AP® Physics 1: Algebra-Based Exam

SECTION I: Multiple Choice

2016

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

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
40
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 40 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.

Because this section offers only four answer options for each question, do not mark the (E) answer circle for any question. If you change an answer, be sure that the previous mark is erased completely.

For questions 1 through 36, select the single best answer choice for each question. After you have decided which of the choices is best, completely fill in the corresponding circle on the answer sheet. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent	Ⓐ ● Ⓒ Ⓓ Ⓔ

For questions 131 through 134, select the two best answer choices for each question. After you have decided which two choices are best, completely fill in the two corresponding circles on the answer sheet. Here is a sample question and answer.

Sample Question	Sample Answer
New York is a (A) state (B) city (C) country (D) continent	● ● Ⓒ Ⓓ

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.

Form I
Form Code 4MBP4-S
83

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,	$k = 1/4\pi\varepsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Speed of light,	$c = 3.00 \times 10^{8}$ m/s	Acceleration due to gravity at Earth's surface,	$g = 9.8$ 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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

$L = I\omega$

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

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

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

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

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

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

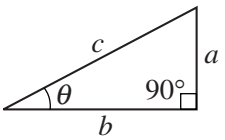
Rectangular solid
$V = \ell wh$

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 I
40 Questions
Time—90 minutes

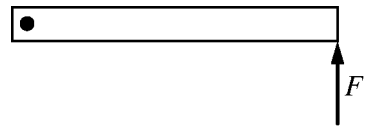
Note: To simplify calculations, you may use $g = 10\ \text{m/s}^2$ in all problems.

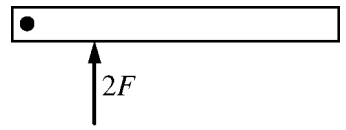
Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

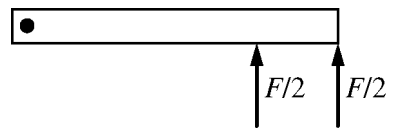
1. A kitten sits in a lightweight basket near the edge of a table. A person accidentally knocks the basket off the table. As the kitten and basket fall, the kitten rolls, turns, kicks, and catches the basket in its claws. The basket lands on the floor with the kitten safely inside. If air resistance is negligible, what is the acceleration of the kitten-basket system while the kitten and basket are in midair?

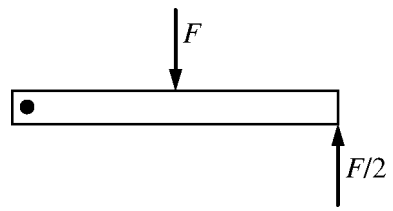
   (A) The acceleration is directed downward with magnitude less than g because the basket is light.
   (B) The acceleration is directed downward with magnitude equal to g because the system is a projectile.
   (C) The acceleration fluctuates because of the rolling, turning, and kicking motion of the kitten.
   (D) The acceleration cannot be determined without knowing how hard the basket is pushed.

2. A solid metal bar is at rest on a horizontal frictionless surface. It is free to rotate about a vertical axis at the left end. The figures below show forces of different magnitudes that are exerted on the bar at different locations. In which case does the bar's angular speed about the axis increase at the fastest rate?

   (A)
   

   (B)
   

   (C)
   

   (D)
   

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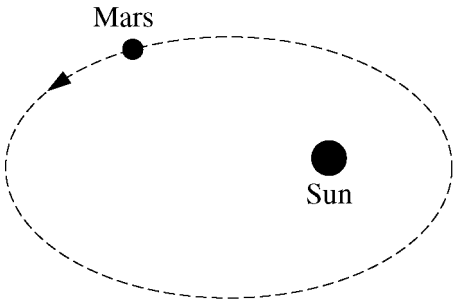
Speed	10 m/s	20 m/s	30 m/s
Braking Distance	6.1 m	23.9 m	53.5 m

3. To analyze the characteristics and performance of the brakes on a 1500 kg car, researchers collected the data shown in the table above. It shows the car's speed when the brakes are first applied and the corresponding braking distance required to stop the car. The magnitude of the average braking force on the car is most nearly

(A) 75,000 N
(B) 30,000 N
(C) 12,000 N
(D) 1600 N



Note: Figure not drawn to scale.

4. Mars moves in an elliptical orbit around the Sun, and the mass of Mars is much less than the mass of the Sun. At the instant shown above, Mars is getting farther away from the Sun. How does this affect the potential energy of the Mars-Sun system and the magnitude of Mars's angular momentum with respect to the Sun?

	System Potential Energy	Mars's Angular Momentum
(A)	Increases	Increases
(B)	Increases	Remains the same
(C)	Decreases	Decreases
(D)	Decreases	Remains the same

5. An ice-skater is moving at a constant velocity across an icy pond. The skater throws a snowball directly ahead. Which of the following correctly describes the velocity of the center of mass of the skater-snowball system immediately after the snowball is thrown? Assume friction and air resistance are negligible.

(A) It is equal to the velocity of the snowball.
(B) It is equal to the new velocity of the skater.
(C) It is equal to half the original velocity of the skater.
(D) It is equal to the original velocity of the skater.

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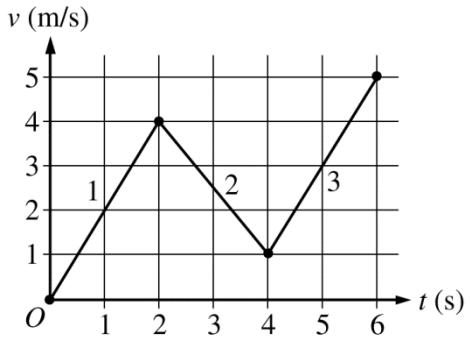
Questions 6-8 refer to the following material.



The graph above shows velocity v as a function of time t for a 0.50 kg object traveling along a straight line. The graph has three segments labeled 1, 2, and 3. A rope exerts a constant force of magnitude F_T on the object along its direction of motion the whole time. During segment 2 only, a frictional force of magnitude F_f is also exerted on the object.

6. Which of the following correctly ranks the displacement Δx for the three segments of the object's motion?

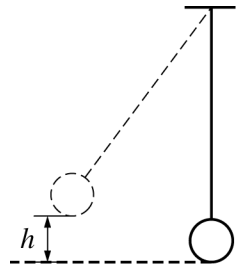
   (A) $\Delta x_3 > \Delta x_2 > \Delta x_1 > 0$
   (B) $\Delta x_1 = \Delta x_2 = \Delta x_3 > 0$
   (C) $(\Delta x_1 = \Delta x_3) > \Delta x_2 > 0$
   (D) $(\Delta x_1 = \Delta x_3) > 0 > \Delta x_2$

7. Which of the following expressions correctly relates the magnitudes F_f and F_T?

   (A) $F_f < F_T$
   (B) $F_f = F_T$
   (C) $F_T < F_f < 2F_T$
   (D) $F_f = 2F_T$

8. For another identical object initially at rest, no frictional force is exerted during segment 2 (between $t = 2$ s and $t = 4$ s). A rope exerts the same constant force of magnitude F_T as in the previous scenario. What is the change in the object's kinetic energy during segment 2?

