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AP® Physics 1: Algebra-Based Exam

SECTION I: Multiple Choice

2015

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

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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 <u>two</u> 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 4LBP4-S

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DO NOT seal answer sheet inside

AP® PHYSICS 1 TABLE OF INFORMATION

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

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

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

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

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

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. Assume air resistance is negligible unless otherwise stated.
III. In all situations, positive work is defined as work done <u>on</u> 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

$$v_x = v_{x0} + a_x t$$

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

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

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

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

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

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

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

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

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

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

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

$$\omega = \omega_0 + \alpha t$$

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

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

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

$$L = I\omega$$

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

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

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

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

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

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

$$\Delta U_g = m g \Delta y$$

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

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

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

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

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

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

ELECTRICITY

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

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

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

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

$$P = I\,\Delta V$$

$$R_s = \sum_i R_i$$

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

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

WAVES

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

f = frequency
v = speed
λ = wavelength

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

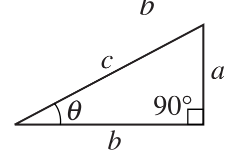
Rectangular solid
$V = \ell w h$

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

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

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

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



PHYSICS 1

Section I

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. In which of the following situations is the kinetic energy of the object decreasing?

   (A) A sphere is dropped from a building.
   (B) A satellite is moving in a circular orbit around Earth.
   (C) A baseball is heading upward after being thrown at an angle.
   (D) An elevator is moving upward at a constant velocity.

2. Two protons are held a distance *d* apart. The electrostatic force and the gravitational force that one proton exerts on the other are F_e and F_g, respectively. Which of the following correctly compares the magnitude and direction of these forces?

	Magnitude	Direction
(A)	$F_e > F_g$	Opposite
(B)	$F_e > F_g$	Same
(C)	$F_e < F_g$	Opposite
(D)	$F_e < F_g$	Same

3. A 2 kg object traveling at $5\ \text{m/s}$ on a frictionless horizontal surface collides head-on with and sticks to a 3 kg object initially at rest. Which of the following correctly identifies the change in total kinetic energy and the resulting speed of the objects after the collision?

	Kinetic Energy	Speed
(A)	Increases	$2\ \text{m/s}$
(B)	Increases	$3.2\ \text{m/s}$
(C)	Decreases	$2\ \text{m/s}$
(D)	Decreases	$3.2\ \text{m/s}$

4. A stone of mass m is thrown upward at a $30°$ angle to the horizontal. At the instant the stone reaches its highest point, why is the stone neither gaining nor losing speed?

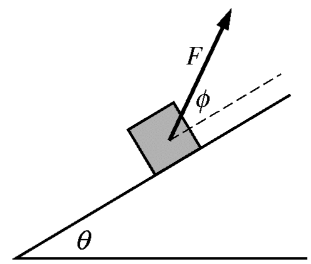
   (A) Because the acceleration of the stone at that instant is zero
   (B) Because the net force acting upon the stone at that instant has magnitude $m\vec{g}$
   (C) Because the angle between the stone's velocity and the net force exerted upon the stone is $90°$
   (D) Because the stone follows a parabolic trajectory and the peak of the trajectory is where the parabola has zero slope

GO ON TO THE NEXT PAGE.

5. A small cart is rolling freely on an inclined ramp with a constant acceleration of $0.50\ \text{m/s}^2$ in the $-x$-direction. At time $t = 0$, the cart has a velocity of $2.0\ \text{m/s}$ in the $+x$-direction. If the cart never leaves the ramp, which of the following statements correctly describes the motion of the cart at a time $t > 5$ s?

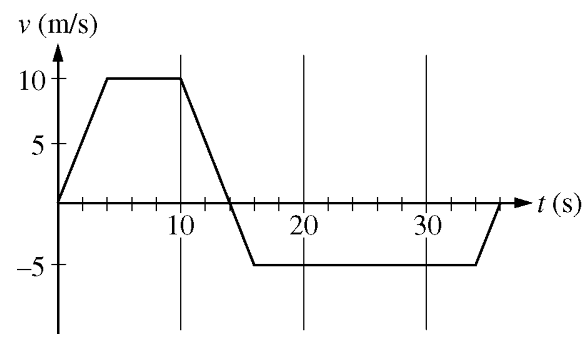
(A) The cart is traveling in the $+x$-direction and is slowing down.
(B) The cart is traveling in the $+x$-direction and is speeding up.
(C) The cart is traveling in the $-x$-direction and is slowing down.
(D) The cart is traveling in the $-x$-direction and is speeding up.

Item 6 was not scored.



7. A box of mass m is on a rough inclined plane that is at an angle θ with the horizontal. A force of magnitude F at an angle ϕ with the plane is exerted on the block, as shown above. As the block moves up the plane, there is a frictional force between the box and the plane of magnitude f. What is the magnitude of the net force acting on the box?

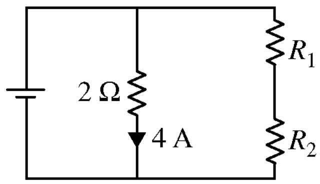
(A) $F\sin\phi - mg\cos\theta - f$
(B) $F\cos(\phi + \theta) + mg\sin\theta - f$
(C) $F\cos\phi - mg\sin\theta - f$
(D) $F\cos(\phi + \theta) - mg\sin\theta - f$



8. An object's velocity v as a function of time t is given in the graph above. Which of the following statements is true about the motion of the object?

(A) The object is not moving from $t = 4$ s to $t = 10$ s.
(B) The object's initial and final positions are the same.
(C) The object is slowing down from $t = 14$ s to $t = 16$ s.
(D) The average acceleration of the object from $t = 0$ s to $t = 4$ s is different from the acceleration from $t = 34$ s to $t = 36$ s.

