# AP® Physics 1: Algebra-Based Exam

## SECTION I: Multiple Choice

2018

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

### At a Glance

**Total Time**
1 hour and 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<br>(A) state<br>(B) city<br>(C) country<br>(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<br>(A) state<br>(B) city<br>(C) country<br>(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 4OBP4-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 | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\theta$ | $0^\circ$ | $30^\circ$ | $37^\circ$ | $45^\circ$ | $53^\circ$ | $60^\circ$ | $90^\circ$ |
| $\sin\theta$ | 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 | $\sqrt{3}$ | $\infty$ |

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
$\ell$ = 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
$\alpha$ = angular acceleration
$\mu$ = coefficient of friction
$\theta$ = angle
$\rho$ = density
$\tau$ = torque
$\omega$ = 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
$\ell$ = length
$P$ = power
$q$ = charge
$R$ = resistance
$r$ = separation
$t$ = time
$V$ = electric potential
$\rho$ = resistivity

## WAVES

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

$f$ = frequency
$v$ = speed
$\lambda$ = wavelength

## GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

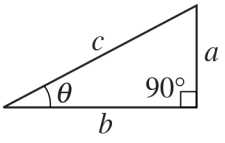
Rectangular solid
$V = \ell wh$

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
$\ell$ = 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

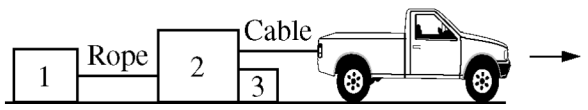
**Section I**

**Time—1 hour and 30 minutes**

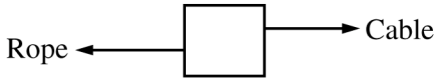
**50 Questions**

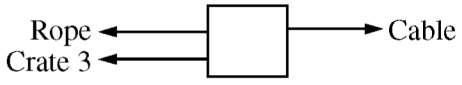
**Note:** To simplify calculations, you may use $g = 10\ \text{m/s}^2$ in all problems.

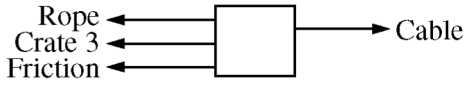
**Directions:** Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

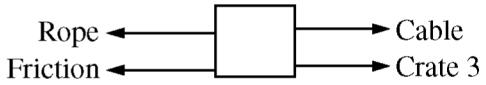



1. The figure above shows a truck pulling three crates across a rough road. Which of the following shows the directions of all the horizontal forces acting on crate 2 ?

(A)



(B)



(C)



(D)






2. Two blocks are on a horizontal, frictionless surface. Block $A$ is moving with an initial velocity of $v_0$ toward block $B$, which is stationary, as shown above. The two blocks collide, stick together, and move off with a velocity of $v_0/3$. Which block, if either, has the greater mass?

(A) Block $A$
(B) Block $B$
(C) Neither; their masses are the same.
(D) The answer cannot be determined without knowing the mass of one of the blocks.

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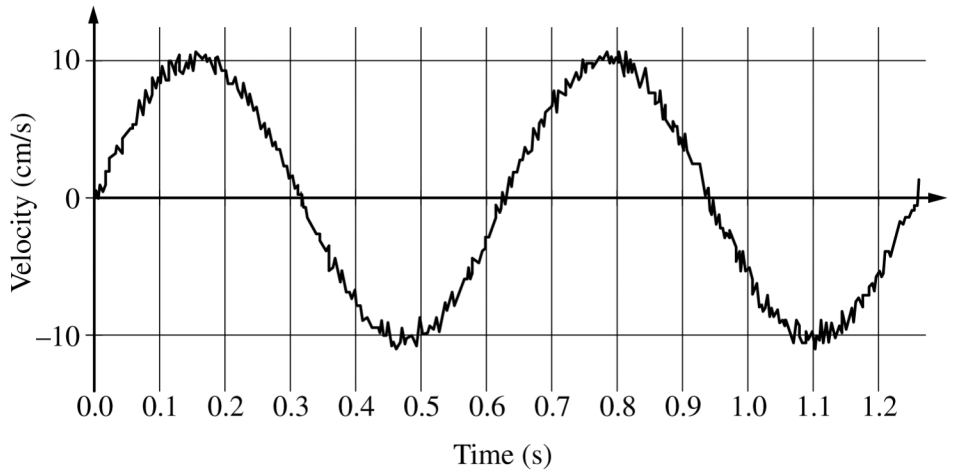
**Questions 3-5 refer to the following material.**




A student sets an object attached to a spring into oscillatory motion and uses a motion detector to record the velocity of the object as a function of time. A portion of the recorded data is shown in the figure above.

3. The total change in the object's speed between 1.0 s and 1.1 s is most nearly

   (A) zero
   (B) 5 cm/s
   (C) 10 cm/s
   (D) 15 cm/s

4. The acceleration of the object at time $t = 0.7$ s is most nearly equal to which of the following?

   (A) The value of the graph where it crosses the 0.7 s grid line
   (B) The slope of the line connecting the origin and the point where the graph crosses the 0.7 s grid line
   (C) The area under the curve between where the graph crosses the time axis near 0.63 s and time 0.7 s
   (D) The slope of the tangent to a best-fit sinusoidal curve at 0.7 s

5. The frequency of oscillation is most nearly

   (A) 0.63 Hz
   (B) 0.80 Hz
   (C) 1.25 Hz
   (D) 1.60 Hz

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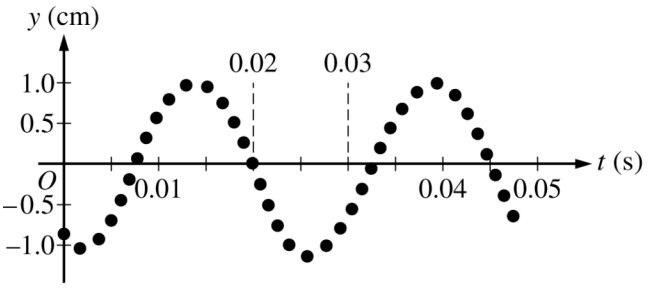
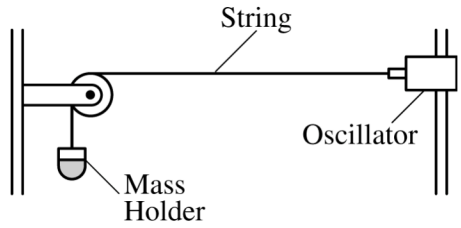


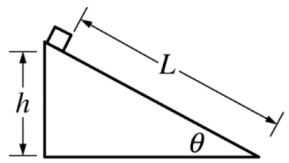

6. One end of a string is fixed in place and the other end is vibrated, allowing a wave to propagate along the string. The vertical position $y$ of a single point on the string is measured at fixed intervals of time t as the wave passes. The graph above shows $y$ as a function of $t$ for the point. A separate measurement indicates that the wave speed on the string is $12\ \text{m/s}$. The wavelength of the wave is most nearly

(A) 0.0021 m
(B) 0.15 m
(C) 0.30 m
(D) 480 m




7. Using the setup above, a student tests how the tension in a string affects the frequency of the fundamental standing wave (with one antinode). In each trial, with a known mass in the holder, the student adjusts the oscillator frequency to produce the fundamental standing wave. The student notices that as the mass in the holder increases, the string stretches and the total string length, from the oscillator to the mass holder, increases. Which of the following procedures could help the student decide if the string's total length has a separate effect from the tension on the fundamental frequency?

