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AP® Physics C: Mechanics Exam

SECTION I: Multiple Choice

2014

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

At a Glance

Total Time
45 minutes
Number of Questions
35
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
None allowed

Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information that may be helpful is in the booklet. 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. After you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

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

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 the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

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Form I
Form Code 4JBP6-S

80

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DO NOT seal answer sheet inside

TABLE OF INFORMATION, EFFECTIVE 2012

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1 \text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

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

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

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

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

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

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

PHYSICS C: MECHANICS
SECTION I
Time—45 minutes
35 Questions

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

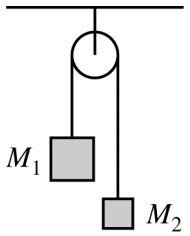
Note: To simplify calculations, you may use $g = 10\,\text{m/s}^2$ in all problems.

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

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

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

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



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

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

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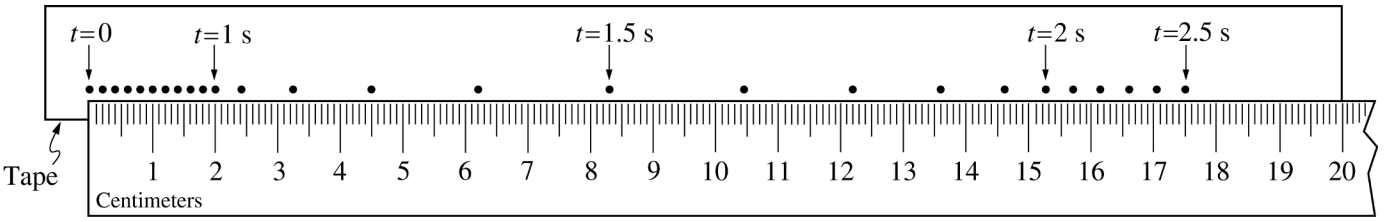
Questions 4-6

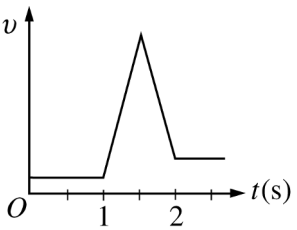
A tape attached to a moving object was pulled by the object through a marker that put dots on the tape at a constant rate of 10 dots per second for a period of 2.5 s. The figure below shows the marked tape next to a centimeter ruler.

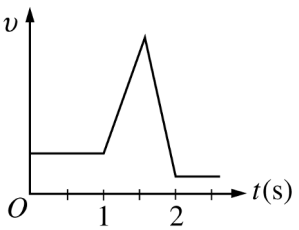


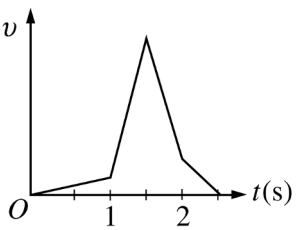
4. The average speed of the object for the total time recorded on the tape is most nearly

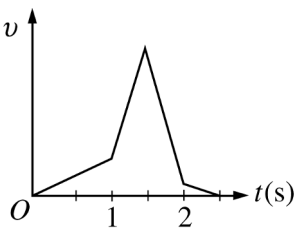
(A) 2.0 cm/s
(B) 3.3 cm/s
(C) 4.5 cm/s
(D) 5.5 cm/s
(E) 7.0 cm/s

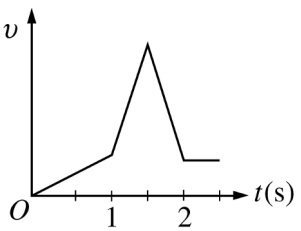
5. Which of the following best represents the graph of the velocity of the object versus time?

(A) 

(B) 

(C) 

(D) 

(E) 

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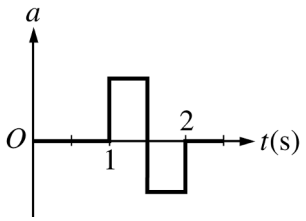
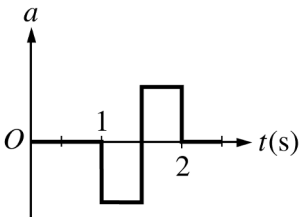
6. Which of the following best represents the graph of the acceleration of the object versus time?

(A)



(B)



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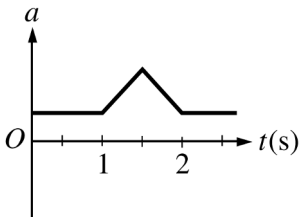

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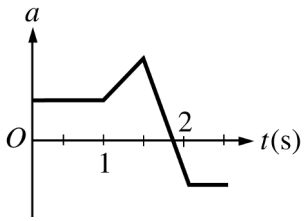

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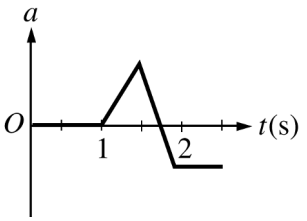

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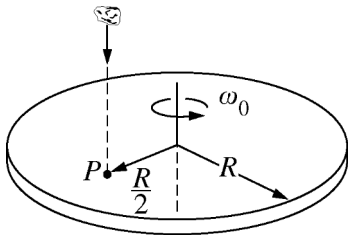
Questions 7-8