   (A) 3.75 J
   (B) 4.00 J
   (C) 12.0 J
   (D) 16.0 J



9. The pendulum shown in the figure above reaches a maximum height h above the equilibrium position as it oscillates. Assuming friction and air resistance are negligible, which of the following is true about the total energy of the Earth-pendulum system as the pendulum oscillates?

   (A) It is at a maximum when the pendulum is at its lowest position.
   (B) It is at a maximum when the pendulum is at its maximum height h.
   (C) It is constant throughout the pendulum's motion.
   (D) It is at a minimum when the pendulum is somewhere between its lowest and highest positions.

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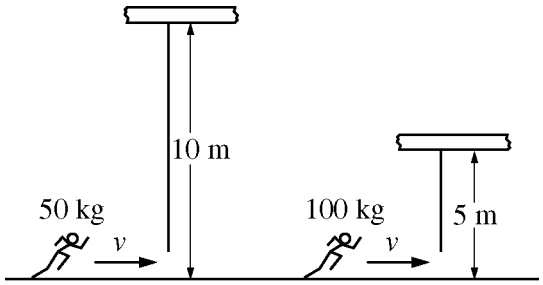
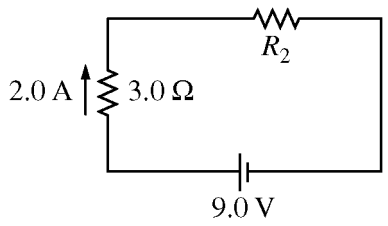


10. A 50 kg athlete running at speed v grabs a light rope that hangs from a 10-meter-high platform and swings to a maximum of 1.8 m above the ground. Later, a 100 kg athlete, running at the same speed, grabs a similar rope hanging from a 5-meter-high platform. What is the maximum height to which the 100 kg athlete swings?

(A) 0.9 m
(B) 1.8 m
(C) 2.5 m
(D) 3.6 m



11. A 9.0 V battery and two resistors are connected in the circuit shown above. The current through the 3.0 Ω resistor is 2.0 A. What is the potential difference across resistor R_2 ?

(A) 9.0 V
(B) 6.0 V
(C) 3.0 V
(D) 1.5 V

12. A student is asked to determine the work done on a block of wood when the block is pulled horizontally using an attached string. The student is supplied with a spring scale, a stopwatch, and a meterstick. Which of the following graphical analysis techniques will allow the student to determine the work done on the block by the string?

(A) Graphing the force as a function of time and calculating the slope
(B) Graphing the force as a function of time and calculating the area under the curve
(C) Graphing the force as a function of distance and calculating the slope
(D) Graphing the force as a function of distance and calculating the area under the curve

13. Block A and block B move toward each other on a level frictionless track. Block A has mass m and velocity $+v$. Block B has mass $2m$ and velocity $-v$. The blocks collide, and during the collision the magnitude of the net force exerted on block A is F. What is the magnitude of the net force exerted on block B, and why does it have that value?

(A) $2F$, because the mass of block B is twice that of block A and the blocks have the same acceleration during the collision.
(B) $F/2$, because the mass of block B is twice that of block A and the blocks have the same acceleration during the collision.
(C) F, because the blocks have the same speed immediately before the collision.
(D) F, because the net force is equal to the mutual contact force between the blocks.

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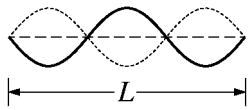
14. The data in the table below were recorded during an experiment in which two carts on a frictionless one-dimensional track collide head-on. What are the values of the magnitude of the change in momentum Δp_2 of cart 2 and the magnitude of its average acceleration a_2 during the collision?

	Cart 1	Cart 2
Mass	5 kg	1 kg
Average Force	15 N	15 N
Change in Momentum	0.3 kg•m/s	Δp_2
Average Acceleration	3 m/s^2	a_2

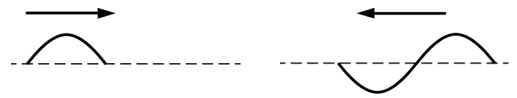
	Δp_2	a_2
(A)	0.3 kg•m/s	3 m/s^2
(B)	0.3 kg•m/s	15 m/s^2
(C)	1.5 kg•m/s	3 m/s^2
(D)	1.5 kg•m/s	15 m/s^2

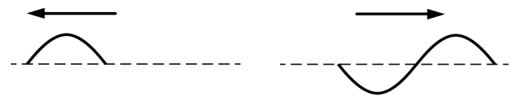
15. A 1.0 kg lump of clay is sliding to the right on a frictionless surface with speed 2 m/s. It collides head-on and sticks to a 0.5 kg metal sphere that is sliding to the left with speed 4 m/s. What is the kinetic energy of the combined objects after the collision?

(A) 6 J
(B) 4 J
(C) 2 J
(D) 0 J



16. A guitar string of length L can vibrate with three antinodes, as shown above. The straight dashed line shows the equilibrium position of the string. The wave pattern is most likely formed by the superposition of which of the following pulses or waves?

(A) 

(B) 

(C) Two periodic waves of wavelength $L/3$, one moving to the left and one moving to the right

(D) Two periodic waves of wavelength $2L/3$, one moving to the left and one moving to the right

17. A speaker is at rest at the side of a straight road. The speaker produces a steady sound of constant frequency. A student is standing still near the speaker. Two vehicles are driven down the road: a truck approaching the speaker and a car moving away from the speaker. If the sound is represented by wave fronts, the student and the vehicle drivers each observe a different amount of time between successive wave fronts: t_s for the student, t_t for the truck driver, and t_c for the car driver. Which of the following correctly ranks the times?

(A) $t_s < t_t < t_c$
(B) $t_c < t_s < t_t$
(C) $t_t < t_s < t_c$
(D) $t_t < t_c < t_s$

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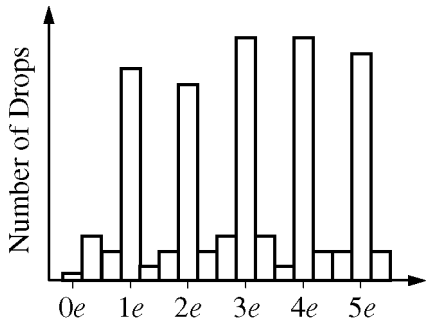
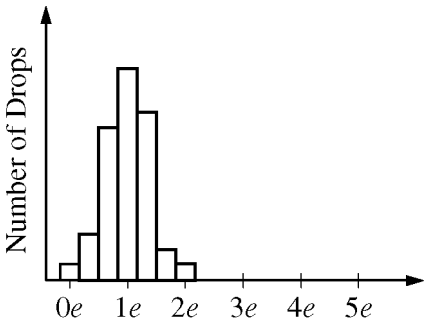


Graph 1



Graph 2

18. Tiny drops of oil that have different amounts of electric charge produced by a random process are sprayed into a region between a positively and a negatively charged plate. The charge on each drop is determined by analyzing the effect of the electric force on the drop's motion. Two graphs of the number of drops as a function of the charge on each drop, where e is the charge of an electron, are shown above. Which graph shows the most likely result after repeating the experiment many times, and why?