(A) Repeating the experiment with a string that does not noticeably stretch when the tension is increased
(B) Repeating the experiment but producing standing waves with two antinodes
(C) Repeating the experiment using a different distance between the oscillator and pulley
(D) Repeating the experiment using lighter blocks




8. A box of mass $m$ is initially at rest at the top of a ramp that is at an angle $\theta$ with the horizontal. The block is at a height $h$ and length $L$ from the bottom of the ramp. The block is released and slides down the ramp. The coefficient of kinetic friction between the block and the ramp is $\mu$.

What is the kinetic energy of the box at the bottom of the ramp?

(A) $mgh$
(B) $\mu mgL\cos\theta$
(C) $mgh - \mu mgL\cos\theta$
(D) $mgL - \mu mgh\cos\theta$

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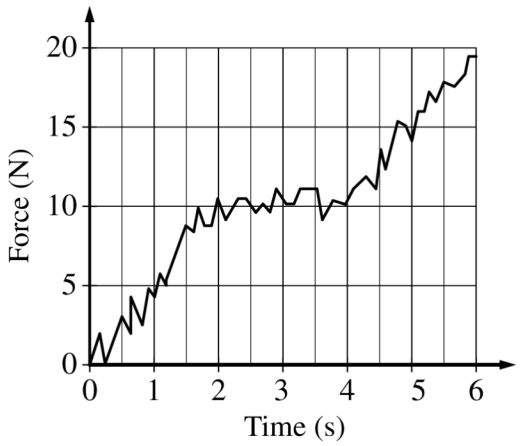
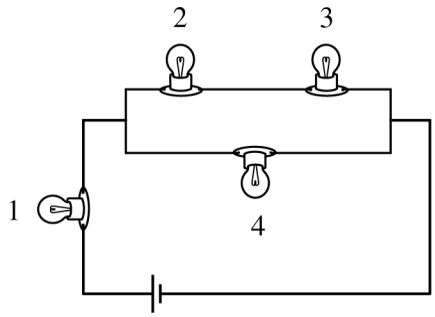


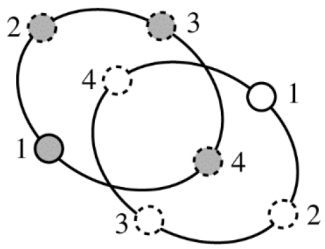

9. During an experiment a student records the net horizontal force exerted on an object moving in a straight line along a horizontal frictionless track. The graph above shows the force as a function of time. Of the following, which is the best approximation of the magnitude of the change in momentum of the object between 0 s and 4 s?

(A) 20 kg•m/s
(B) 30 kg•m/s
(C) 40 kg•m/s
(D) The magnitude of the change in momentum cannot be determined without knowing the mass of the object.




10. The figure above shows four identical lightbulbs connected to a battery. Which of the following correctly ranks the power $P$ dissipated by the lightbulbs?

(A) $P_1 > (P_2 = P_3 = P_4)$
(B) $(P_2 = P_3 = P_4) > P_1$
(C) $P_1 > P_4 > (P_2 = P_3)$
(D) $P_1 = P_2 = P_3 = P_4$




11. The figure above shows the paths of two stars of equal mass as they orbit their common center of mass. The positions of the stars at four different times are labeled in the figure. At which of the positions do the stars have their greatest speed?

(A) Position 2 only
(B) Position 4 only
(C) Positions 1 and 3 only
(D) All of the positions, since the stars move with constant speed

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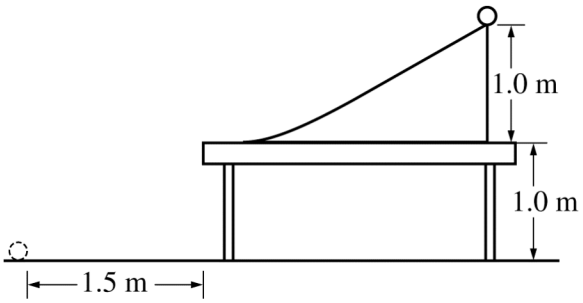
**Questions 12-14 refer to the following material.**




A cylinder at rest is released from the top of a ramp, as shown above. The ramp is 1.0 m high, and the cylinder rolls down the ramp without slipping. At the bottom of the ramp, the cylinder makes a smooth transition to a small section of a horizontal table and then travels over the edge at a height of 1.0 m above the floor, eventually landing on the floor at a horizontal distance of 1.5 m from the table.

12. As the cylinder rolls down the ramp, how do the potential energy of the cylinder-Earth system and the kinetic energy of the cylinder change, if at all?

| | Potential Energy of Cylinder-Earth System | Kinetic Energy of Cylinder |
|---|---|---|
| (A) | Stays the same | Increases |
| (B) | Stays the same | Decreases |
| (C) | Decreases | Increases |
| (D) | Decreases | Decreases |

13. After the cylinder leaves the table, but before it lands, how do the rotational kinetic energy and translational kinetic energy of the cylinder change, if at all?

| | Rotational Kinetic Energy | Translational Kinetic Energy |
|---|---|---|
| (A) | Increases | Increases |
| (B) | Increases | Stays the same |
| (C) | Stays the same | Increases |
| (D) | Stays the same | Stays the same |

14. A sphere with the same mass and radius as the original cylinder, but a smaller rotational inertia, is released from rest from the top of the ramp. As and $K_c$ are the sphere's and the cylinder's total kinetic energy at the bottom of the ramp, respectively. How do $K_s$ and $K_c$ compare, and why?

(A) $K_s < K_c$, because the sphere will gain less rotational kinetic energy.