Questions 9-10 refer to the following material.



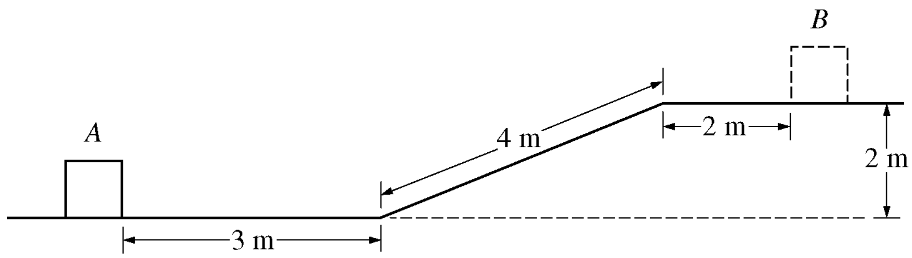
In the circuit shown above, the sum of the resistances of resistors R_1 and R_2 is 8 Ω.

9. What is the current through the battery?

(A) 4 A
(B) 5 A
(C) 8 A
(D) 20 A

10. Resistor R_1 and the 2 Ω resistor are now swapped. How does the current in the right branch of the circuit change, and why?

(A) The current does not change, because the total resistance does not change.
(B) The current increases, because the total resistance will always decrease.
(C) The current decreases, because the total resistance will always increase.
(D) The change in current cannot be determined without knowing the resistances of R_1 and R_2.



11. A block of mass 10 kg moves from position A to position B shown in the figure above. The speed of the block is 10 m/s at A and 4.0 m/s at B. The work done by friction on the block as it moves from A to B is most nearly

(A) −280 J
(B) −220 J
(C) −200 J
(D) 0 J

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12. To determine the speed of waves on a string, some students tie a long string of unknown length between a wave generator and a wall. They vary the frequency f of the generator to get a standing wave. They count the nodes n and measure the wavelength λ. They repeat the experiment, creating standing waves with different frequencies. Which of the following is the best relationship to graph to determine the speed of the waves on the string?

(A) f as a function of λ
(B) f as a function of $1/\lambda$
(C) f as a function of n
(D) f as a function of $1/n$

13. A ladder at rest is leaning against a wall at an angle. Which of the following forces must have the same magnitude as the frictional force exerted on the ladder by the floor?

(A) The force of gravity on the ladder
(B) The normal force exerted on the ladder by the floor
(C) The frictional force exerted on the ladder by the wall
(D) The normal force exerted on the ladder by the wall

14. Some students want to calculate the work done by friction as an object with unknown mass moves along a straight line on a rough horizontal surface. The students have a force probe, a meterstick, and a stopwatch. Which of the following will allow the students to take the measurements needed to calculate the work done by friction?

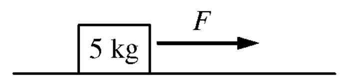
(A) Pulling the block at an unknown constant acceleration with the force probe for a measured time
(B) Pulling the block at an unknown constant speed with the force probe for a measured time
(C) Pulling the block at an unknown constant acceleration with the force probe for a measured distance
(D) Pulling the block at an unknown constant speed with the force probe for a measured distance

15. A pendulum consisting of a sphere suspended from a light string is oscillating with a small angle with respect to the vertical. The sphere is then replaced with a new sphere of the same size but greater density and is set into oscillation with the same angle. How do the period, maximum kinetic energy, and maximum acceleration of the new pendulum compare to those of the original pendulum?

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

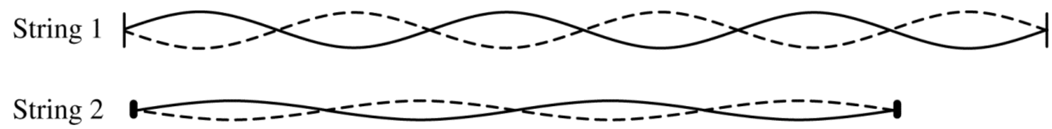
16. Planet X has twice Earth's mass and three times Earth's radius. The magnitude of the gravitational field near Planet X's surface is most nearly

(A) 2 N/kg
(B) 7 N/kg
(C) 10 N/kg
(D) 20 N/kg



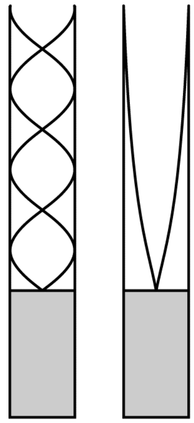
17. A force F is exerted on a 5 kg block to move it across a rough surface, as shown above. The magnitude of the force is initially 5 N, and the block moves at a constant velocity. While the block is moving, the force is instantaneously increased to 12 N. How much kinetic energy does the block now gain as it moves a distance of 2 m?

(A) 10 J
(B) 14 J
(C) 24 J
(D) 34 J



18. The figure above represents two guitar strings of different materials and lengths, which are on two guitars of different sizes. String 1 is plucked so it vibrates in the pattern shown. Very soon after string 1 is plucked, string 2, which is a short distance away, vibrates in the pattern shown. The guitars are placed in a sealed chamber and then the air is pumped out of the chamber. String 1 is again plucked and vibrates in the pattern shown. Does string 2 again vibrate in the pattern shown, and why or why not?