(A) Graph 1, because it shows peaks with approximately the same amplitude
(B) Graph 1, because it shows that within experimental error charge only exists in multiples of e
(C) Graph 2, because it shows a peak value at the charge of an electron
(D) Graph 2, because it shows a narrower range of measurement error

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19. The magnitude of the gravitational field on the surface of a particular planet is $2g$. The planet's mass is half the mass of Earth. What is the planet's radius in terms of the radius R_E of Earth?

(A) $R_E/4$

(B) $R_E/2$

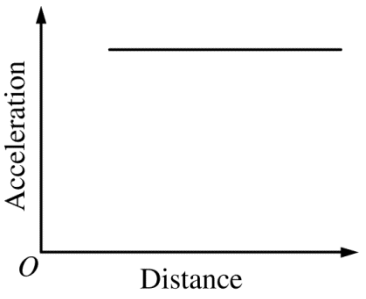
(C) $R_E/\sqrt{2}$

(D) $2R_E$

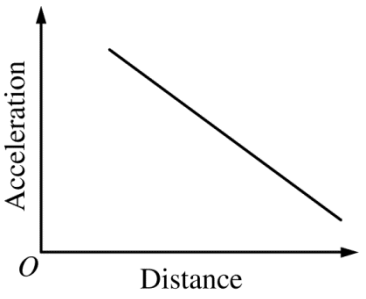


20. A small object with positive charge Q is fixed in place. A small bead with positive charge q is released from rest from the position shown above. In the absence of forces other than the electric force, which of the following graphs best represents the bead's acceleration as a function of its distance from the fixed object?

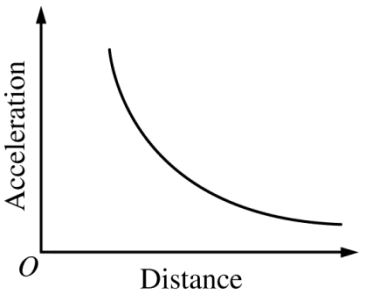
(A)



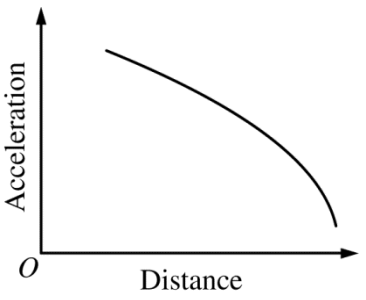
(B)



(C)



(D)



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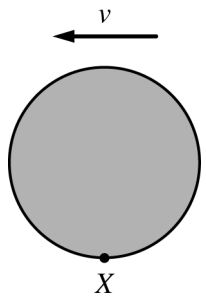
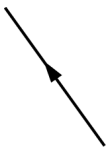


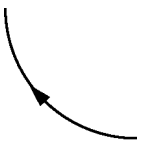
Top View

21. A stone disk is sliding on frictionless ice to the west with speed v, as shown in the figure above. As the disk slides by, a child uses a rubber mallet to hit the disk at point X, exerting a force directly toward the center of the disk. The child hits point X every half second for about 10 s, changing the trajectory of the disk but not causing it to rotate. Which of the following most closely approximates the path of the disk while the child is hitting it?

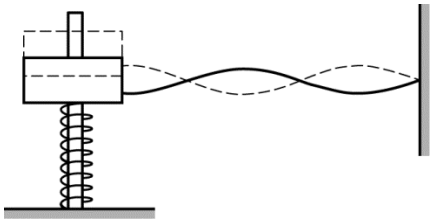
(A)  A northward linear path

(B)  A northwestward linear path

(C)  A parabolic path

(D)  A circular path

Questions 22-23 refer to the following material.



The figure above shows a pole with a spring around it and a 0.10 kg block with a hole in the middle on top of the spring. A light horizontal string is attached to the block and a wall. When the block is oscillating at 5.0 Hz, the standing wave shown is formed.

22. The spring constant of the spring is approximately which of the following?

(A) 100 N/m
(B) 10 N/m
(C) 1.0 N/m
(D) 0.1 N/m

23. What additional measurement is needed to determine the speed of the wave on the string?

(A) The mass of the string
(B) The effective spring constant of the spring
(C) The distance between the wall and the block
(D) The amplitude of the block's oscillation

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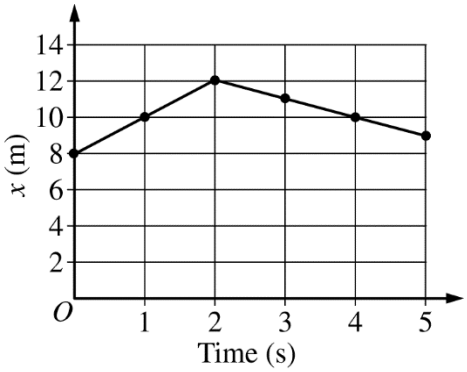
24. Two identical blocks with mass 5.0 kg each are connected to the opposite ends of a compressed spring. The blocks initially slide together on a frictionless surface with velocity 2 m/s to the right. The spring is then released by remote control. At some later instant, the left block is moving at 1 m/s to the left, and the other block is moving to the right. What is the speed of the center of mass of the system at that instant?

(A) 4 m/s

(B) 3 m/s

(C) 2 m/s

(D) 0 m/s



25. The graph above shows the position x as a function of time for the center of mass of a system of particles of total mass 6.0 kg. For a very short time interval around 2.0 s, an external force is exerted on an object in the system. What is the resulting change in momentum of the system?

