) The two magnitudes are equal when the elevator is moving at constant speed and different when it is accelerating.

41. Assume the elevator is moving at constant speed, and consider the bottom box in the stack that has two boxes of mass $2M$. Let F_{floor} be the force exerted by the floor on the box, F_g be the force exerted by gravity on the box, and F_{box} be the force exerted by the top box on the bottom box. Which of the following best represents the forces exerted on the bottom box?

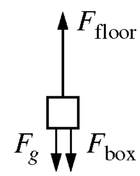
(A)



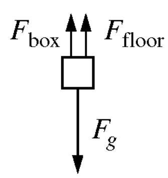
(B)



(C)



(D)



42. Assume the elevator has upward acceleration a, and consider the stack that has two boxes of mass M. What is the magnitude of the force exerted on the top box by the bottom box?

(A) Mg
(B) Ma
(C) $M(a-g)$
(D) $M(a+g)$

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Questions 43-53

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.

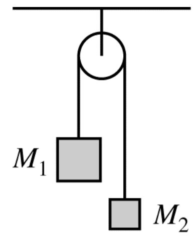
Note: To simplify calculations, you may use $g = 10\,\text{m/s}^2$ in all problems.

43. An object is released from rest from a great height and reaches its terminal velocity. Which of the following statements is true of the object while it is falling with terminal velocity?

(A) There is no longer a gravitational force on it.
(B) There is no longer a drag (air resistance) force on it.
(C) Its acceleration is upward.
(D) The magnitudes of the gravitational and drag forces on it are equal.
(E) The gravitational and drag forces on it act in the same direction.

44. A student with a mass of 50 kg is standing on a bathroom scale while riding in an elevator. If the reading on the scale is 400 N, which of the following is a correct description of the elevator's motion?

(A) Moving upward with increasing speed
(B) Moving upward with constant speed
(C) Moving downward with constant speed
(D) Moving downward with increasing speed
(E) Moving downward with decreasing speed

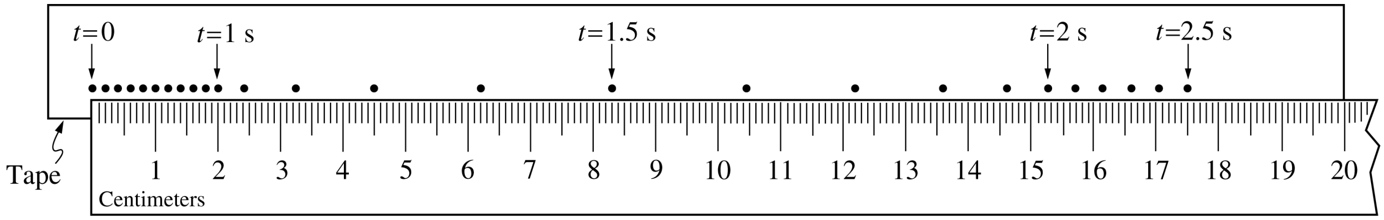


45. The system represented above consists of two objects of unequal masses, M_1 and M_2, with $M_1 > M_2$. The objects hang from the ends of a cord of negligible mass that passes over a pulley with negligible mass and friction. Which of the following is true about the changes in the gravitational potential energy, ΔU, and kinetic energy, ΔK, of the system soon after the objects are released from rest?

(A) $\Delta U < 0$ and $\Delta K > 0$
(B) $\Delta U = 0$ and $\Delta K > 0$
(C) $\Delta U < 0$ and $\Delta K = 0$
(D) $\Delta U = 0$ and $\Delta K = 0$
(E) $\Delta U > 0$ and $\Delta K < 0$

Questions 46-48 refer to the following material.

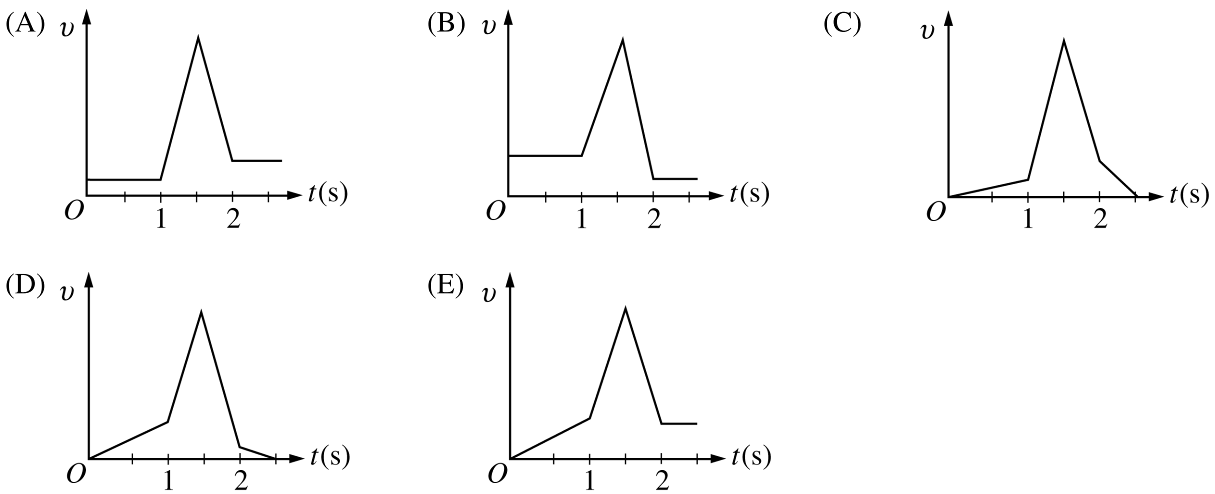
A tape attached to a moving object was pulled by the object through a marker that put dots on the tape at a constant rate of 10 dots per second for a period of 2.5 s. The figure below shows the marked tape next to a centimeter ruler.