(B) $K_s < K_c$, because the sphere has a greater acceleration and therefore has less time to gain kinetic energy.

(C) $K_s = K_c$, because both objects accelerate at the same rate.

(D) $K_s = K_c$, because the gravitational force does equal work on each object as it rolls down the ramp.

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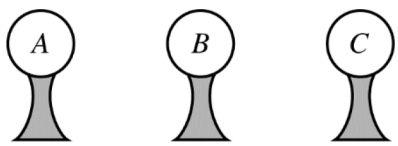


15. Three identical metal spheres on insulating stands are initially isolated from each other, as shown above. The spheres $A$, $B$, and $C$ carry electric charges $+12Q$, $-12Q$, and $+12Q$, respectively. Whenever two of the spheres come into contact, each sphere ends up with the same net charge as the other sphere. Spheres $A$ and $B$ are brought into contact with each other and separated. Spheres $A$ and $C$ are then brought into contact with each other and separated. Which of the following correctly shows the final charge on each sphere?

| | $A$ | $B$ | $C$ |
|---|---|---|---|
| (A) | 0 | 0 | $+12Q$ |
| (B) | $+4Q$ | $+4Q$ | $+4Q$ |
| (C) | $+6Q$ | 0 | $+6Q$ |
| (D) | $+12Q$ | $+12Q$ | $-12Q$ |

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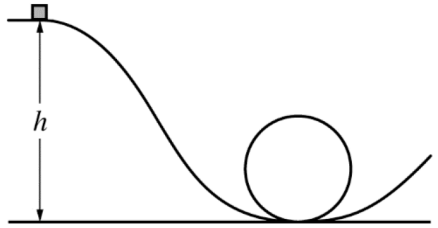
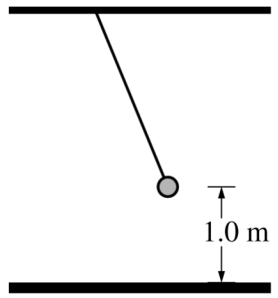



Note: Figure not drawn to scale.

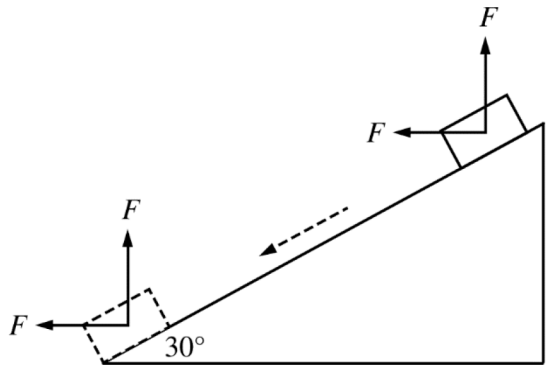
16. A small block slides without friction along a track toward a circular loop. The block has more than enough speed to remain firmly in contact with the track as it goes around the loop. The magnitude of the block's acceleration at the top of the loop is

(A) zero
(B) greater than zero but less than $g$
(C) equal to $g$
(D) greater than $g$




17. A 0.5 kg pendulum bob is raised to 1.0 m above the floor, as shown in the figure above. The bob is then released from rest. When the bob is 0.8 m above the floor, its speed is most nearly

(A) 5 m/s
(B) 4 m/s
(C) 2 m/s
(D) 1 m/s




18. A block is released from rest and slides down a frictionless ramp inclined at 30° from the horizontal. When the block reaches the bottom, the block-Earth system has mechanical energy $E_0$. The experiment is repeated, but now horizontal and vertical forces of magnitude $F$ are exerted on the block while it slides, as shown above. When the block reaches the bottom, the mechanical energy of the block-Earth system

(A) is greater than $E_0$
(B) is equal to $E_0$
(C) is less than $E_0$
(D) cannot be determined without knowing $F$

19. An apple is released from rest 500 m above the ground. Due to the combined forces of air resistance and gravity, it has a speed of 40 m/s when it reaches the ground. What percentage of the initial mechanical energy of the apple-Earth system was dissipated due to air resistance? Take the potential energy of the apple-Earth system to be zero when the apple reaches the ground.

(A) 16%
(B) 40%
(C) 60%
(D) 84%

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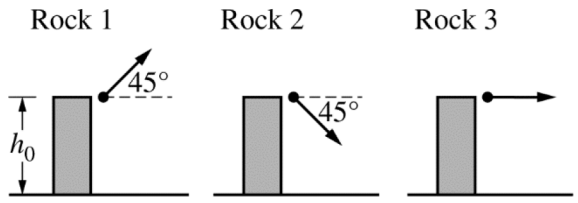
**Questions 20-21 refer to the following material.**




Three identical rocks are launched with identical speeds from the top of a platform of height ho. The rocks are launched in the directions indicated above.

20. Which of the following correctly relates the magnitude $v_y$ of the vertical component of the velocity of each rock immediately before it hits the ground?

(A) $\left(v_{y1} = v_{y2}\right) > v_{y3}$

(B) $v_{y1} > v_{y3} > v_{y2}$

(C) $v_{y2} > v_{y3} > v_{y1}$

(D) $v_{y1} = v_{y2} = v_{y3}$

21. Rock 1, of mass *m*, reaches a maximum height $h_{\max}$ after being launched. During the time between the instant rock 1 is launched from height ho and the instant it returns to height ho, the work done on the rock by the gravitational force is

(A) 0

(B) $-mgh_0$

(C) $-mg\left(h_{\max} - h_0\right)$

(D) $2mg\left(h_{\max} - h_0\right)$

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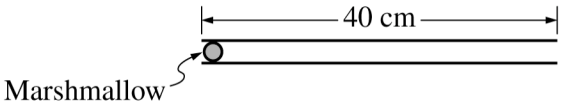
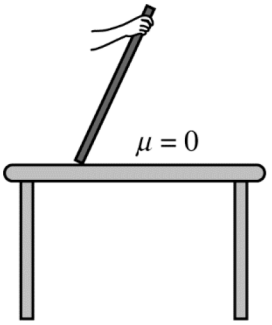



22. A 2.5 g marshmallow is placed in one end of a 40 cm pipe, as shown in the figure above. A person blows into the left end of the pipe to eject the marshmallow from the right end. The average net force exerted on the marshmallow while it is in the pipe is 0.7 N. The speed of the marshmallow as it leaves the pipe is most nearly

(A) 4.7 m/s
(B) 11 m/s
(C) 15 m/s
(D) 280 m/s




23. A meterstick is held as shown above and then released from rest. The tabletop has negligible friction. Which figure below best indicates the path of the center of mass of the meterstick as it falls?