(A) Yes, because waves again carry some of the energy produced by string 1 to string 2
(B) Yes, because the strings share the same fundamental frequency
(C) No, because the amplitude of the vibration of string 1 becomes zero too quickly for string 2 to start vibrating
(D) No, because almost no energy associated with the vibration of string 1 reaches string 2



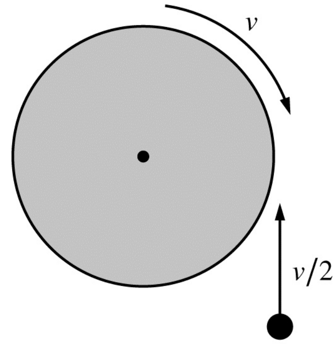
19. The figure above represents standing wave patterns in two identical tubes. The tubes contain the same amount of water, and the standing waves are produced by holding a vibrating tuning fork near the top of each tube. What is the relationship between the wavelengths λ_X and λ_Y of the standing waves?

(A) $\lambda_X = \frac{1}{7}\lambda_Y$

(B) $\lambda_X = \frac{2}{7}\lambda_Y$

(C) $\lambda_X = \frac{7}{2}\lambda_Y$

(D) $\lambda_X = 7\lambda_Y$



20. A system consists of a disk rotating on a frictionless axle and a piece of clay moving toward it, as shown in the figure above. The outside edge of the disk is moving at a linear speed v, and the clay is moving at speed $v/2$. The clay sticks to the outside edge of the disk. How does the angular momentum of the system after the clay sticks compare to the angular momentum of the system before the clay sticks, and what is an explanation for the comparison?

(A) It is the same because there is no external torque acting on the system.
(B) It is greater because the rotating mass increases, which increases the rotational inertia.
(C) It is less because the speed of the disk decreases when the clay sticks to it.
(D) It is less because the angular momentum of the clay opposes that of the disk.

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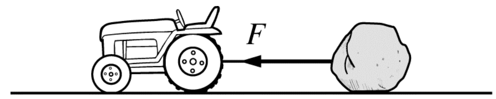
21. A disk of known radius and rotational inertia can rotate without friction in a horizontal plane around its fixed central axis. The disk has a cord of negligible mass wrapped around its edge. The disk is initially at rest, and the cord can be pulled to make the disk rotate. Which of the following procedures would best determine the relationship between applied torque and the resulting change in angular momentum of the disk?

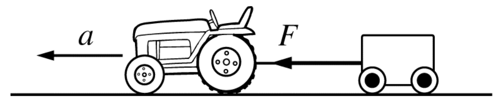
(A) Pulling on the cord, exerting a force of 15 N for 2 s and then 25 N for 3 s, and measuring the final angular velocity of the disk
(B) For five different time intervals, pulling on the cord, exerting a force of 15 N, and then measuring the angle through which the disk rotates in each case
(C) For five different time intervals, pulling on the cord, exerting a force of 15 N, and then measuring the final angular velocity of the disk
(D) For five forces of different magnitude, pulling on the cord for 5 s, and then measuring the final angular velocity of the disk

22. When object *X* with charge $+2\ \mu\text{C}$ is 1 m from object *Y* with charge $-3\ \mu\text{C}$, the magnitude of the force between them is *F*. Object *Y* is removed, and object *Z* with charge $-2\ \mu\text{C}$ is placed 2 m from object *X*. What is the magnitude of the force between objects *X* and *Z* ?

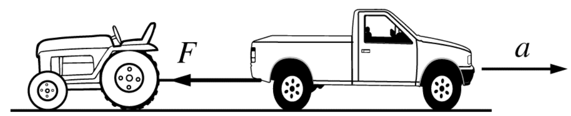
(A) $F/2$
(B) $F/3$
(C) $F/4$
(D) $F/6$



Boulder: Force *F* to the left
No acceleration



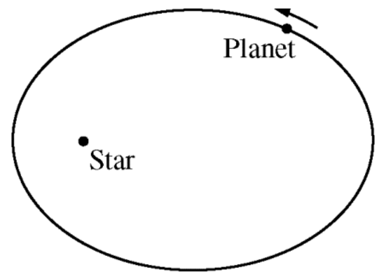
Wagon: Force *F* to the left
Acceleration *a* to the left



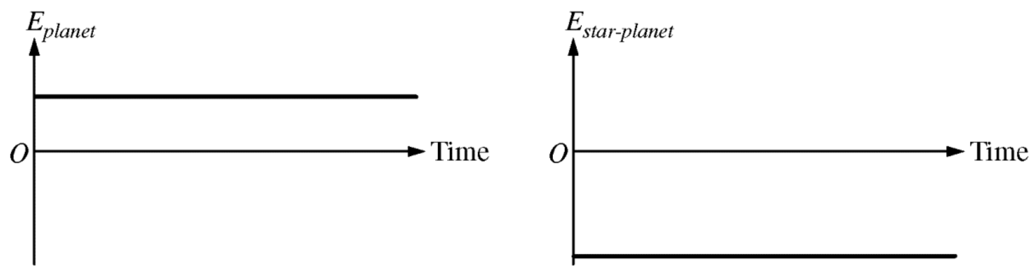
Truck: Force *F* to the left
Acceleration *a* to the right

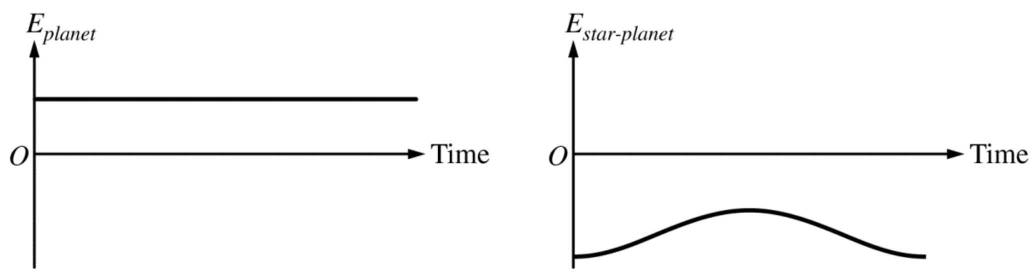
23. Each of the figures above shows a tractor attached to an object. The tractor exerts the same constant force *F* on each object in every case. Which of the following is a true statement about an object and the relative magnitude of the force exerted by the object on the tractor?