46. The average speed of the object for the total time recorded on the tape is most nearly

(A) 2.0 cm/s
(B) 3.3 cm/s
(C) 4.5 cm/s
(D) 5.5 cm/s
(E) 7.0 cm/s

47. Which of the following best represents the graph of the velocity of the object versus time?



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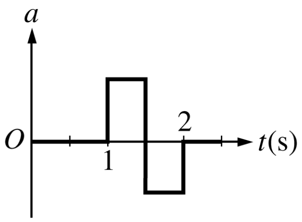
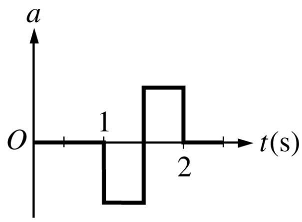
48. Which of the following best represents the graph of the acceleration of the object versus time?

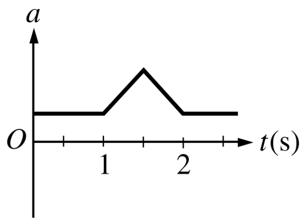
(A)



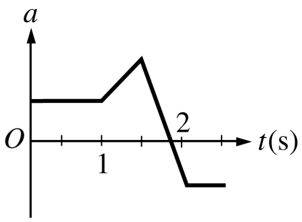
(B)



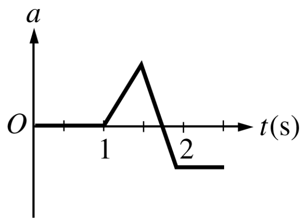
(C)



(D)



(E)



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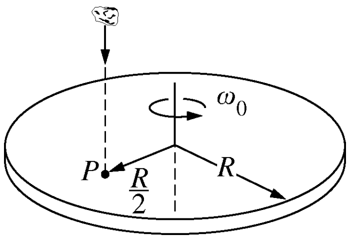
Questions 49-50 refer to the following material.



A turntable with mass m, radius R, and rotational inertia $\frac{mR^2}{2}$ initially rotates freely about an axis through its center at constant angular speed with negligible friction. A piece of clay, also of mass m, falls vertically onto the turntable, as shown above, and sticks to it at point P, a distance $\frac{R}{2}$ from the center of rotation.

49. What is the rotational inertia of the clay-turntable system after the collision?

(A) $\frac{1}{4}mR^2$

(B) $\frac{1}{2}mR^2$

(C) $\frac{3}{4}mR^2$

(D) mR^2

(E) $2mR^2$

50. What happens to the rotational speed of the turntable and the angular momentum of the clay-turntable system about the axis as a result of the collision?

	Rotational Speed	Angular Momentum
(A)	Stays the same	Increases
(B)	Stays the same	Stays the same
(C)	Stays the same	Decreases
(D)	Decreases	Stays the same
(E)	Decreases	Decreases

51. Which of the following must be true in order for a rotating platform to continue rotating with a constant angular velocity?

(A) There are no forces exerted on it.
(B) There is no friction exerted on it.
(C) There is zero net force exerted on it.
(D) There are no torques exerted on it.
(E) There is zero net torque exerted on it.

52. A newly discovered planet is found to have twice the radius and three times the mass of Earth. If the acceleration due to gravity at the surface of Earth is g, the acceleration due to gravity at the surface of the new planet is

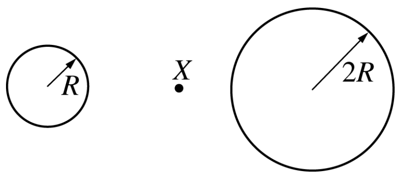
(A) $\frac{2g}{3}$

(B) $\frac{3g}{4}$

(C) g

(D) $\frac{4g}{3}$

(E) $\frac{3g}{2}$



53. At point X shown above, which is midway between the centers of two isolated planets of radii R and $2R$, the net gravitational force on an object is zero. If the mass of the smaller planet is M, the mass of the larger planet is

(A) $\frac{M}{4}$

(B) $\frac{M}{2}$

(C) M

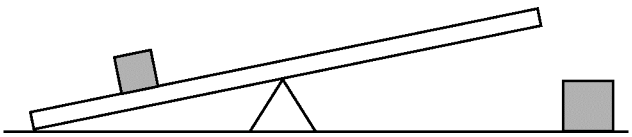
(D) $2M$

(E) $4M$

GO ON TO THE NEXT PAGE.

Questions 131-135

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 enter both of the appropriate letters in the corresponding space on the answer sheet.



A uniform plank is placed with a pivot at its center. A block is placed on the plank to the left of the pivot, as shown in the figure above. A student is asked to place a second block of greater mass on the plank so it will balance when horizontal. Which of the following quantities are needed to determine where the second block should be placed? Select two answers.