(A)



(B)



(C)



(D)



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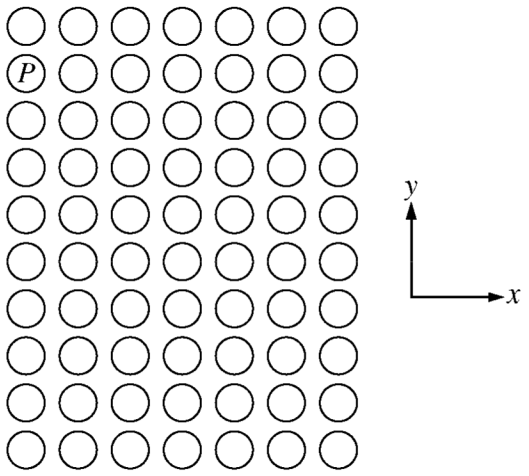


Figure 1

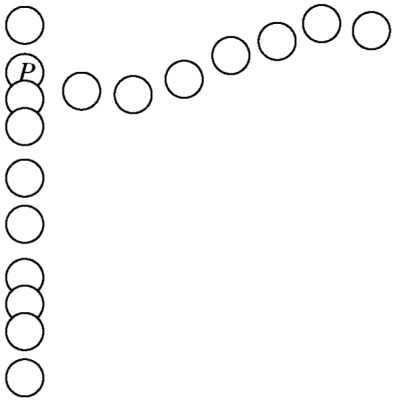


Figure 2

24. Figure 1 above represents atoms in a solid material. A particle hits atom $P$ and the atom vibrates, disturbing nearby atoms. Figure 2 represents just the vertical and horizontal rows containing atom $P$ and shows the propagation of the disturbance along them. Which of the following statements correctly indicates the direction of atom $P$'s vibration and the type of wave along each row?

| | $P$'s Vibration | Wave Along Vertical Row | Wave Along Horizontal Row |
|---|---|---|---|
| (A) | Along y axis | Longitudinal | Transverse |
| (B) | Along y axis | Transverse | Longitudinal |
| (C) | Along x axis | Longitudinal | Transverse |
| (D) | Along x axis | Transverse | Longitudinal |

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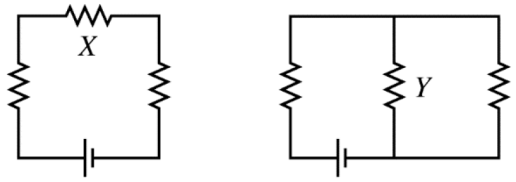
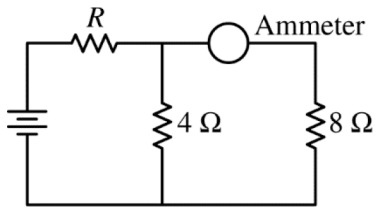



Circuit 1 Circuit 2

25. The two circuits shown above contain identical resistors and batteries. Which of the following best explains why resistors *X* and *Y* dissipate the same power?

(A) Resistors *X* and *Y* have the same potential difference across them because each is the second resistor in its circuit.
(B) Both circuits have identical batteries and contain the same number of identical resistors.
(C) Although each circuit has a different total current, the current through an individual resistor depends only on its resistance.
(D) Compared to circuit 1, the total current through circuit 2 is twice as much, but only half that current flows through resistor *Y*.




26. In the circuit above, the current through the ammeter is 2 A. What is the current through the resistor of unknown resistance *R* ?

(A) 6 A
(B) 4 A
(C) 3 A
(D) The current cannot be determined without knowing the value of *R*.

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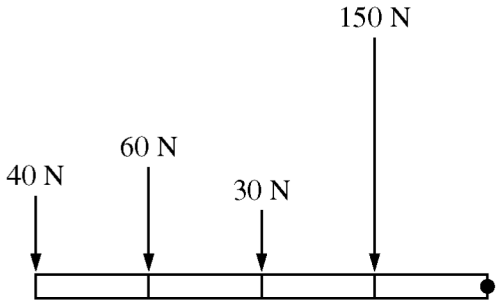
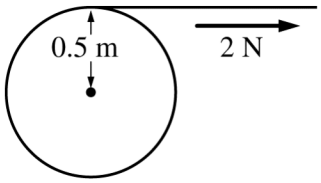



27. The figure above represents a stick of uniform density that is attached to a pivot at the right end and has equally spaced marks along its length. Any one of the four forces shown can be exerted on the stick as indicated. Which force will create the largest rate of change in the stick's angular momentum?

(A) The 30 N force
(B) The 40 N force
(C) The 60 N force
(D) The 150 N force




28. A disk with radius of 0.5 m is free to rotate around its center without friction. A string wrapped around the disk is pulled, as shown above, exerting a 2 N force tangent to the edge of the disk for 1 s. If the disk starts from rest, what is its angular speed after 1 s?

(A) 0 rad/s
(B) 1 rad/s
(C) 4 rad/s
(D) It cannot be determined without knowing the rotational inertia of the disk.

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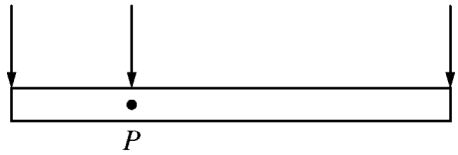


Top View

29. The figure above shows a rod that is fixed to a horizontal surface at pivot *P*. The rod is initially rotating without friction in the counterclockwise direction. At time *t*, three forces of equal magnitude are applied to the rod as shown. Which of the following is true about the angular speed and direction of rotation of the rod immediately after time *t* ?

| | Angular Speed | Direction of Rotation |
|---|---|---|
| (A) | Decreasing | Counterclockwise |
| (B) | Decreasing | Clockwise |
| (C) | Increasing | Counterclockwise |
| (D) | Increasing | Clockwise |

30. Two systems are in oscillation: a simple pendulum swinging back and forth through a very small angle and a block oscillating on a spring. The block-spring system takes twice as much time as the pendulum to complete one oscillation.

Which of the following changes could make the two systems oscillate with the same period?