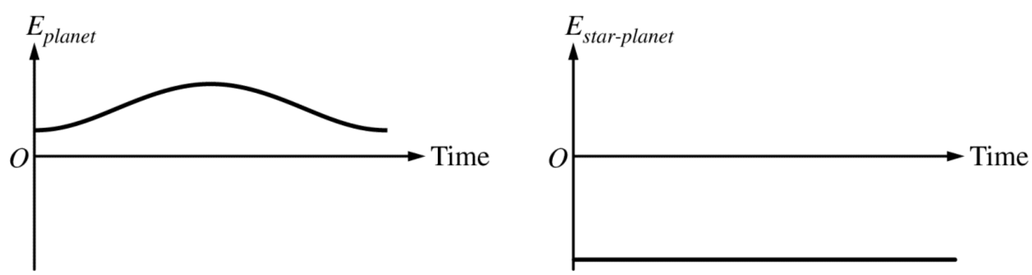
(A) The magnitude of the force exerted by the truck on the tractor is greatest, because the resulting motion is in the direction opposite the tractor's pull.
(B) The magnitude of the force exerted by the boulder on the tractor is least, because no motion results.
(C) The magnitude of the force exerted by the wagon on the tractor is least, because the resulting motion is in the direction of the tractor's pull.
(D) The magnitude of the force exerted by each object on the tractor is equal, because the tractor exerts an equal force on each object.

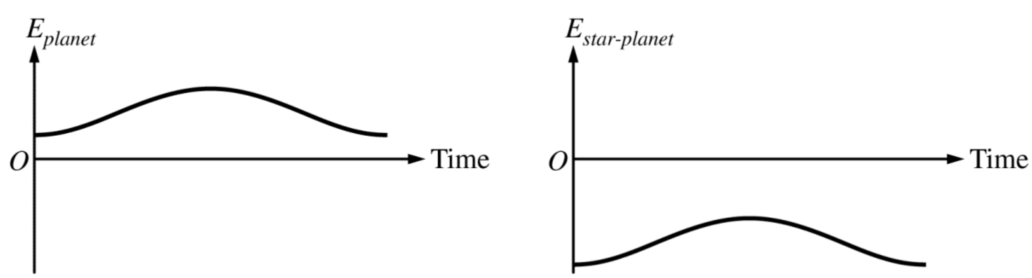


24. A planet is in an elliptical orbit around a star, as shown above. Which of the following best represents the mechanical energy E_{planet} of just the planet and the mechanical energy $E_{star\text{-}planet}$ of the star-planet system as functions of time for one complete orbit?

(A)


(B)


(C)


(D)


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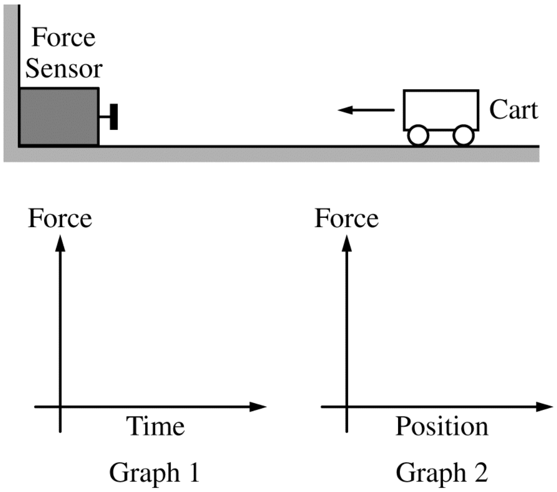
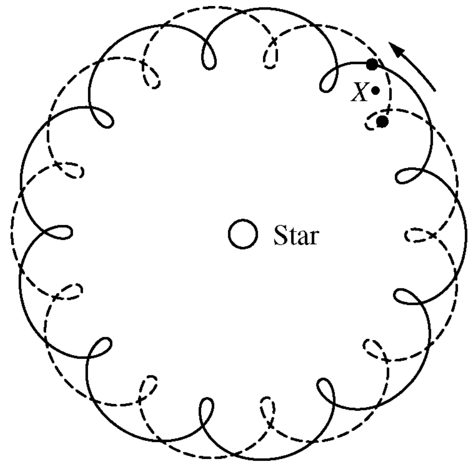
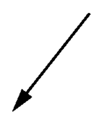


25. A cart of known mass moves with known speed along a level, frictionless track, as shown in the figure above. The cart hits a force sensor and rebounds. The force sensor measures the force exerted on the cart as a function of time and as a function of the position of the cart. The results will be graphed on the axes shown. Which of the two graphs can be used to determine the cart's speed after it rebounds?

(A) Only graph 1; graph 2 will have no information useful for finding the speed.
(B) Only graph 2; graph 1 will have no information useful for finding the speed.
(C) Either graph 1 or graph 2 can be used.
(D) Neither graph alone is sufficient; both graph 1 and graph 2 are needed.

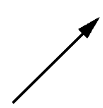


26. The figure above represents the orbits of two planets of equal mass that orbit their star in the counterclockwise direction as a double-planet system. From the point of view of an observer on either planet, the planets appear to orbit each other while also orbiting the star. The dots on the orbits represent the position of the planets at time t_0, and X is the position of their center of mass at that time. Which of the following arrows best represents the acceleration of the center of mass of the double-planet system when it is at point X ?