(A) The mass of the plank
(B) The mass of each block
(C) The length of the plank
(D) The distance from the pivot to the left block

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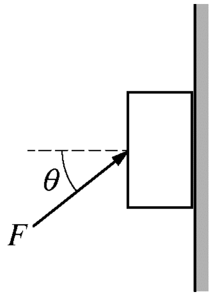

132. A block is held at rest against a wall by a force of magnitude F exerted at an angle θ from the horizontal, as shown in the figure above. Let $\vec{F}_g$ be the gravitational force exerted by Earth on the block, $\vec{F}_N$ be the normal force exerted by the wall on the block, and $\vec{F}_f$ be the frictional force exerted by the wall on the block. Which of the following statements about the magnitudes of the forces on the block must be true? Select two answers.

(A) $F = F_g / \sin\theta$
(B) $F\cos\theta = F_N$
(C) $F\sin\theta = F_g \pm F_f$
(D) $F = F_g + F_N \pm F_f$

133. Some students have determined the gravitational mass of an object and want to compare it to the object's inertial mass. Procedures that would allow them to accomplish this include which of the following? Select two answers.

(A) Hanging the object vertically from a spring scale and recording the scale reading
(B) Placing the object on one side of a double pan balance, adding objects of known mass to the other side until the masses are balanced, and recording the amount of mass added
(C) Attaching the object to a spring of known spring constant, allowing it to oscillate horizontally on a nearly frictionless surface, and measuring the period
(D) Attaching the object to a force sensor, using the sensor to pull the object across a nearly frictionless horizontal surface, and measuring the acceleration

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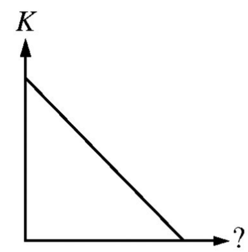


134. A block is given a short push and then slides with constant friction across a horizontal floor. The graph above shows the kinetic energy of the block after the push ends as a function of an unidentified quantity. The quantity could be which of the following? Select two answers.

(A) Time elapsed since the push

(B) Distance traveled by the block

(C) Speed of the block

(D) Magnitude of the net work done on the block

135. A 0.2 kg rock is dropped into a lake from a few meters above the surface of the water. The rock reaches terminal velocity in the lake after 5 s in the water. During the final 3 s of its descent to the lake bottom, the rock moves at a constant speed of 4 m/s. Which of the following can be determined from the information given? Select two answers.

(A) The speed of the rock as it enters the lake

(B) The distance the rock travels in the first 5 s of its descent in the water

(C) The acceleration of the rock 2 s before it reaches the lake bottom

(D) The change in potential energy of the rock-Earth-water system during the final 3 s of the rock's descent

AP® Physics 1 Practice Exam

SECTION II: Free Response

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
90 minutes
Number of Questions
5
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Suggested Time
Approximately 25 minutes each for questions 2 and 3 and 13 minutes each for questions 1, 4, and 5
Weight
Approximate weights:
Questions 2 and 3: 26% each
Questions 1, 4, and 5: 16% each

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐

   First letter of your first name ☐

2. Date of birth

   ☐☐ ☐☐ ☐☐☐☐
   Month Day Year

3. Six-digit school code

   ☐☐☐☐☐☐

4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.

   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

NO TEST MATERIAL ON THIS PAGE

AP® PHYSICS 1 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	Coulomb's law constant, $k = 1/4\pi\varepsilon_0 = 9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Universal gravitational constant, $G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Speed of light, $c = 3.00 \times 10^8$ m/s	Acceleration due to gravity at Earth's surface, $g = 9.8\ \text{m/s}^2$

UNIT SYMBOLS								
	meter,	m	kelvin,	K	watt,	W	degree Celsius,	°C
	kilogram,	kg	hertz,	Hz	coulomb,	C		
	second,	s	newton,	N	volt,	V		
	ampere,	A	joule,	J	ohm,	Ω		

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. Assume air resistance is negligible unless otherwise stated.
III. In all situations, positive work is defined as work done on a system.
IV. The direction of current is conventional current: the direction in which positive charge would drift.
V. Assume all batteries and meters are ideal unless otherwise stated.

AP® PHYSICS 1 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$

$v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

$|\vec{F}_f| \le \mu |\vec{F}_n|$

$a_c = \frac{v^2}{r}$

$\vec{p} = m\vec{v}$

$\Delta \vec{p} = \vec{F}\,\Delta t$

$K = \frac{1}{2}mv^2$

$\Delta E = W = F_{\parallel}d = Fd\cos\theta$

$P = \frac{\Delta E}{\Delta t}$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$

$\omega = \omega_0 + \alpha t$

$x = A\cos(2\pi ft)$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

$\tau = r_{\perp}F = rF\sin\theta$

$L = I\omega$

$\Delta L = \tau\,\Delta t$

$K = \frac{1}{2}I\omega^2$

$|\vec{F}_s| = k|\vec{x}|$

$U_s = \frac{1}{2}kx^2$

$\rho = \frac{m}{V}$

a = acceleration
A = amplitude
d = distance
E = energy
f = frequency
F = force
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
V = volume
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
ρ = density
τ = torque
ω = angular speed