(A) Increasing the mass of the pendulum bob
(B) Increasing the angle through which the pendulum swings by a small amount
(C) Decreasing the mass of both the block and the pendulum bob
(D) Shortening the pendulum

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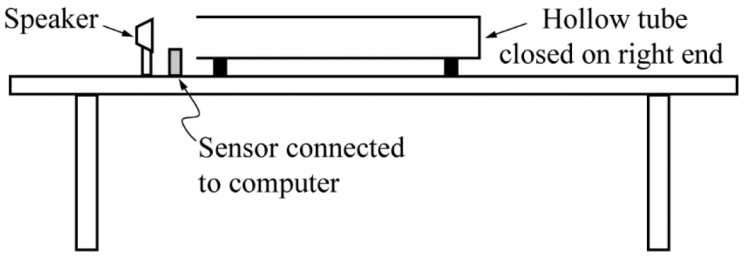
**Questions 31-32 refer to the following material.**




Students use a speaker connected to a sine wave generator to project sound waves into the open left end of a tube that is closed on the right end. The speaker is very close to the tube. A sensor is used to measure the pressure differences created by the sound and the results are displayed on a computer. The entire apparatus is in a sealed chamber that can be filled with different gases.

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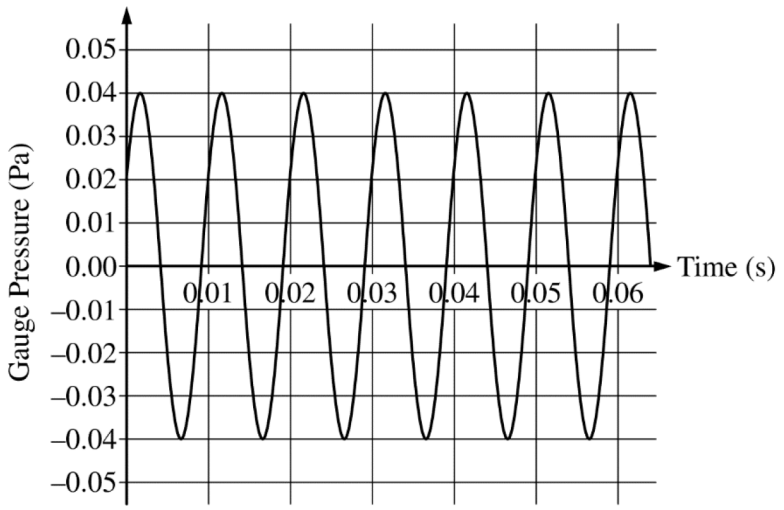


31. The students vary the frequency of the sound until the maximum loudness from the tube is achieved. The graph above represents the computer display of gauge pressure (the amount by which the pressure is above or below atmospheric pressure) as a function of time. What are the amplitude and frequency of the wave?

| | Amplitude | Frequency |
|---|---|---|
| (A) | 0.04 Pa | 0.01 Hz |
| (B) | 0.04 Pa | 100 Hz |
| (C) | 0.08 Pa | 0.01 Hz |
| (D) | 0.08 Pa | 100 Hz |

32. The chamber is now filled with a gas that has an unknown speed of sound. The students find that the lowest frequency at which they can hear a maximum in the sound level is 200 Hz. If the students slowly increase the frequency, what is the next frequency at which the sensor would measure a maximum in the sound level?

(A) 300 Hz
(B) 400 Hz
(C) 600 Hz
(D) 800 Hz

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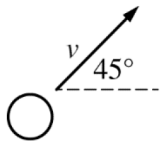
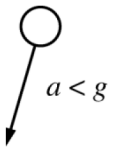
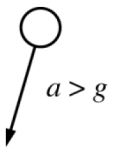
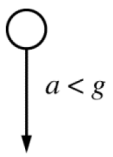
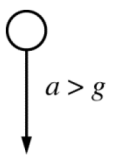


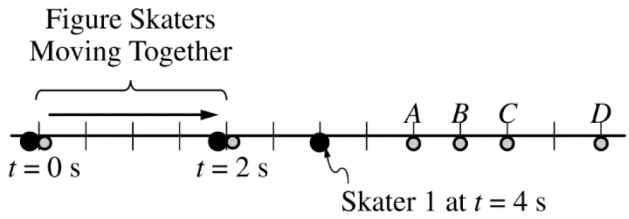

33. A hollow plastic ball is projected into the air. There is significant air resistance opposing the ball's motion, so the magnitude of the ball's acceleration is not equal to g. At time t, the ball is moving up and to the right at an angle of $45°$ to the horizontal, as shown above. Which of the following best shows the magnitude a and the direction of the ball's acceleration at time $t$ ?

(A) 


(B) 


(C) 


(D) 


Top View

34. At time $t = 0$ two figure skaters are moving together over ice with negligible friction, as shown above. Skater 1, represented by the large black dot, is twice as massive as skater 2, represented by the gray dot. At $t = 2$ s the skaters push off of one another. The location of skater 1 is shown at $t = 4$ s . At $t = 4$ s , skater 2 is located at which of the labeled points?

(A) Point $A$
(B) Point $B$
(C) Point $C$
(D) Point $D$

35. A charged sphere located at the origin of the $xy$-plane exerts a force of magnitude $F$ on a charged particle located at $(+d, 0)$ . The sphere will exert a force $F/2$ on the particle if the particle is moved to which of the following locations?

(A) $(+2d, 0)$
(B) $(+d, +d)$
(C) $(+d/2, 0)$
(D) $(0, -d)$

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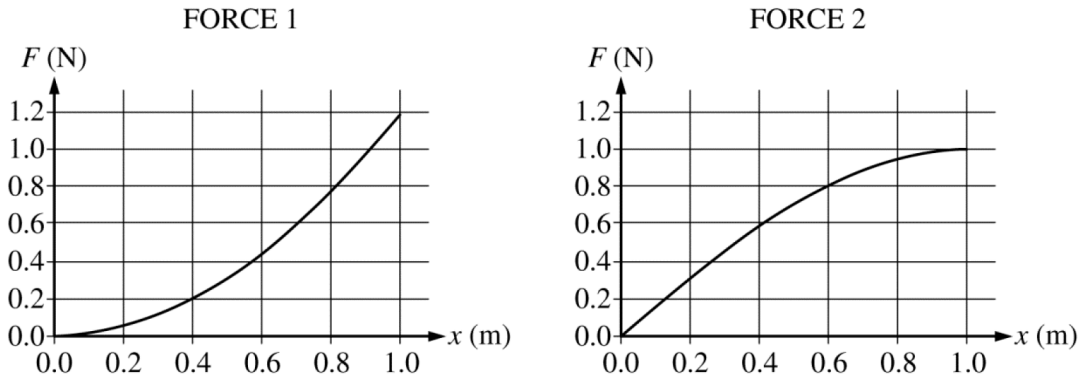


36. The graphs above show the magnitude $F$ of a force exerted on an object as a function of the object's position $x$ for two trials in an experiment. $W_1$ and $W_2$ are the work done on the object by force 1 and force 2, respectively. How do $W_1$ and $W_2$ compare, and why?