(A) 52 kg•m/s

(B) 6 kg•m/s

(C) −6 kg•m/s

(D) −18 kg•m/s

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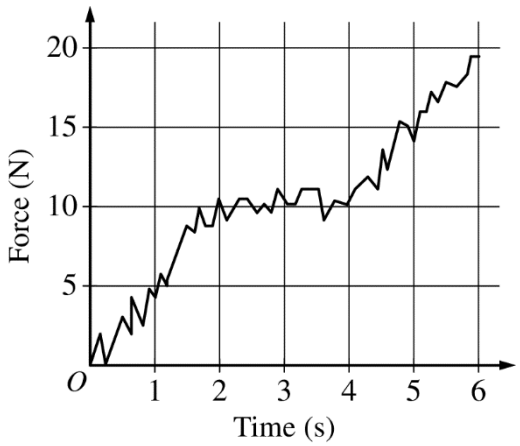
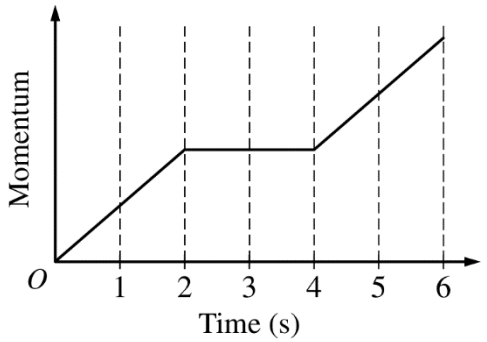
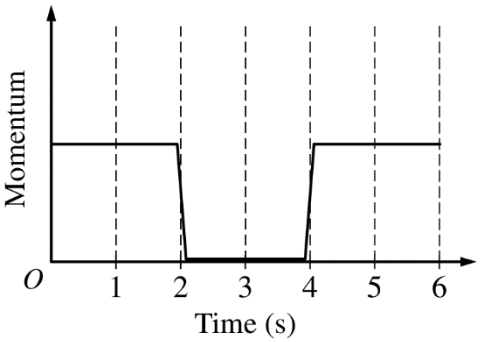


26. Using a force probe, a student generates the graph above of the force exerted on a small wagon as a function of time. The wagon starts from rest and rolls with negligible friction in the axles. Which of the following graphs best represents the wagon's momentum as a function of time?

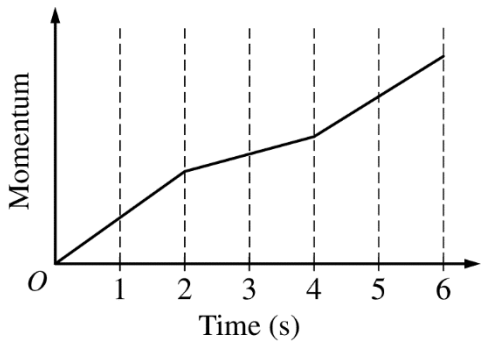
(A)



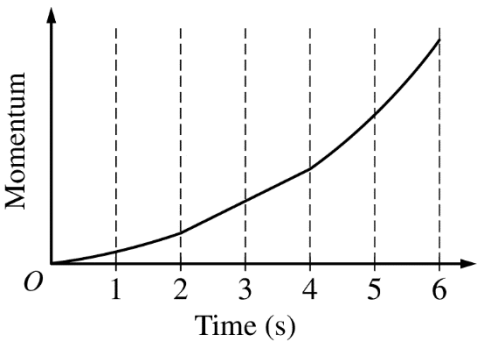
(B)



(C)



(D)



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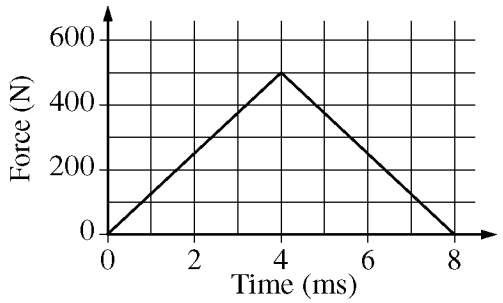

27. A 0.050 kg tennis ball is moving to the left at 10 m/s when it is hit by a tennis racket that is moving to the right. The magnitude of the force exerted on the ball by the racket as a function of time is shown in the figure above. What is the speed of the ball after the collision with the racket?

(A) 30 m/s
(B) 50 m/s
(C) 70 m/s
(D) 90 m/s

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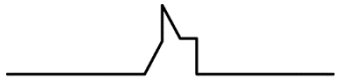

Figure *W*

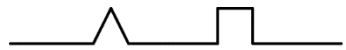

Figure *X*

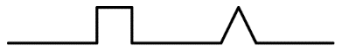

Figure *Y*



Figure *Z*

28. Two wave pulses are created simultaneously at opposite ends of a string and move toward the center of the string, as shown in the top figure above. Both pulses have the same width. The labeled figures show possible shapes of the string at different moments in time. Which of the following indicates a correct time order for the shape of the string as the pulses move along the string, come together, and move apart?

(A) Figure *X*, Figure *W*, Figure *X*
(B) Figure *X*, Figure *W*, Figure *Y*
(C) Figure *X*, Figure *Z*, Figure *X*
(D) Figure *X*, Figure *Z*, Figure *Y*

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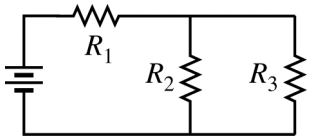
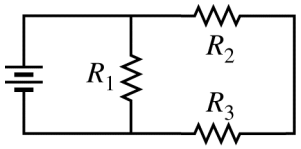
Circuit Element	Potential Difference (V)	Current (A)
Battery	10	8
Resistor R_1	6	8
Resistor R_2	4	3
Resistor R_3	4	5

29. The above table shows the potential difference and current for each circuit element in a circuit consisting of a battery and three resistors. Which of the following diagrams could represent the circuit?

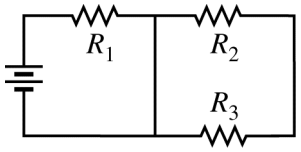
(A)



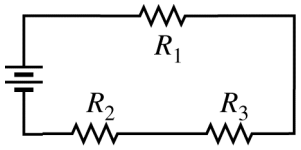
(B)



(C)

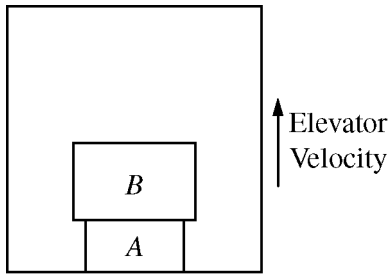


(D)



30. An object starts from rest and slides with negligible friction down an air track tipped at an angle θ from the horizontal. A student records values of the object's position along the track at various times. The value of θ can best be determined from which of the following?

(A) The y-intercept of a graph of position as a function of time
(B) The y-intercept of a graph of position as a function of the square of time
(C) The slope of a graph of position as a function of time
(D) The slope of a graph of position as a function of the square of time



31. Box A of mass m sits on the floor of an elevator, with box B of mass $2m$ on top of it, as shown in the figure above. The elevator is moving upward and slowing down. F_A is the magnitude of the force exerted on box A by box B, F_B is the magnitude of the force exerted on box B by box A, and F_g is the magnitude of the gravitational force exerted on box B. Which of the following ranks the forces in order of increasing magnitude?