$\Delta U_g = mg\,\Delta y$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$|\vec{F}_g| = G\frac{m_1 m_2}{r^2}$

$\vec{g} = \frac{\vec{F}_g}{m}$

$U_G = -\frac{Gm_1 m_2}{r}$

ELECTRICITY

$|\vec{F}_E| = k\left|\frac{q_1 q_2}{r^2}\right|$

$I = \frac{\Delta q}{\Delta t}$

$R = \frac{\rho \ell}{A}$

$I = \frac{\Delta V}{R}$

$P = I\,\Delta V$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

A = area
F = force
I = current
ℓ = length
P = power
q = charge
R = resistance
r = separation
t = time
V = electric potential
ρ = resistivity

WAVES

$\lambda = \frac{v}{f}$

f = frequency
v = speed
λ = wavelength

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

Rectangular solid
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

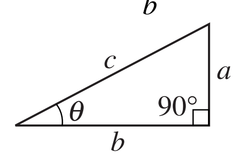
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

Right triangle
$c^2 = a^2 + b^2$

$\sin\theta = \frac{a}{c}$

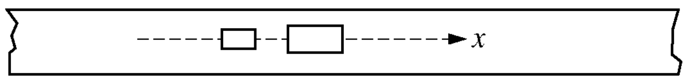
$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$



PHYSICS 1
Section II
5 Questions
Time—90 minutes

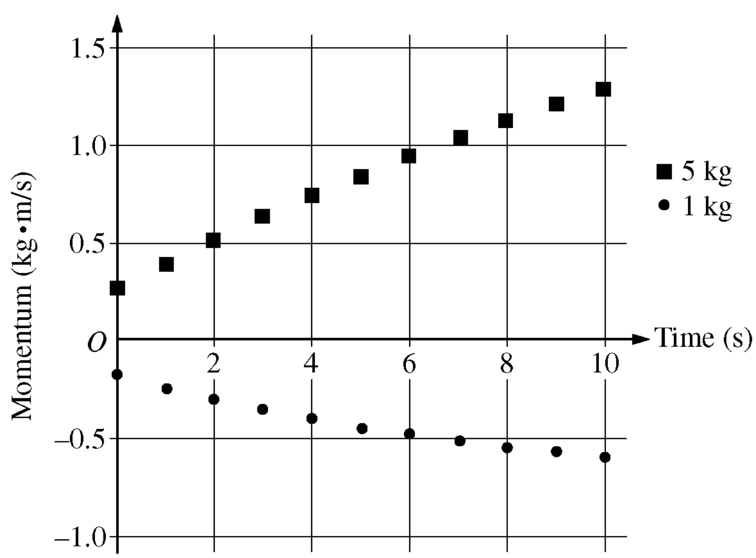
Directions: Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Show your work for each part in the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



Top View

1. (7 points, suggested time about 13 minutes)
The figure above represents two carts, with magnets attached, that make up a system. The mass of one cart and magnet is 1 kg and the mass of the other is 5 kg. The carts are initially at rest on a frictionless track. They are released from rest and exert a repulsive force on each other. The track is not quite horizontal, with the right side slightly lower than the left side.

The speeds of the carts are measured over a 10 s interval. The graph below shows the momentum of the two carts as a function of time for this interval as they move along the x-axis.



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(a) Based on the graph, were the measurements started at the instant the carts were released?

Justify your answer.

(b) Calculate the magnitude of the external force exerted on the system.

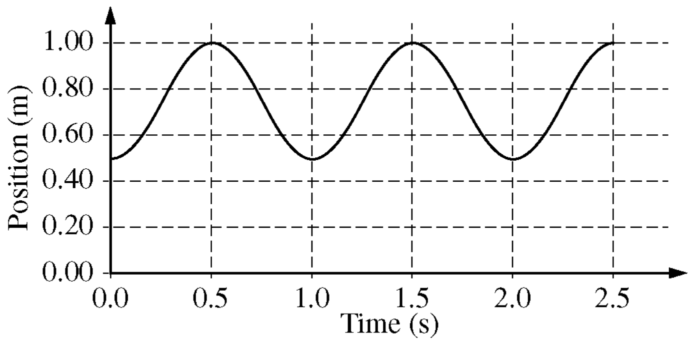
(c) Suppose the experiment is repeated with different carts, so that the masses of cart plus magnet are 2 kg and 4 kg. Would your answer to part (b) be different with the new masses?

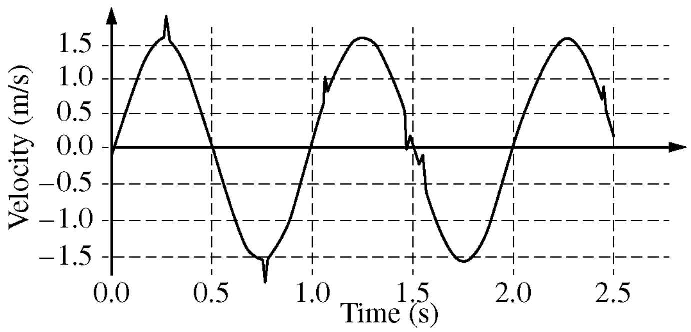
Justify your answer.

GO ON TO THE NEXT PAGE.