(A) 

(B) 

(C) 

(D) 

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27. Two identical blocks are connected to the opposite ends of a compressed spring. The blocks initially slide together on a frictionless surface with velocity v to the right. The spring is then released by remote control. At some later instant, the left block is moving at $v/2$ 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) $5v/2$
(B) $3v/2$
(C) v
(D) $v/2$

28. A person holds a book at rest a few feet above a table. The person then lowers the book at a slow constant speed and places it on the table. Which of the following accurately describes the change in the total mechanical energy of the Earth-book system?

(A) The total mechanical energy is unchanged, because there is no change in the book's kinetic energy as it is lowered to the table.
(B) The total mechanical energy is unchanged, because no work is done on the Earth-book system while the book is lowered.
(C) The total mechanical energy decreases, because the person does positive work on the book by exerting a force that opposes the gravitational force.
(D) The total mechanical energy decreases, because the person does negative work on the book by exerting a force on the book in the direction opposite to its displacement.

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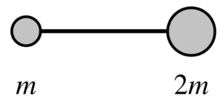
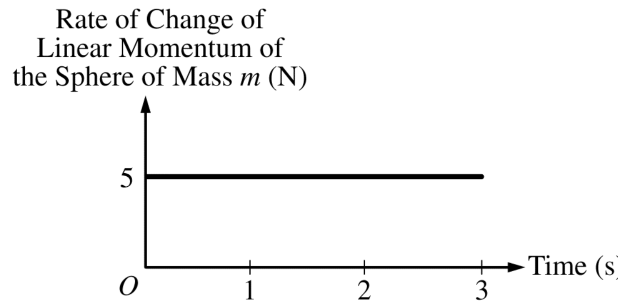
Questions 29-30 refer to the following material.



A system consists of two spheres, of mass m and $2m$, connected by a rod of negligible mass, as shown above. The system is held at its center of mass with the rod horizontal and released from rest near Earth's surface at time $t = 0$.



29. The graph above shows the rate of change of linear momentum of the sphere of mass m as a function of time. What is the linear momentum of the two-sphere system at time $t = 3.0$ s ?

(A) 5 kg•m/s
(B) 15 kg•m/s
(C) 45 kg•m/s
(D) 60 kg•m/s

30. Which of the following best explains why the system does not rotate around its center of mass as it falls?

(A) The Earth exerts the same gravitational force on both spheres, causing them to accelerate at the same rate.
(B) The Earth exerts the same gravitational force on both spheres, generating torques that cancel out.
(C) The Earth exerts a larger gravitational force on the sphere of mass $2m$, but that sphere is closer to the center of mass and the torques cancel out.
(D) The Earth exerts a larger gravitational force on the sphere of mass $2m$, but that sphere has more inertia and the torques cancel out.

31. A person is running on a track. Which of the following forces propels the runner forward?

(A) The normal force exerted by the ground on the person
(B) The normal force exerted by the person on the ground
(C) The force of friction exerted by the ground on the person
(D) The force of friction exerted by the person on the ground

32. In a one-dimensional perfectly elastic collision, an object of mass m is traveling with speed v_0 in the $+x$-direction when it strikes an object with mass $3m$ that is at rest. What are the objects' velocities following the collision?

	Object of Mass m	Object of Mass $3m$
(A)	Zero	$v_0/3$, $+x$-direction
(B)	$v_0/4$, $+x$-direction	$v_0/2$, $+x$-direction
(C)	$v_0/2$, $+x$-direction	$v_0/2$, $+x$-direction
(D)	$v_0/2$, $-x$-direction	$v_0/2$, $+x$-direction

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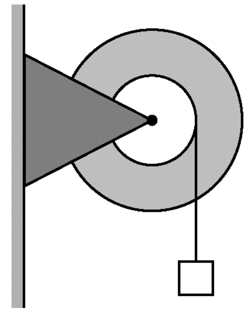
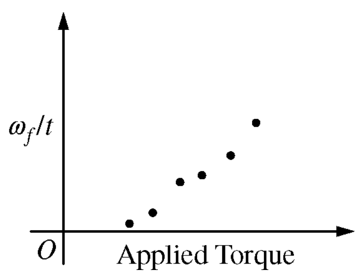


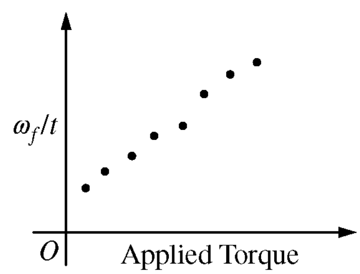
33. A student conducts an experiment to determine the relationship between applied torque and change in angular velocity. The student uses the apparatus shown in the figure above, consisting of two disks that are glued together and mounted on a horizontal axle. Blocks of varying mass are hung from a string wound around the smaller disk. The blocks are released from rest, exerting different torques on the disks, and are allowed to fall a fixed distance. For each block, the time of fall t and the final angular velocity ω_f of the disks are measured.

There is considerable friction between the disks and the axle. Which of the following best represents a plot that can be obtained from the student's data?