(A) $W_1 > W_2$, because the maximum value of force 1 is greater than the maximum value of force 2.

(B) $W_1 > W_2$, because the slope of force 1's graph increases, while the slope of force 2's graph decreases.

(C) $W_1 < W_2$, because the average value of force 1 is smaller than the average value of force 2.

(D) $W_1 < W_2$, because at the midpoint, $x = 0.5$ m, the value of force 1 is less than the value of force 2.

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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. A water-skier with weight $F_g = mg$ moves to the right with acceleration $a$. A horizontal tension force $T$ is exerted on the skier by the rope, and a horizontal drag force $F_d$ is exerted by the water on the ski. The water also exerts a vertical lift force $L$ on the skier. Which of the following are correct relationships between the forces exerted on the skier-ski system? Select two answers.

(A) $T - F_d = ma$

(B) $L - F_g = ma$

(C) $L - F_g = 0$

(D) $T - F_d = 0$

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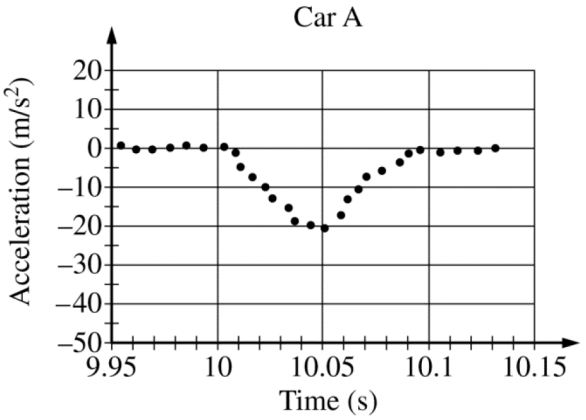


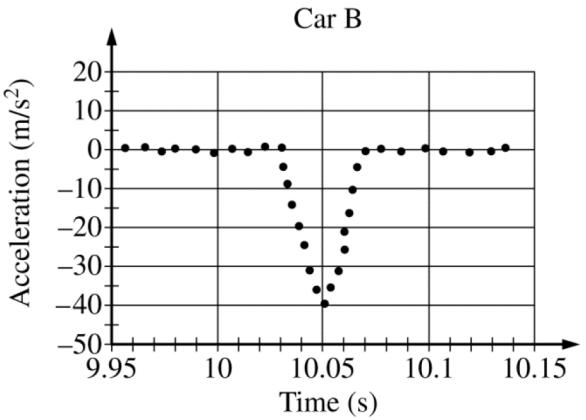


132. Two model cars, A and B, have the same mass but different bumpers. The acceleration of each car during its collision with a wall is measured, and the data are shown in the graphs above. Which of the following statements about the collisions are correct? Select two answers.

(A) Both cars reach their maximum speed at 10.05 s.
(B) The cars experience approximately the same impulse.
(C) Car B experiences a nonzero force for a longer time than car A.
(D) The change in momentum for car B occurs over a shorter period of time than for car A.

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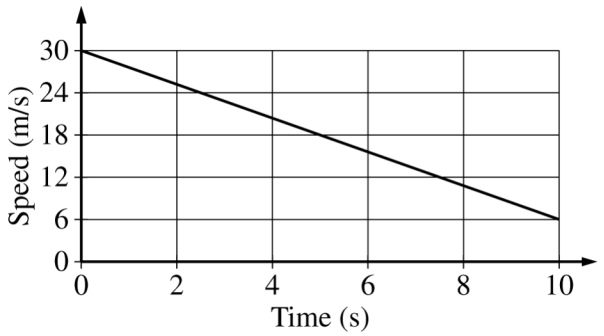


133. The graph above shows the speed of a truck as it moves along a straight, level road. Which of the following describe a method to determine the distance $d$ the truck travels during the 10 s time interval shown? Select two answers.

(A) Multiply the average speed of $18\ \text{m/s}$ by the 10 s travel time.

(B) Multiply half the initial speed of $30\ \text{m/s}$ by the 10 s travel time.

(C) Calculate the slope of the line in the graph to determine the acceleration a and then use $d = (1/2)at^2$, where $t$ is the travel time.

(D) Calculate the area under the line in the graph.

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134. A vehicle lands on Mars and explores its surface.

The average gravitational field on the surface of Mars is $3.7\ \mathrm{N/kg}$. The weight of the vehicle is defined as the gravitational force exerted on it.

Which of the following statements are true about the vehicle's weight? Select two answers.

(A) The vehicle's weight was constant until it reached the surface of Mars.

(B) The vehicle's weight increased while it was descending to the surface of Mars.

(C) The vehicle's weight always equals the normal force exerted by Mars on the vehicle while it is landing.

(D) The vehicle weighs less on the surface of Mars than on the surface of Earth.

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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.**

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**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

2018

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

### At a Glance

**Total Time**
1 hour and 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.
   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 4OBP4-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 | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\theta$ | 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
$\ell$ = 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
$\alpha$ = angular acceleration
$\mu$ = coefficient of friction
$\theta$ = angle
$\rho$ = density
$\tau$ = torque
$\omega$ = 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
$\ell$ = length
$P$ = power
$q$ = charge
$R$ = resistance
$r$ = separation
$t$ = time
$V$ = electric potential
$\rho$ = resistivity

## WAVES

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

$f$ = frequency
$v$ = speed
$\lambda$ = wavelength

## GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

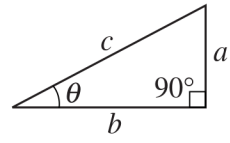
Rectangular solid
$V = \ell wh$

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
$\ell$ = length
$w$ = width
$r$ = radius

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



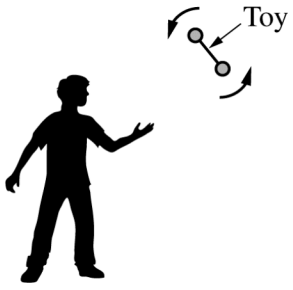
**PHYSICS 1**

**Section II**

**Time—1 hour and 30 minutes**

**5 Questions**

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

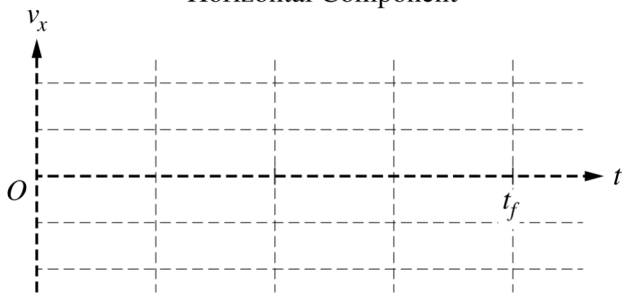



1. (7 points, suggested time 13 minutes)