(A) $F_B = F_A = F_g$
(B) $(F_B = F_A) < F_g$
(C) $F_B < (F_A = F_g)$
(D) $F_g < F_B < F_A$

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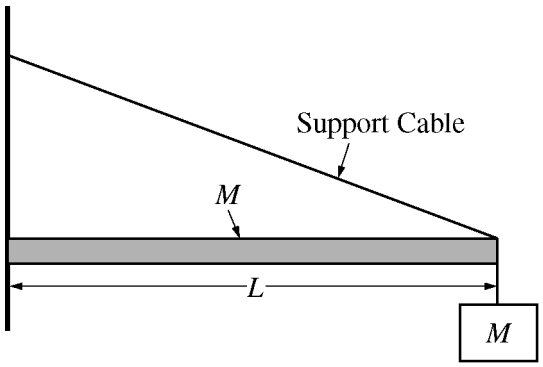
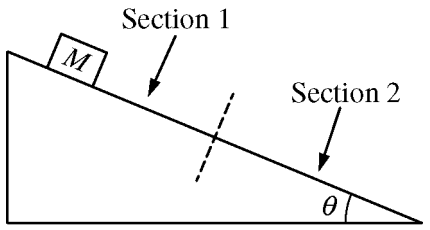


32. The figure above shows a uniform beam of length L and mass M that hangs horizontally and is attached to a vertical wall. A block of mass M is suspended from the far end of the beam by a cable. A support cable runs from the wall to the outer edge of the beam. Both cables are of negligible mass. The wall exerts a force F_W on the left end of the beam. For which of the following actions is the magnitude of the vertical component of F_W smallest?

(A) Keeping the support cable and block as shown in the diagram
(B) Moving the lower end of the support cable to the center of the beam and leaving the block at the outer end of the beam
(C) Keeping the lower end of the support cable at the outer end of the beam and moving the block to the center of the beam
(D) Moving both the support cable and the block to the center of the beam

Questions 33-34 refer to the following material.



The inclined plane in the figure above has two sections of equal length and different roughness. The dashed line shows where section 1 ends and section 2 begins. A block of mass M is placed at different locations on the incline. The coefficients of kinetic and static friction between the block and each section are shown in the table below.

Coefficient of Friction	Section 1	Section 2
Static	μ_{S1}	$\mu_{S2} (> \mu_{S1})$
Kinetic	μ_k	$2\mu_k$

33. If the block is at rest on section 1 of the incline, what is the magnitude of the force of static friction exerted on the block by the incline?

(A) $\mu_{S1} Mg \cos\theta$
(B) $\mu_{S1} Mg \tan\theta$
(C) $Mg \sin\theta$
(D) $Mg / \tan\theta$

34. If the block is sliding up section 2, what is the magnitude of the force of friction that is exerted on the block by the incline?

(A) $2\mu_k Mg \cos\theta$
(B) $2\mu_k Mg \tan\theta$
(C) $Mg \sin\theta$
(D) $Mg / \tan\theta$

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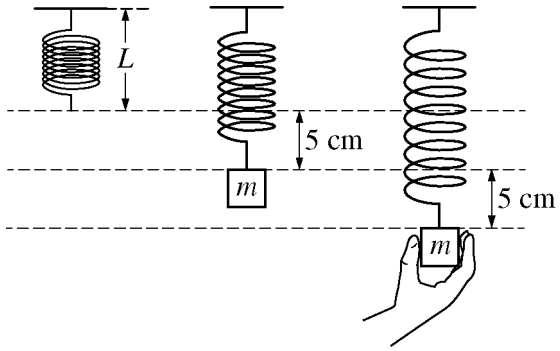

35. An object with mass m is suspended at rest from a spring with a spring constant of $200\ \text{N/m}$. The length of the spring is 5.0 cm longer than its unstretched length L, as shown above. A person then exerts a force on the object and stretches the spring an additional 5.0 cm. What is the total energy stored in the spring at the new stretched length?

(A) 0.25 J
(B) 1.0 J
(C) 10 J
(D) 20 J

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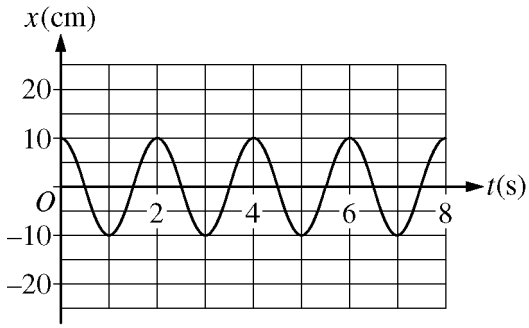
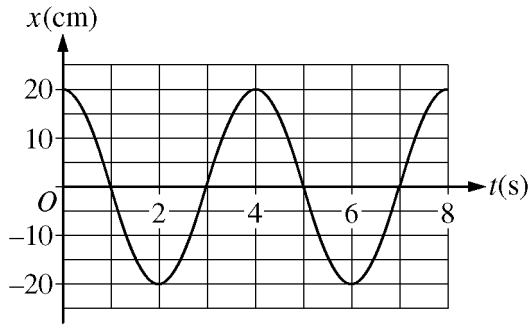


Block *A*



Block *B*

36. Two blocks are connected to identical ideal springs and are oscillating on a horizontal frictionless surface. Block *A* has mass *m*, and its motion is represented by the graph of position as a function of time shown above on the left. Block *B*'s motion is represented above on the right. Which of the following statements comparing block *B* to block *A* is correct?

(A) Because block *B* covers more distance per cycle than block *A*, block *B* takes more time to complete each cycle.
(B) Because the spring attached to block *B* is initially stretched a greater distance, the spring constant is smaller and therefore block *B* has a slower average speed than block *A* does.
(C) Because block *B* has more mass, it has a slower average speed than block *A* does.
(D) Because block *B* has more mass, its acceleration is smaller than that of block *A* at any given displacement from the equilibrium position.

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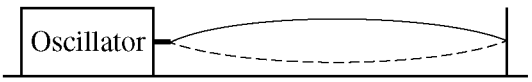
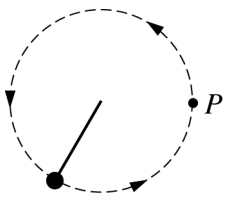
Directions: For each of the questions or incomplete statements below, two of the suggested answers will be correct. For each of these questions, you must select both correct choices to earn credit. No partial credit will be earned if only one correct choice is selected. Select the two that are best in each case and then fill in the corresponding circles that begin with number 131 on page 3 of the answer sheet.



131. The figure above shows a string held taut between a post and an oscillator that vibrates the end of the string. In an experiment, the oscillator is adjusted to find many frequencies that will create a standing wave, one of which is shown. The number of nodes in each standing wave is counted. Which of the following quantities must also be measured to determine the speed of traveling waves on the string? Select two answers.