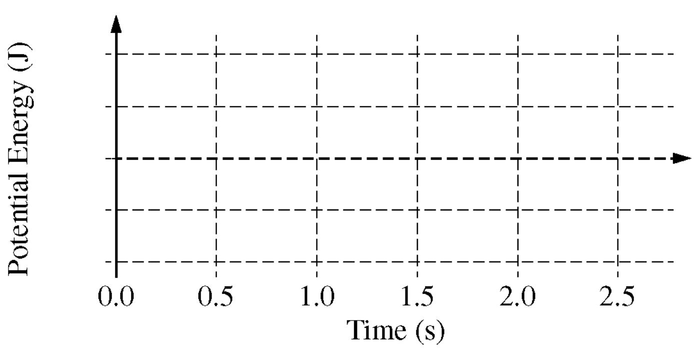
2. (12 points, suggested time 25 minutes)

A student hangs a 0.125 kg object on a spring, sets it into oscillation, and obtains the data for the position and velocity of the object as a function of time shown in the graphs below.

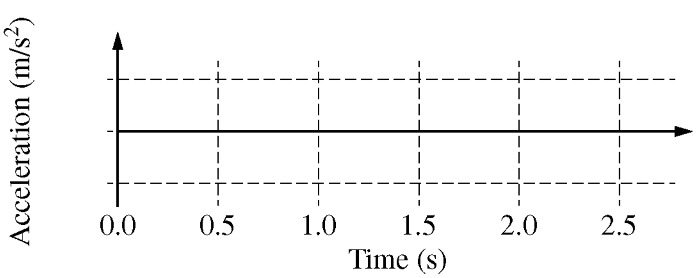




(a) On the grid below, sketch the potential energy of the object-spring-Earth system as a function of time. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values, as appropriate.



(b) On the axes below, sketch the acceleration of the object as a function of time. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values, as appropriate.



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Next the student is given a rubber band and asked to determine whether the relationship between the restoring force exerted by the rubber band and the amount it is stretched is the same as that of an ideal spring.

(c) Describe an experimental procedure that the student could use to collect the necessary data, including all the equipment the student would need.

(d) How should the student analyze the data to determine whether the relationship between the restoring force exerted by the rubber band and the amount it is stretched is the same as that of an ideal spring? What evidence from the analysis would be used to make the determination?

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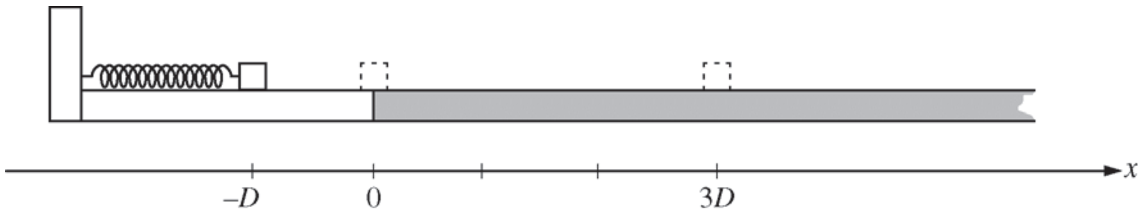


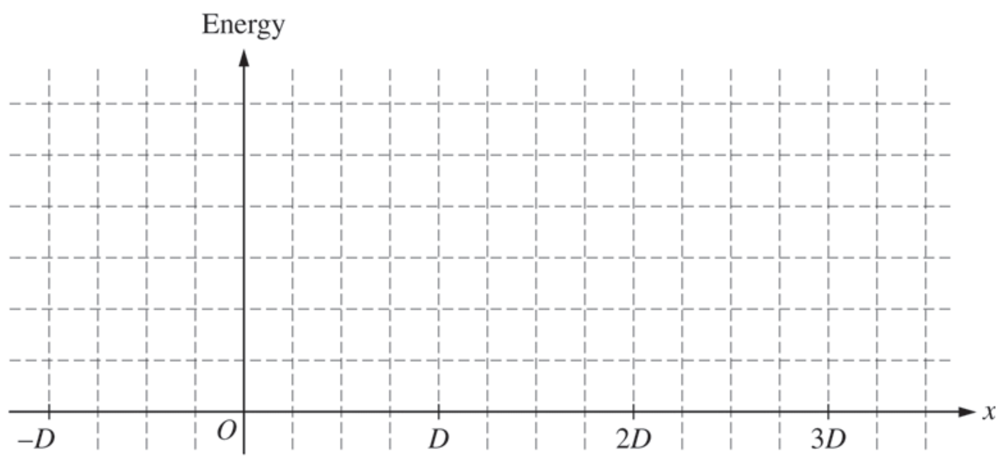
3. (12 points, suggested time 25 minutes)

   A block is initially at position $x = 0$ and in contact with an uncompressed spring of negligible mass. The block is pushed back along a frictionless surface from position $x = 0$ to $x = -D$, as shown above, compressing the spring by an amount $\Delta x = D$. The block is then released. At $x = 0$ the block enters a rough part of the track and eventually comes to rest at position $x = 3D$. The coefficient of kinetic friction between the block and the rough track is μ.