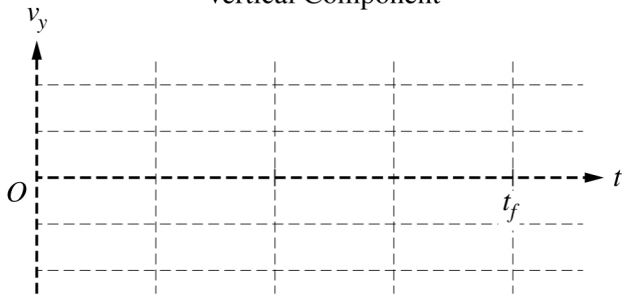
   A toy consists of two identical solid spheres connected by a string with negligible mass. The toy is thrown at an angle above the horizontal (not straight up) such that the string remains taut and both spheres are revolving counterclockwise in a vertical plane around the center of the string, as shown above.

   (a) Sketch graphs of the horizontal and vertical components of the velocity of the center of the string as a function of time, from the instant the spheres are released at time $t = 0$ until the instant the system returns to its initial height at time ty. Take the positive direction to be toward the right for the horizontal component and the positive direction to be upward for the vertical component.

Horizontal Component




Vertical Component

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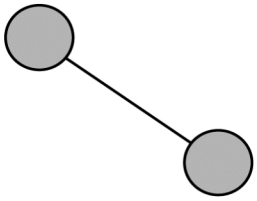
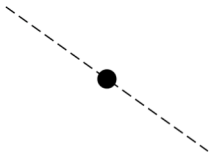


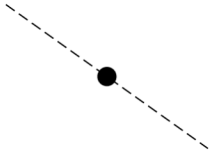
(b) The figure above shows the toy at the instant the center of the string reaches the top of its trajectory. This is a side view: the sphere on the left is higher than the sphere on the right.

i. On the dot below, which represents the left sphere only, draw and label the forces (not components) exerted on the left sphere at this instant. Represent each force by a distinct arrow starting on, and pointing away from, the dot. The dashed line is drawn at the same angle as the string.



Left Sphere

ii. On the dot below, which represents the whole toy (the spheres-string system), draw and label the forces (not components) that act on the system at this instant. Represent each force by a distinct arrow starting on, and pointing away from, the dot. The dashed line is drawn at the same angle as the string.



Whole Toy

iii. When the toy was released, the center of the string was moving with an initial speed of 15 m/s at a 60° angle above the horizontal. Calculate the speed of the center of the string at the instant shown above, when the center of the string reaches the top of its trajectory.

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2. (12 points, suggested time 25 minutes)

A heavy lab cart moves with kinetic energy $K_{\text{init}}$ on a track and collides with a lighter lab cart that is initially at rest. The carts bounce off each other but the collision is not perfectly elastic, causing the two-cart system to lose kinetic energy $K_{\text{lost}}$. A student wonders if the fraction of kinetic energy lost from the two-cart system during the collision $\left(\frac{K_{\text{lost}}}{K_{\text{init}}}\right)$ depends on the speed of the first cart before the collision and plans to perform an experiment.

(a) The student hypothesizes that a greater fraction of kinetic energy is lost from the system during the collision when the speed of the first cart is greater.

Briefly state one reason the hypothesis might be correct.

(b) Design an experimental procedure that could be used to test the student's hypothesis. Assume equipment usually found in a school physics laboratory is available.

In the table below, list the quantities that would be measured and the equipment that would be used to measure each quantity. Also, define a symbol to represent each quantity. You do not need to use every row and may add additional rows as needed.

| Quantity to be Measured | Symbol | Equipment for Measurement |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

Describe the overall procedure to be used, referring to the table above. Provide enough detail so that another student could replicate the experiment. As needed, use the symbols defined in the table and/or include a simple diagram of the setup. Be sure to address how experimental uncertainty could be reduced.

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(c) Describe how the experimental data could be analyzed to confirm or disconfirm the hypothesis that a greater fraction of kinetic energy is lost from the system during the collision when the speed of the first cart is greater. Include a description or example of any equations, data tables, graphs, or other representations that could be used.

(d) Consider a different scenario in which the carts stick together after the collision. The masses of the heavier and lighter cart are my and my, respectively. Derive an expression for the fraction of kinetic energy lost $\left(\frac{K_{\text{lost}}}{K_{\text{init}}}\right)$ during the collision. Express your answer in terms of $m_1$ and $m_2$.

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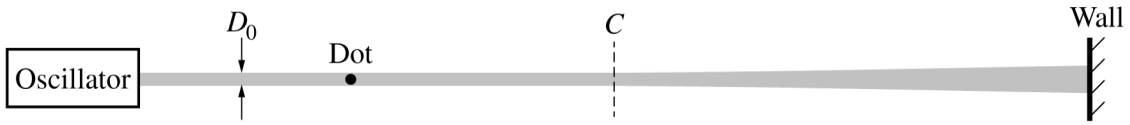



Note: Figure not drawn to scale.

3. (12 points, suggested time 25 minutes)

As shown above, the left end of a horizontal string is attached to an oscillator and the right end is attached to a wall. The string's midpoint is labeled $C$, and a dot has been painted on the left half of the string. The left half of the string is uniformly thick, with diameter Do, while the right half of the string gradually increases in thickness from the midpoint $C$ to the wall. The string is made of a material with uniform density (mass per unit volume).

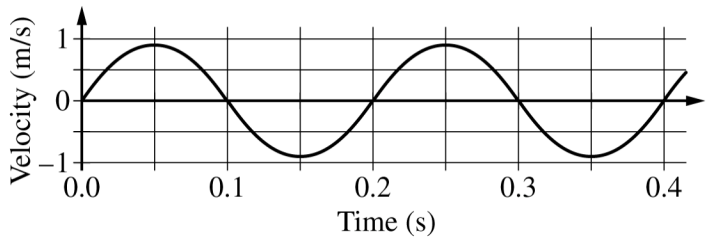
(a) The oscillator shakes the left end of the string up and down, creating waves traveling to the right with speed $v_0$. A student observes that every wave crest approaching the midpoint $C$ passes through $C$ but gradually slows down on the right half of the string.

i. On which half of the string, if either, do the waves have a longer wavelength?

____ Left half ____ Right half ____ Same wavelength on both halves

Briefly explain your reasoning.

ii. The graph below represents the vertical velocity of the dot on the left half of the string as a function of time.