(A) The length of the string
(B) The mass of the string
(C) The amplitudes of the standing wave patterns
(D) The frequencies of the standing wave patterns



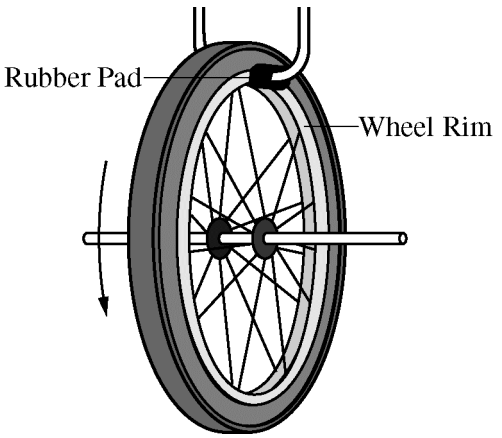
Side View

132. A ball attached to a light string swings in a counterclockwise vertical circle, as shown above. Which of the following arrows represent one of the forces exerted on the ball at the moment it passes through point P ? Select two answers.

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

133. Object A has mass 2 kg and is traveling to the right at speed $3\ \text{m/s}$. Object B is traveling to the left at $3\ \text{m/s}$. The objects collide head-on, and afterward each has a speed of $3\ \text{m/s}$. Which of the following could be the mass of object B ? Select two answers.

(A) 3 kg
(B) 2 kg
(C) 1 kg
(D) Negligible compared to 2 kg



134. Some bicycle brakes work by pressing rubber pads against the rim of the wheel. To test newly designed brakes, bicycle engineers mount a wheel of known rotational inertia on a low-friction axle, as shown above. The engineers spin the wheel with known initial angular speed and then apply the brakes with a constant force. Which of the following procedures would enable the engineers to find the torque exerted by the brakes on the wheel? Select two answers.

(A) Measuring how much time the wheel takes to come to rest
(B) Measuring how many rotations the wheel completes while coming to rest
(C) Measuring the distance from axle to brakes and the normal force between the rubber pads and the rim
(D) Measuring the mechanical energy dissipated as the rim rubs against the rubber pads

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GO ON TO THE NEXT PAGE.

END OF SECTION I

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

DO NOT GO ON TO SECTION II UNTIL YOU ARE TOLD TO DO SO.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET.**

AP® Physics 1: Algebra-Based Exam

SECTION II: Free Response

2016

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

At a Glance

Total Time
1 hour, 30 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.
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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 4MBP4-S

83

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,	$k = 1/4\pi\varepsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Speed of light,	$c = 3.00 \times 10^{8}$ m/s	Acceleration due to gravity at Earth's surface,	$g = 9.8$ 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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

$L = I\omega$

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

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

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

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

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

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

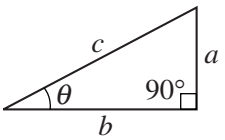
Rectangular solid
$V = \ell wh$

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
$c^2 = a^2 + b^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



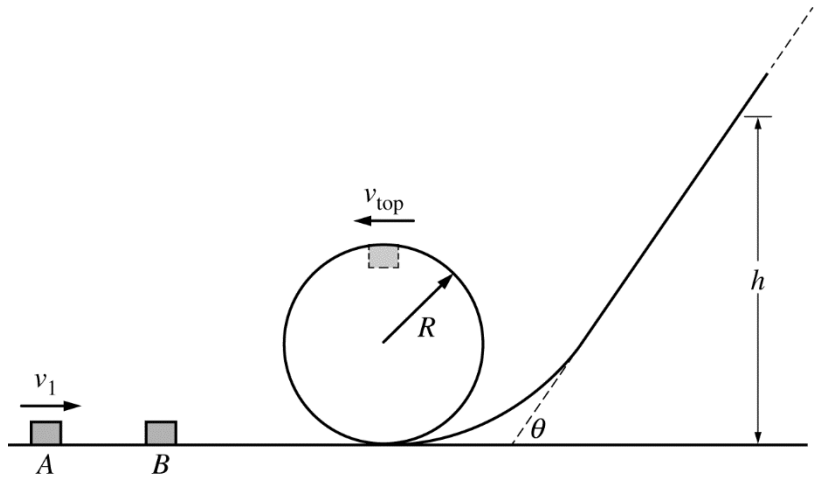
PHYSICS 1

Section II

5 Questions

Time—90 minutes

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



Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

   Two blocks A and B of equal mass m are on a frictionless track, as shown in the figure above. Block A, initially moving with speed v_1, has a perfectly elastic collision with block B. Block B has a speed v_1 immediately after the collision, and then it travels around a circular loop of radius R, where R is much larger than the size of the blocks. The speed of block B at the top of the loop is v_{top}. Block B then slides up a ramp until it comes momentarily to rest at a height h above the floor.

   (a) Derive an equation for the height h in terms of m, R, v_{top}, and g, as appropriate.

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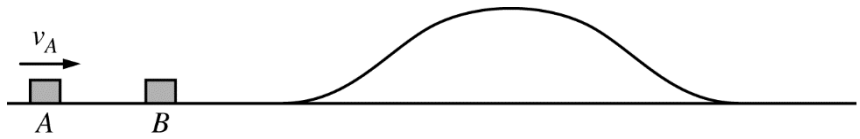
GO ON TO THE NEXT PAGE.

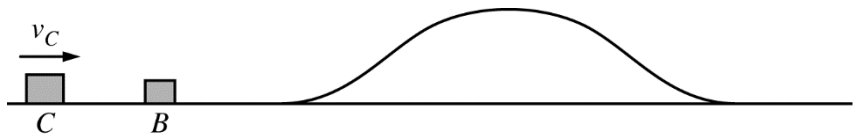
(b) Suppose that the speed v_1 of block *A* is doubled. Will the final height of block *B* be greater than, less than, or equal to $2h$?

____ Greater than $2h$ ____ Less than $2h$ ____ Equal to $2h$

Briefly explain how you arrived at your answer.



(c) Blocks *A* and *B* (both of mass *m*) are moved to a different frictionless track, as shown above. Let v_A be the minimum initial speed for block *A* that allows block *B* to make it over the hump in the track. Block *A* is then replaced with a larger block, block *C*, which has mass $2m$, as shown below.



Block *C* makes a completely inelastic collision with block *B* so that both blocks stick together and travel along the track. What is the minimum initial speed v_C that block *C* must have so that the two-block system makes it over the hump? Express your answer in terms of v_A.