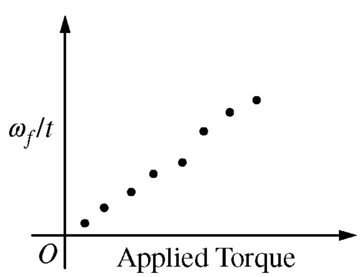
(A)



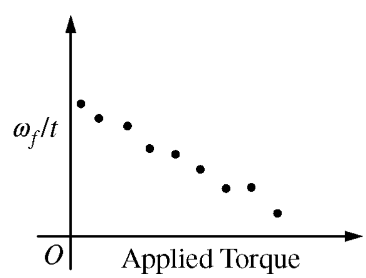
(B)



(C)



(D)



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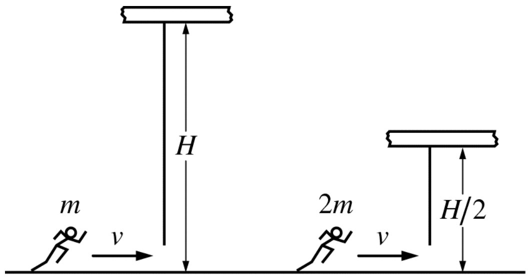
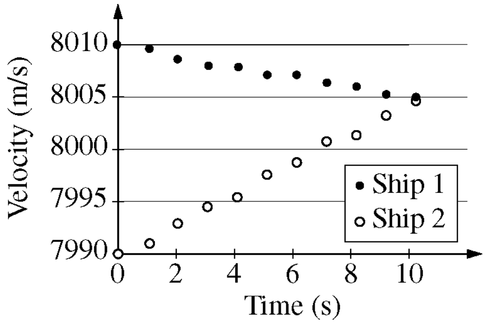


34. An athlete with mass m running at speed v grabs a light rope that hangs from a ceiling of height H and swings to a maximum height of h_1. In another room with a lower ceiling of height $H/2$, a second athlete with mass $2m$ running at the same speed v grabs a light rope hanging from the ceiling and swings to a maximum height of h_2. How does the maximum height reached by the two athletes compare, and why?

(A) The first athlete reaches a greater height, because this athlete swings on a longer rope.
(B) The second athlete reaches a greater height, because this athlete has a greater mass.
(C) The two athletes reach the same height, because the effect of the rope length offsets the effect of the athletes' masses.
(D) The two athletes reach the same height, because the athletes run with the same speed.

Questions 35-36 refer to the following material.



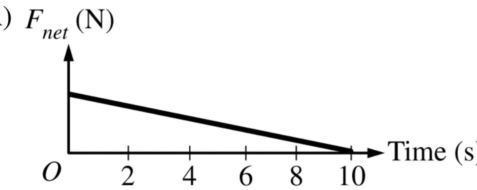
Two identical spaceships are traveling in deep space, far from any planets or stars. The ships travel in the same direction, with the slower one directly behind the faster one. The ships are connected by a cable attached to a spool, so that the part of the cable outside the ships can be made longer or shorter as needed. The cable is used to bring the ships to the same speed for a transfer of cargo. The graph above shows the speed of the two ships during a 10 s interval.

35. Does at least one of the ships have its engine turned on during the time interval shown, and what evidence indicates so?

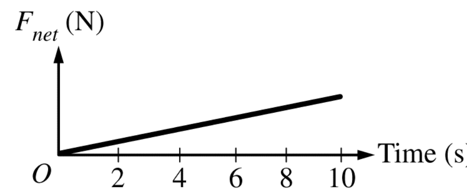
(A) Yes, because Ship 2 is speeding up.
(B) Yes, because the momentum of the two-rocket system increases.
(C) Yes, because an engine is needed to keep the system moving.
(D) No, because the cable alone could be responsible for making Ship 1 slow down and Ship 2 speed up.

36. Which of the following graphs best represents the net force F_{net} exerted on the two-ship system?

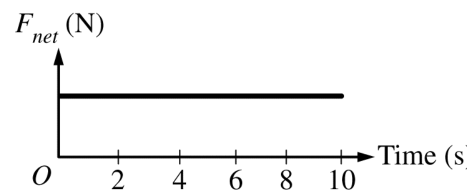
(A)



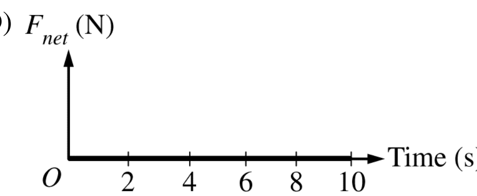
(B)



(C)



(D)



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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.

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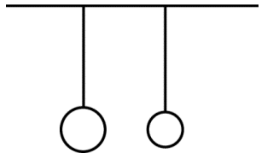
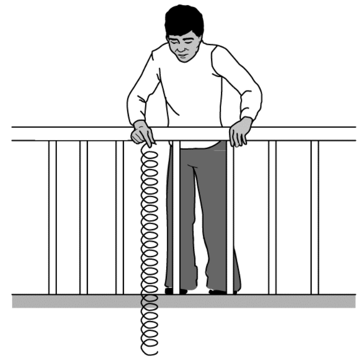


131. Two hollow, uncharged conducting spheres hang by threads from the ceiling, as shown above. The spheres have the same mass but are different sizes. A charge $+Q$ is deposited on the larger sphere. The spheres are then momentarily brought into contact and separated, after which they move away from each other. Which of the following statements about the final state of the spheres and strings must be true? Select two answers.

(A) The spheres have charges of opposite sign.
(B) The sum of the charges on the spheres is $+Q$.
(C) The tension in each string is larger than it was initially.
(D) The force exerted by the ceiling on each string is directed vertically upward.



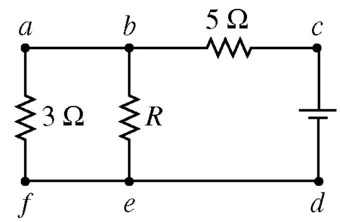
132. A student wants to demonstrate a transverse wave for a friend. The student holds a long spring with his fingertips and lets it hang vertically over the edge of a railing, as shown above. The student can move his hand in a way that creates waves that propagate down the spring. Which of the following movements of the student's hand will create a transverse wave? Select two answers.