Describe how you could use the graph to estimate the amplitude of the waves at the dot's location. You do NOT have to actually calculate the amplitude.

(b) In a different experiment, the oscillator shakes the left end of the string up and down at a rate of 50 cycles per second. The leading edge of the wave reaches the midpoint $C$, which is 0.75 m from the left end of the string, 0.030 second after the oscillator starts shaking the string. Calculate the wavelength of the wave on the left half of the string.

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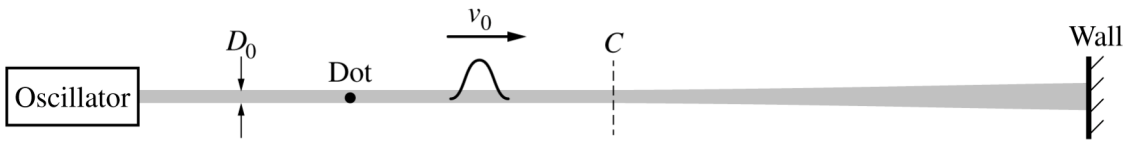



Note: Figure not drawn to scale.

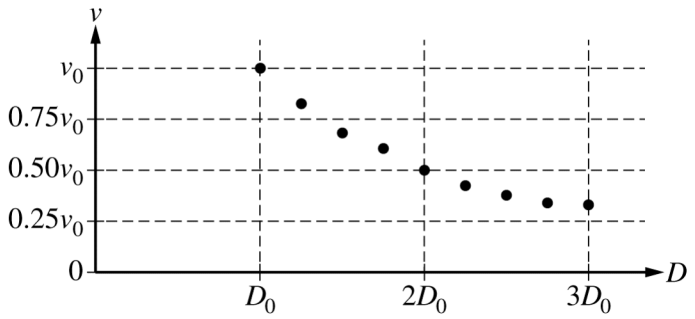
Later, the student uses the oscillator to create a single pulse with initial speed vo at the left end of the string, as shown above. The student wants to quantify the observation that the pulse slows down on the right half of the string. The student comes up with the following equation relating the string's diameter $D$ at a given point on the string to the speed $v$ of the pulse at that point: $v = v_0\left(\frac{D_0}{D}\right)$.

(c) Is the equation consistent with the observation that the pulse slows down on the right half of the string?

____ Yes ____ No

Briefly explain your reasoning.

(d) Using frame-by-frame analysis of video of the pulse, the student plots the speed $v$ of the pulse as a function of the string diameter $D$, as shown below.




Are the data in the graph consistent with the student's equation above?

____ Yes ____ No

Briefly explain your answer.

Question 3 continues on the next page.

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Note: Figure not drawn to scale.

(e) The figure above shows only the right half of the string. The solid line represents the shape of the wave pulse when its peak reaches point $X$, which is to the right of the midpoint $C$. Draw the pulse when it reaches point $Y$. Your drawing should clearly indicate whether the width of the pulse at point $Y$ is greater than, equal to, or less than the width of the pulse at point $X$.

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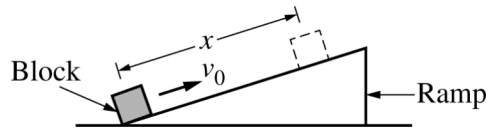
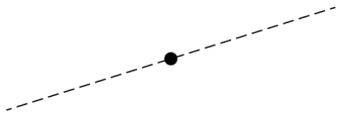
4. (7 points, suggested time 13 minutes)

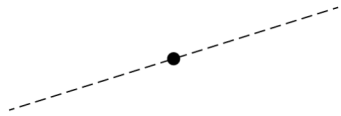
A student strikes a block at the bottom of a ramp, giving it an initial speed $v_0$ up the ramp, as shown at right. There is friction between the ramp and the block as it slides a distance $x$ up the ramp and then slides back down.




(a) On the dots below, which represent the block as it is sliding up the ramp and down the ramp, draw and label the forces (not components) exerted on the block. Represent each force by a distinct arrow starting on, and pointing away from, the dot. The dashed lines are drawn at the same angle as the surface of the ramp.



Up the Ramp



Down the Ramp

(b) The block takes time tup to slide up the ramp a distance x. The block then takes time fdown to slide back down to the bottom of the ramp, where it has speed $v_f$. Is $t_{\text{down}}$ greater than, equal to, or less than $t_{\text{up}}$?

____ $t_{\text{down}} > t_{\text{up}}$ ____ $t_{\text{down}} = t_{\text{up}}$ ____ $t_{\text{down}} < t_{\text{up}}$

In a clear, coherent paragraph-length response that may also contain figures and/or equations, explain your reasoning. If you need to draw anything other than what you have shown in part (a) to assist in your response, use the space below. Do NOT add anything to the figures in part (a).

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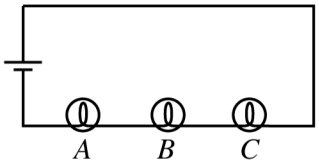


Figure 1

5. (7 points, suggested time 13 minutes)

Students in a physics lab use a battery and three identical lightbulbs to construct the circuit shown in Figure 1 above. The brightness of each bulb increases when the current through the bulb increases.

(a) Which bulb, if any, is the brightest?

____ *A* ____ *B* ____ *C* ____ All bulbs have the same brightness.

Briefly explain your reasoning in terms of current and/or potential difference.

(b) The students observe the brightness of bulbs *A*, *B*, and *C*. The students then add a fourth lightbulb *D,* with a larger resistance than bulbs *A*, *B*, and *C*, as shown in Figure 2 below.

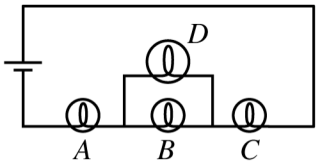


Figure 2

i. Is bulb *A* now brighter than, dimmer than, or the same brightness as it was in the circuit in Figure 1 ?

____ Brighter ____ Dimmer ____ Same brightness

Briefly explain your reasoning.

ii. Is bulb *B* now brighter than, dimmer than, or the same brightness as it was in the circuit in Figure 1 ?

____ Brighter ____ Dimmer ____ Same brightness

Briefly explain your reasoning.

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(c) Bulbs $A$, $B$, and $C$ each have resistance 10 Ω, while bulb $D$ has a resistance of 30 Ω. In the circuit shown in Figure 2, the current through bulb $D$ is measured to be 0.20 A. Calculate the potential difference across bulb $A$.

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

**STOP**

**END OF EXAM**

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

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- **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 ON THE FRONT COVER.**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**