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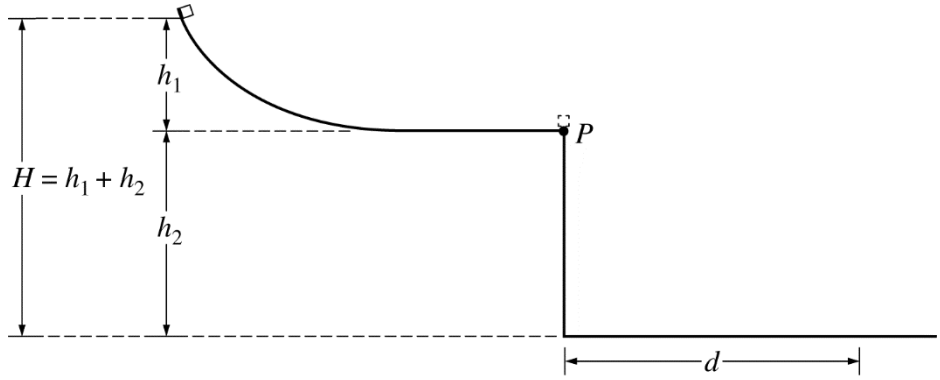

2. (12 points, suggested time 25 minutes)

A student releases a block of mass *m* from rest at the top of a slide of height h_1. The block moves down the slide and off the end of a table of height h_2, landing on the floor a horizontal distance *d* from the edge of the table. Friction and air resistance are negligible. The overall height *H* of the setup is determined by the height of the room. Therefore, if h_1 is increased, h_2 must decrease by the same amount so that the sum $h_1 + h_2$ remains equal to *H*. The student wants to adjust h_1 and h_2 to make *d* as large as possible.

(a)

i. Without using equations, explain why making h_1 very small would cause *d* to be small, even though h_2 would be large.

ii. Without using equations, explain why making h_2 very small would cause *d* to be small, even though h_1 would be large.

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GO ON TO THE NEXT PAGE.

(b) Derive an equation for d in terms of h_1, h_2, m, and physical constants, as appropriate.

(c)

i. Write the equation or step in your derivation in part (b) (not your final answer) that supports your reasoning in part (a)i.

Briefly explain your choice.

ii. Write the equation or step in your derivation in part (b) (not your final answer) that supports your reasoning in part (a)ii.

Briefly explain your choice.

(d) If the experiment is repeated on the Moon without changing h_1 or h_2, will the new landing distance d be greater than, less than, or the same as the landing distance when the experiment is performed on Earth?

____ Greater than ____ Less than ____ The same as

Briefly explain how you arrived at your answer.

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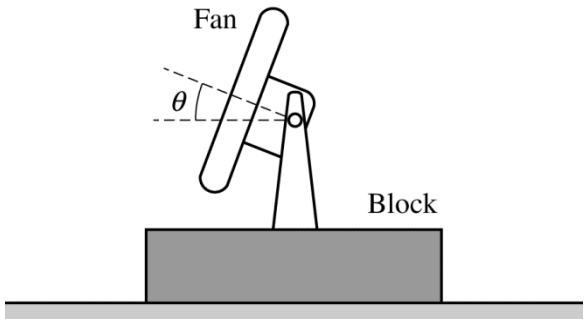

3. (12 points, suggested time 25 minutes)

A student in a physics lab has a block with a fan attached to it, as shown in the figure above. The fan has a pivot so that the angle θ it makes with the horizontal can be adjusted between $0°$ and $90°$. When the fan is pointed horizontally so that $\theta = 0°$, the block accelerates from rest along a track, even though there is friction between the block and the track. For the following questions, assume that the student has access to equipment that would usually be found in a school physics laboratory.

(a) Describe an experimental procedure that the student could use to measure the force F that the air exerts on the fan-block system when the fan is turned on. Assume that the magnitude of this force is the same for all angles θ.

i. What quantities would be measured?

ii. What equipment would be used for the measurements, and how would that equipment be used? Include a labeled diagram of the experimental setup.

iii. Describe the overall procedure to be used. Give enough detail so that another student could replicate the experiment.

iv. Describe how the force can be determined from the measurements described in parts (a)i–iii.

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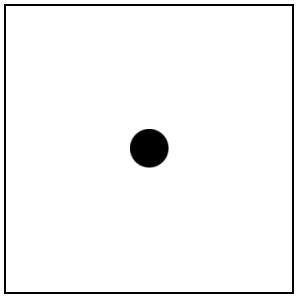
(b) Describe an experimental procedure that would allow the student to use the fan-block system, with the fan turned on, to find the coefficient of kinetic friction between the block and the track.

i. What quantities would be measured?

ii. What equipment would be used for the measurements, and how would that equipment be used? Include a labeled diagram of the experimental setup.

iii. Describe the overall procedure to be used. Give enough detail so that another student could replicate the experiment.

iv. On the dot to the right, which represents the fan-block system, draw and label the forces (not components) that are exerted on the system during the experiment described in parts (b)i–iii. Represent each force by a distinct arrow starting on, and pointing away from, the dot.



(c) Describe how to analyze the data from the experiment described in parts (b)i–iii in order to determine the coefficient of kinetic friction between the block and the track. Your analysis may include the force F exerted by the air on the fan-block system. Do not add to the free-body diagram in part (b)iv.

Question 3 continues on next page.

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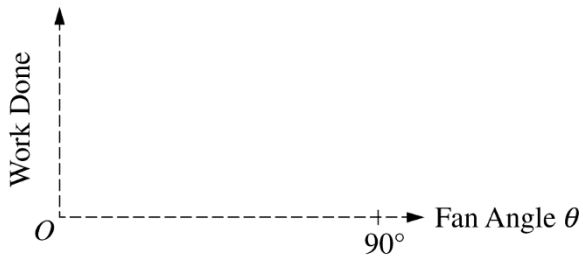
(d) In a different experiment, the student attaches the block to the top of a low-friction cart. On the axes below, sketch a graph of the work done by air on the fan-block-cart system as a function of θ when the system travels a fixed distance D.



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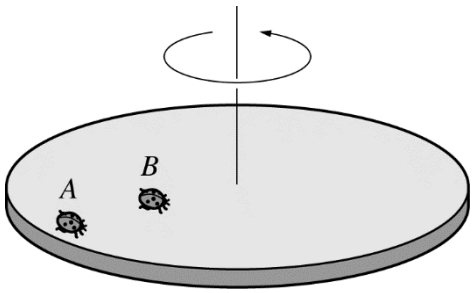

4. (7 points, suggested time 13 minutes)

Two ladybugs are standing on a rotating disk that is spinning counterclockwise, as shown in the figure above. Assume that friction in the bearings of the axle is negligible.

(a)

i. Is the angular speed of ladybug *A* greater than, less than, or the same as the angular speed of ladybug *B* ?

____ Greater ____ Less ____ The same

Briefly justify your answer.

ii. Is the linear speed of ladybug *A* greater than, less than, or the same as the linear speed of ladybug *B* ?

____ Greater ____ Less ____ The same

Briefly justify your answer.

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(b) Ladybug *A* begins walking in a circular path in the direction of the disk's rotation. Does the magnitude of the angular momentum of the disk alone (not the ladybugs-disk system) increase, decrease, or stay the same?