   (a) On the axes below, sketch and label graphs of the following two quantities as a function of the position of the block between $x = -D$ and $x = 3D$. You do not need to calculate values for the vertical axis, but the same vertical scale should be used for both quantities.

      i. The kinetic energy K of the block

      ii. The potential energy U of the block-spring system



The spring is now compressed twice as much, to $\Delta x = 2D$. A student is asked to predict whether the final position of the block will be twice as far at $x = 6D$. The student reasons that since the spring will be compressed twice as much as before, the block will have more energy when it leaves the spring, so it will slide farther along the track before stopping at position $x = 6D$.

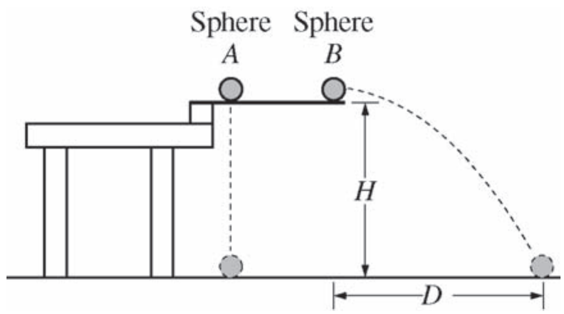
(b)

i. Which aspects of the student's reasoning, if any, are correct? Explain how you arrived at your answer.

ii. Which aspects of the student's reasoning, if any, are incorrect? Explain how you arrived at your answer.

(c) Use quantitative reasoning, including equations as needed, to develop an expression for the new final position of the block. Express your answer in terms of D.

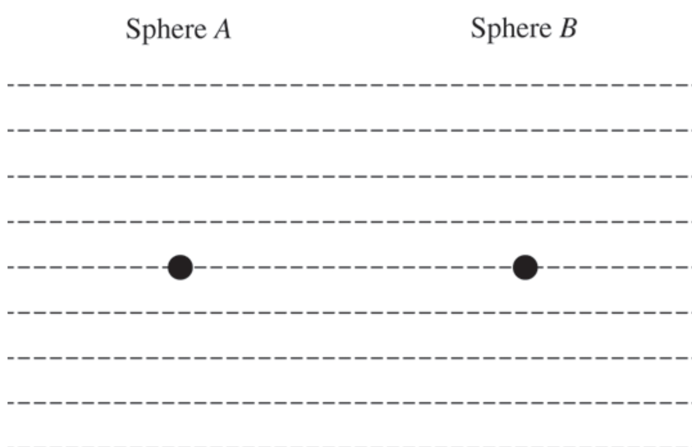
(d) Explain how any correct aspects of the student's reasoning identified in part (b) are expressed by your mathematical relationships in part (c). Explain how your relationships in part (c) correct any incorrect aspects of the student's reasoning identified in part (b). Refer to the relationships you wrote in part (c), not just the final answer you obtained by manipulating those relationships.



4. (7 points, suggested time 13 minutes)

Two identical spheres are released from a device at time $t = 0$ from the same height H, as shown above. Sphere A has no initial velocity and falls straight down. Sphere B is given an initial horizontal velocity of magnitude v_0 and travels a horizontal distance D before it reaches the ground. The spheres reach the ground at the same time t_f, even though sphere B has more distance to cover before landing. Air resistance is negligible.

(a) The dots below represent spheres A and B. Draw a free-body diagram showing and labeling the forces (not components) exerted on each sphere at time $\frac{t_f}{2}$.



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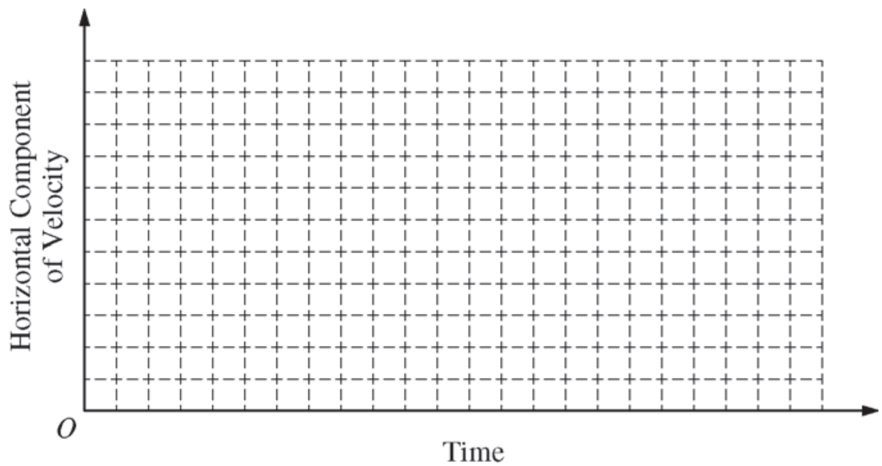
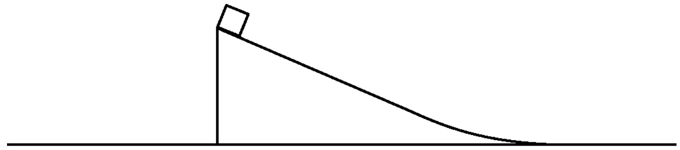
(b) On the axes below, sketch and label a graph of the horizontal component of the velocity of sphere A and of sphere B as a function of time.



(c) In a clear, coherent, paragraph-length response, explain why the spheres reach the ground at the same time even though they travel different distances. Include references to your answers to parts (a) and (b).