(A) Left and right
(B) Forward and backward
(C) Up and down
(D) Releasing the spring

GO ON TO THE NEXT PAGE.

133. Suppose two square wave pulses that are in the same plane could be created on a string, one with a maximum displacement of 4 cm and the other with a maximum displacement of 2 cm. Which of the following is a possible displacement of the string when the wave pulses overlap? Select two answers.

(A) 2 cm
(B) 3 cm
(C) 6 cm
(D) 8 cm



134. The figure above shows a circuit with three resistors—two with known resistance and one with unknown resistance—and a battery with unknown potential difference. Which of the following sets of measurements of potential difference will allow determination of the unknown resistance R ? Select two answers.

(A) Between points b and e only
(B) Between points a and f and between points b and c
(C) Between points b and c and between points c and d
(D) Between points a and f and between points b and e

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.**

Section II: Free-Response Questions

This is the free-response section of the 2015 AP exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

AP® Physics 1: Algebra-Based Exam

SECTION II: Free Response

2015

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.
   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.

AP® PHYSICS 1 TABLE OF INFORMATION

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

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

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

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

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

The following conventions are used in this exam.

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

AP® PHYSICS 1 EQUATIONS

MECHANICS

$$v_x = v_{x0} + a_x t$$

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

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

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

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

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

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

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

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

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

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

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

$$\omega = \omega_0 + \alpha t$$

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

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

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

$$L = I\omega$$

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

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

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

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

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

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

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

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

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

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

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

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

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

ELECTRICITY

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

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

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

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

$$P = I\,\Delta V$$

$$R_s = \sum_i R_i$$

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

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

WAVES

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

- f = frequency
- v = speed
- λ = wavelength

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

Rectangular solid
$V = \ell w h$

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

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

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

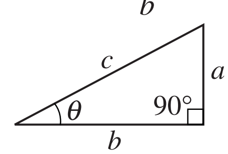
Right triangle

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

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

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

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



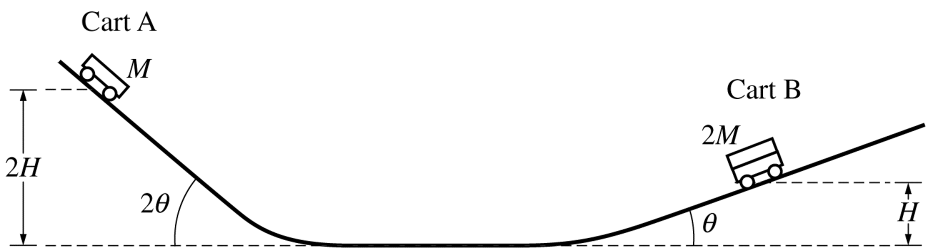
PHYSICS 1

Section 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.



1. (7 points, suggested time 13 minutes)

   Cart *A* has mass M and is released from rest at a height $2H$ on a ramp making an angle 2θ with the horizontal, as shown above. Cart B has mass $2M$ and is released from rest at a height H on a ramp making an angle θ with the horizontal. The carts roll toward each other, have a head-on collision on the horizontal portion of the ramp, and stick together. The masses of the carts' wheels are negligible, as are any frictional or drag forces.

   (a) Indicate whether the carts remain at rest, move to the left, or move to the right after the collision.

   ____ Remain at rest ____ Move to the left ____ Move to the right

   Explain how you arrived at your answer.

(b) Consider the time interval from when the two carts are released until just after they collide.

i. For the system consisting of the two carts and Earth, indicate whether the total mechanical energy increases, decreases, or remains the same.

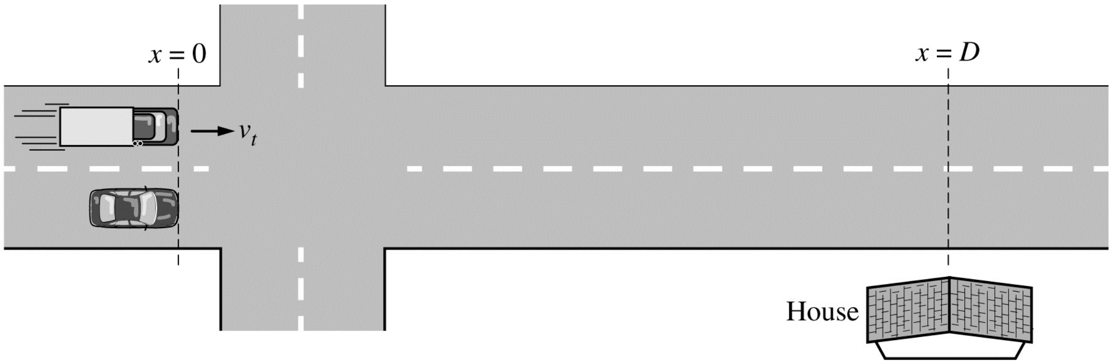
____ Increases ____ Decreases ____ Remains the same

Justify your answer.

ii. For the system consisting of only the two carts, indicate whether the total mechanical energy increases, decreases, or remains the same.

____ Increases ____ Decreases ____ Remains the same

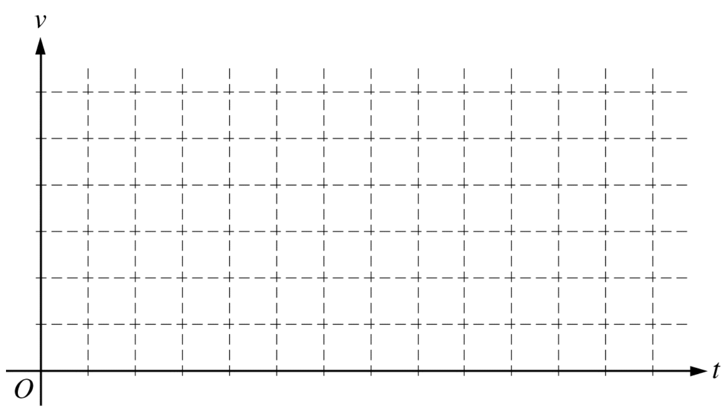
Justify your answer.