____ Increase ____ Decrease ____ Stay the same

Briefly explain your reasoning.

(c) In a different scenario, a single ladybug is standing near the edge of the disk at a distance of $0.9R$ from the center, where R is the radius of the disk, as shown in Figure 1 below. The rotational inertia of the ladybug-disk system is I_1, and the disk completes one rotation in 2.5 s. The ladybug then walks toward the center of the disk to a distance of $0.1R$ from the center and comes to a stop relative to the disk, as shown in Figure 2. Now the rotational inertia of the system is I_2, and the disk completes one rotation every 2.0 s.

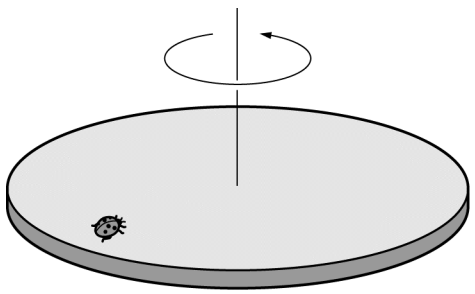

Figure 1

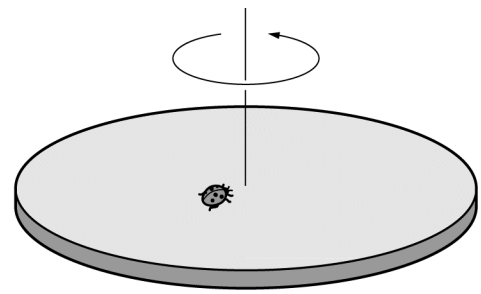

Figure 2

i. Derive an equation for I_2 in terms of I_1.

ii. While the ladybug is walking toward the center of the disk, does it exert a torque on the disk?

____ Yes ____ No

Briefly explain your reasoning.

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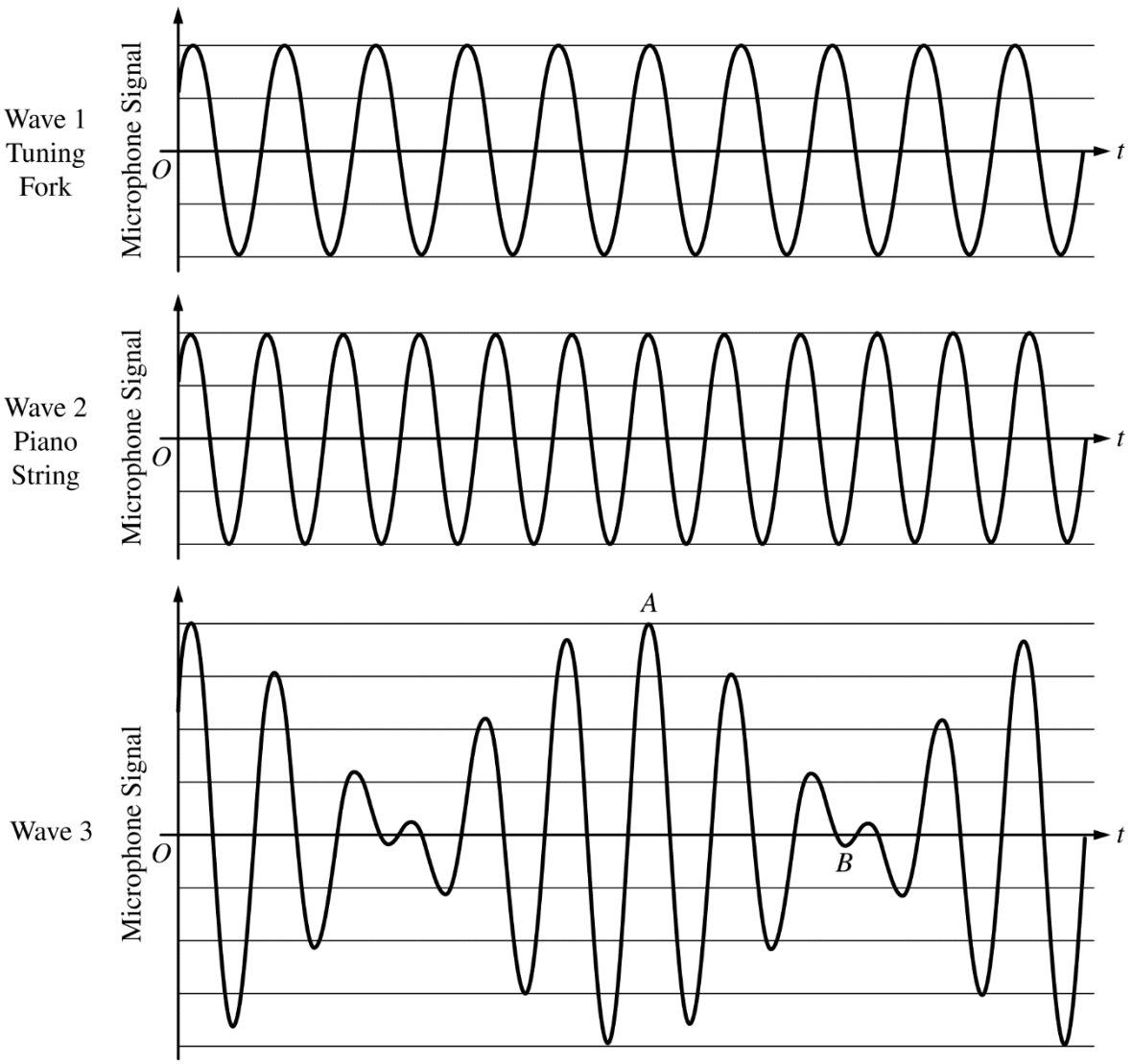

5. (7 points, suggested time 13 minutes)

The graphs shown above represent the variations in air pressure in the sound waves recorded by a microphone as functions of time t. Wave 1 represents the sound wave when a tuning fork has been struck, wave 2 represents the sound wave when a particular piano string has been struck, and wave 3 represents the sound wave when both the tuning fork and the piano string have been struck.

(a) Briefly explain why the peaks in wave 3 at time A and nearby times are relatively large.

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(b) Briefly explain why the peaks in wave 3 at time *B* and nearby times are relatively small.

If the fundamental frequency of the piano string is close to the frequency of the tuning fork, the phenomenon illustrated in wave 3 is detectable by ear. A piano tuner can loosen or tighten a piano string to change the fundamental frequency of the string.

(c) In a clear, coherent paragraph-length response referring to the graphs on the previous page, describe how and why the graph of wave 3, including the locations of points *A* and *B*, would change as the piano tuner loosens or tightens the string. Your response should also describe how the sound heard by the piano tuner changes during the process of adjusting the frequency of the string and how the piano tuner can tell when the string's frequency matches that of the tuning fork.

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STOP

END OF EXAM

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