5. (7 points, suggested time about 13 minutes)
The figure above shows part of a system consisting of a block at the top of an inclined plane that rests on a table, which is located on Earth. The block and plane are at rest when the block is released. In trial 1 there is no friction between the block and the plane or between the plane and the table. In trial 2 the plane is fixed to the table so it cannot move, but there is still no friction between the block and the plane.

Indicate whether the speed of the block relative to the table when the block reaches the bottom of the plane is greater in trial 1 or trial 2. Justify your answer in a clear, coherent, paragraph-length explanation.

GO ON TO THE NEXT PAGE.

S T O P

END OF EXAM

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

AP® Physics C: Mechanics Exam

SECTION II: Free Response

2014

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
3
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Weight
The questions are weighted equally.

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ ☐☐ ☐☐☐☐
   Month Day Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Form I
Form Code 4JBP6-S
80

TABLE OF INFORMATION, EFFECTIVE 2012

CONSTANTS AND CONVERSION FACTORS

Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1\ \text{eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$	Universal gravitational constant, $G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Universal gas constant, $R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface, $g = 9.8\ \text{m/s}^2$
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg} = 931\ \text{MeV}/c^2$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J}\cdot\text{s} = 4.14 \times 10^{-15}\ \text{eV}\cdot\text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J}\cdot\text{m} = 1.24 \times 10^{3}\ \text{eV}\cdot\text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T•m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T•m)/A
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^{5}\ \text{N/m}^2 = 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES

Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

ADVANCED PLACEMENT PHYSICS C EQUATIONS, EFFECTIVE 2012

MECHANICS

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2}at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$\mathbf{F} = \frac{d\mathbf{p}}{dt}$

$\mathbf{J} = \int \mathbf{F}\,dt = \Delta\mathbf{p}$

$\mathbf{p} = m\mathbf{v}$

$F_{fric} \le \mu N$

$W = \int \mathbf{F} \cdot d\mathbf{r}$

$K = \frac{1}{2}mv^2$

$P = \frac{dW}{dt}$

$P = \mathbf{F} \cdot \mathbf{v}$

$\Delta U_g = mgh$

$a_c = \frac{v^2}{r} = \omega^2 r$

$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$

$\sum \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$

$I = \int r^2 dm = \sum mr^2$

$\mathbf{r}_{cm} = \sum m\mathbf{r} / \sum m$

$v = r\omega$

$\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$

$K = \frac{1}{2}I\omega^2$

$\omega = \omega_0 + \alpha t$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$

a = acceleration
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed
α = angular acceleration
ϕ = phase angle

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$x = x_{\max}\cos(\omega t + \phi)$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$\mathbf{F}_G = -\frac{Gm_1m_2}{r^2}\hat{\mathbf{r}}$

$U_G = -\frac{Gm_1m_2}{r}$

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$

$E = -\frac{dV}{dr}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$C = \frac{Q}{V}$

$C = \frac{\kappa\epsilon_0 A}{d}$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$I = \frac{dQ}{dt}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$R = \frac{\rho\ell}{A}$

$\mathbf{E} = \rho\mathbf{J}$

$I = Nev_d A$

$V = IR$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$P = IV$

$\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
J = current density
L = inductance
ℓ = length
n = number of loops of wire per unit length
N = number of charge carriers per unit volume
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux
κ = dielectric constant

$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$

$d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I\,d\boldsymbol{\ell} \times \mathbf{r}}{r^3}$

$\mathbf{F} = \int I\,d\boldsymbol{\ell} \times \mathbf{B}$

$B_s = \mu_0 nI$

$\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$

$\mathcal{E} = \oint \mathbf{E} \cdot d\boldsymbol{\ell} = -\frac{d\phi_m}{dt}$

$\mathcal{E} = -L\frac{dI}{dt}$

$U_L = \frac{1}{2}LI^2$

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

$A = \frac{1}{2}bh$

Circle

$A = \pi r^2$

$C = 2\pi r$

Rectangular Solid

$V = \ell wh$

Cylinder

$V = \pi r^2 \ell$

$S = 2\pi r\ell + 2\pi r^2$

Sphere

$V = \frac{4}{3}\pi r^3$

$S = 4\pi r^2$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

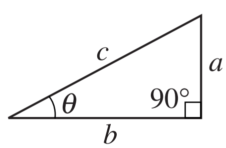
Right Triangle

$a^2 + b^2 = c^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$



CALCULUS

$$\frac{df}{dx} = \frac{df}{du}\frac{du}{dx}$$

$$\frac{d}{dx}\left(x^n\right) = nx^{n-1}$$

$$\frac{d}{dx}\left(e^x\right) = e^x$$

$$\frac{d}{dx}(\ln x) = \frac{1}{x}$$

$$\frac{d}{dx}(\sin x) = \cos x$$

$$\frac{d}{dx}(\cos x) = -\sin x$$

$$\int x^n\,dx = \frac{1}{n+1}x^{n+1},\ n \neq -1$$

$$\int e^x\,dx = e^x$$

$$\int \frac{dx}{x} = \ln|x|$$

$$\int \cos x\,dx = \sin x$$

$$\int \sin x\,dx = -\cos x$$

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.

Mech 1.

Experiment 1: A block of mass 1.5 kg is placed on a long board. You are to design an experiment to determine the coefficient of static friction between the block and the board.