2. (12 points, suggested time 25 minutes)

A car is stopped at a traffic light. The light turns green, and at time $t = 0$ the car starts moving and travels with a constant acceleration. At that instant a truck traveling at constant speed v_t is alongside the car, with the front of each vehicle at position $x = 0$, as shown above. The truck passes the car, but the car later catches up to the truck in front of a house, such that at time t_D the front of each vehicle is at position $x = D$.

(a) On the axes below, sketch and label graphs of the velocity of the car and the velocity of the truck as a function of time. Indicate any important velocities or times.



(b) Two students are discussing how the speed of the car compares to the speed of the truck when both vehicles are in front of the house.

Student 1 says, "The distance traveled by the car and the truck is the same, and the time is the same, so they must have the same speed."

Student 2 says, "I don't see how that can be. The car catches up to the truck, so the car has to be going faster."

i. Which aspects of Student 1's reasoning, if any, are correct? Support your answer in terms of relevant features of your graphs in part (a).

ii. Which aspects of Student 2's reasoning, if any, are correct? Support your answer in terms of relevant features of your graphs in part (a).

(c) Derive an expression for the acceleration of the car. Express your answer in terms of D and v_t.

(d) Determine the time at which the speed of the car is equal to the speed v_t of the truck. Express your answer in terms of t_D. Justify your answer.

3. (12 points, suggested time 25 minutes)

You are given a long length of string and an oscillator that can shake one end of the string at any desired frequency. The oscillator has a display that indicates the frequency. You are asked to design an experiment to study how the velocity of waves on the string depends on the string's tension. You do not have any way to measure time with sufficient accuracy to help in your investigation.

(a) Describe your experimental setup and procedure, including any additional pieces of equipment you would need and the kind of data you would record. Include enough detail that another student could follow and complete the experiment successfully.

(b) Describe how you would analyze your data to obtain information about the wave velocity's dependence on tension.

GO ON TO THE NEXT PAGE.

(c) A student performs the experiment and can see from the data table below that the velocity of the waves on the string increases when the tension in the string increases. The student claims that the velocity is directly proportional to the tension. Do the results support the student's claim? Explain in detail how you arrived at your answer.

Velocity (m/s)	17	24	29	34	38
Tension (N)	2.0	4.0	6.0	8.0	10.0

(d) After the experiment is completed, a student attaches a string to the wall and the other end of the string to an oscillator. The frequency of the oscillator is adjusted to make a standing wave. The string is allowed to vibrate in a standing wave with constant amplitude.

i. While the string is vibrating as a standing wave with constant amplitude, is the oscillator doing work on the string? Explain your reasoning.

ii. While the string is vibrating as a standing wave with constant amplitude, is the string gaining mechanical energy? Explain your reasoning.

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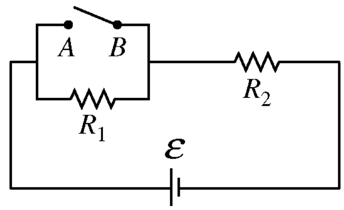


4. (7 points, suggested time 13 minutes)

The circuit shown above contains two resistors, an ideal battery, and a switch. The resistance of resistor R_1 is less than the resistance of resistor R_2.

(a) Indicate whether the current through resistor R_2 when the switch is open is greater than, less than, or equal to the current through resistor R_2 when the switch is closed.

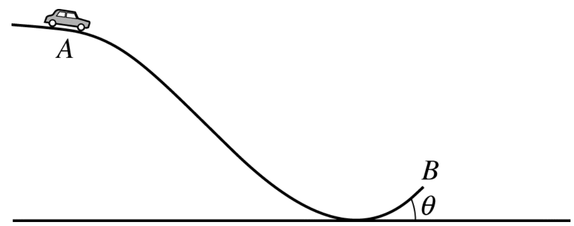
____ Greater than ____ Less than ____ Equal to

Briefly explain how you arrived at your answer.

(b) Closing the switch creates a short circuit. Indicate whether the absolute value of the potential difference between points A and B when the switch is open is greater than, less than, or equal to the absolute value of the potential difference when the switch is closed.

____ Greater than ____ Less than ____ Equal to

Explain your reasoning in a clear, coherent paragraph-length explanation that may also contain equations and/or drawings. Address the conditions before and after the switch is closed.



5. (7 points, suggested time 13 minutes)

A toy car coasts along the curved track shown above. The car has initial speed v_A when it is at point A at the top of the track, and the car leaves the track at point B with speed v_B at an angle θ above the horizontal. Assume that the rotational kinetic energy of the car's wheels and energy losses due to friction are both negligible.

(a) Suppose the toy car is released from rest at point A $(v_A = 0)$.

i. After the car leaves the track and reaches the highest point in its trajectory it will be at a different height than it was at point A. Briefly explain why this is so.

ii. Determine the speed of the car when it is at the highest point in its trajectory after leaving the track, in terms of v_B and θ. Briefly explain how you arrived at your answer.

(b) Suppose the toy car is given an initial push so that it has nonzero speed at point A. Determine the speed v_A of the car at point A such that the highest point in its trajectory after leaving the track is the same as its height at point A. Express your answer in terms of v_B and θ. Explain how you arrived at your answer.

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.

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

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**

- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX 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.**