(a)

i. From the following list of available equipment, check those additional items you would use for the purpose of determining the coefficient of static friction.

____ Ruler	____ Spring scale	____ String
____ Meterstick	____ Pulley	____ Protractor
____ Photogate	____ Stopwatch	____ Mass hanger
____ Clamps and supports	____ Objects of various known masses	

ii. Sketch a diagram of your experimental setup and label the pieces of equipment that would be used.

iii. Outline the experimental procedure you would use, including a list of quantities you would measure. For each quantity, identify the equipment you would use to make the measurement.

(b) Explain how to use the measurements described in part (a) to calculate the coefficient of static friction. Include a free-body diagram in your explanation that shows all forces (not components) acting on the block while the measurements are being made.

Experiment 2: In a second experiment, the coefficient of kinetic friction between the block and the board is determined to be 0.10. The board is now inclined at an angle of $25°$ above the horizontal. The block is released from rest at the top of the incline and slides 2.0 m down the incline.

(c) Calculate the work done by kinetic friction as the block slides down the incline.

(d) The mass of the block is now increased without changing the coefficient of kinetic friction, and experiment 2 is repeated. How does each of the following change?

i. The magnitude of the frictional force

__ Increases __ Decreases __ Remains the same

ii. The magnitude of the velocity of the block as it reaches the bottom of the incline

__ Increases __ Decreases __ Remains the same

iii. The kinetic energy of the block at the bottom of the incline

__ Increases __ Decreases __ Remains the same

GO ON TO THE NEXT PAGE.

Mech 2.

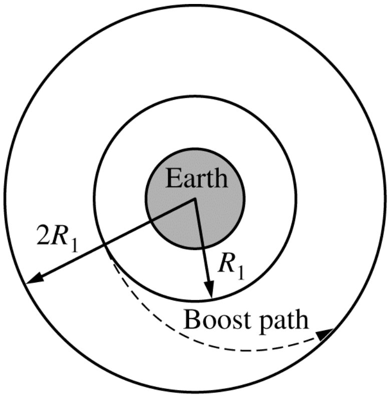
A satellite of mass m is in a stable circular orbit around Earth at a distance R_1 from the center of Earth. The mass of Earth is M_e.

(a) Derive an expression for the following in terms of m, R_1, M_e, and fundamental constants, as appropriate.

i. The orbital speed v_1 of the satellite

ii. The total energy of the satellite in this orbit, assuming gravitational potential energy to be zero at an infinite distance from the center of Earth

The satellite's booster rockets fire and lift the satellite to a higher circular orbit of radius $2R_1$. The satellite follows the path shown in the diagram below, moving a total distance S during the orbital change. The component of the rockets' force parallel to the path is given by the equation $F = F_0\left(1 - \frac{x}{S}\right)$, where x is the variable distance traveled along the path at any moment.



(b) Derive an expression for the total work done on the satellite by the force F in terms of F_0 and S.

(c) If the total distance S is equal to $3R_1$, derive an expression for F_0 in terms of M_e, R_1, m, and fundamental constants, as appropriate.

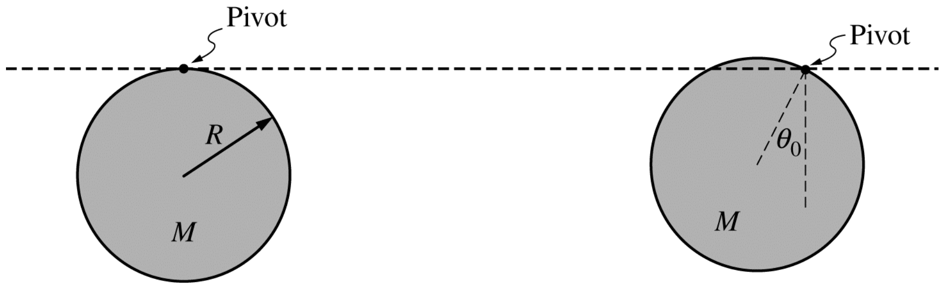


Figure 1 Figure 2

Mech 3.

A uniform disk of mass M and radius R is suspended vertically from a pivot on its edge so that it is free to swing without friction, as shown in Figure 1 above. The disk is raised to an initial angular displacement θ_0 with respect to the vertical, as shown in Figure 2 above, and released from rest. The rotational inertia of the disk about its center of mass is $I = MR^2/2$. Express all algebraic answers in terms of the given quantities and fundamental constants, as appropriate.

(a) Derive an expression for the rotational inertia of the disk about the pivot.

(b) Derive an expression for the maximum angular velocity of the disk during its swing.

(c) Using Newton's second law in either translational or rotational form, as appropriate, write a differential equation that could be used to determine the angular displacement of the disk θ as a function of time t. Do not solve the equation.

GO ON TO THE NEXT PAGE.

(d) Derive an expression for the period for small-amplitude oscillations of the disk.

(e) Suppose the disk is replaced with another uniform disk with twice the radius, and the pivot point is again on the edge of the disk. How will the period of small-amplitude oscillations be affected by the new disk?

__ It will increase.   __ It will decrease.   __ It will remain the same.

__ There is not enough information to determine the period.

Justify your answer.

GO ON TO THE NEXT PAGE.

THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX(ES) ON THE COVER(S).**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**