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

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

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

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

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

   (D) mR^2

   (E) $2mR^2$

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

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

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

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

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

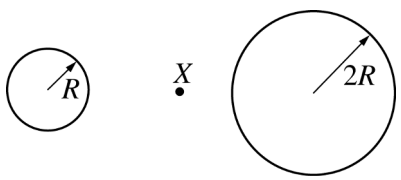
    (A) $\frac{2g}{3}$

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

    (C) g

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

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



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

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

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

    (C) M

    (D) $2M$

    (E) $4M$

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12. A particle moves along a straight line. Its speed in m/s is given by $v = a + bt^2$, where a and b are constants and t is time in seconds. How far does the particle move between $t = 1$ s and $t = 2$ s ?

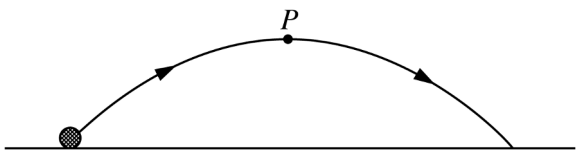
(A) $2b$

(B) $a + b$

(C) $a + 2b$

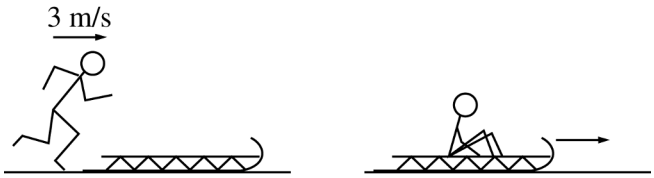
(D) $a + \frac{7}{3}b$

(E) $a + \frac{7}{2}b$



13. A ball is tossed and follows the trajectory shown above. Point P is the highest point on the trajectory, and air resistance is negligible. Which of the following statements is true of the ball while it is in motion?

(A) Its speed is constant.
(B) Its acceleration is constant.
(C) The horizontal component of its velocity is zero at point P.
(D) The vertical component of its velocity is a maximum at point P.
(E) Its kinetic energy is a maximum at point P.



Before Jump After Jump

14. As shown in the figure above, a child of mass 25 kg who is running at a speed of 3 m/s jumps onto a stationary sled of mass 5 kg on a frozen lake. The speed at which the child and sled begin to slide across the ice is most nearly

(A) 0.4 m/s
(B) 0.6 m/s
(C) 1.3 m/s
(D) 2.5 m/s
(E) 15 m/s

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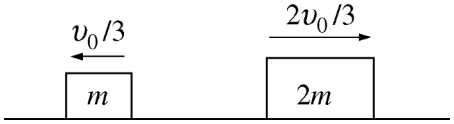
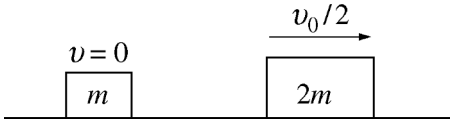
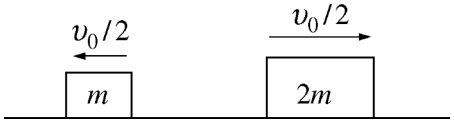
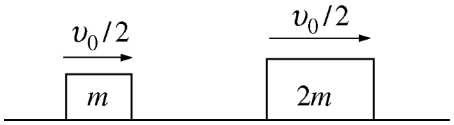
15. A block of mass m is initially sliding with speed v_0 on a horizontal frictionless surface, as shown above. It makes an elastic, head-on collision with another block of mass $2m$ that is initially at rest. Which of the following correctly shows the motion of the blocks after the collision?

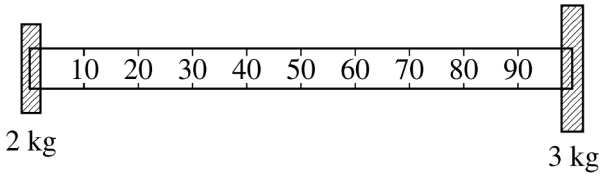
(A)


(B)


(C)


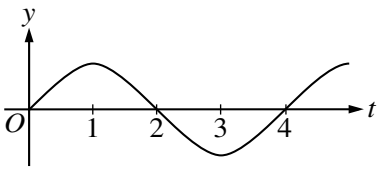
(D)


(E)




16. A 2 kg mass is attached to the 0 cm mark of a lightweight meter stick, and a 3 kg mass is attached to the 100 cm mark, as shown above. The center of mass of the combined system (meter stick and both masses) is located nearest which of the following marks on the meter stick?

(A) 33 cm
(B) 40 cm
(C) 60 cm
(D) 67 cm
(E) 75 cm



17. For a mass attached to a vertical spring, the vertical displacement y of the mass is given as a function of time t in the diagram above. At what time t does the mass experience a maximum positive acceleration?

(A) $t = 1$
(B) $t = 2$
(C) $t = 3$
(D) $t = 4$
(E) None of the above, since its acceleration is constant

18. For an object in simple harmonic motion with amplitude A, the kinetic energy will equal the potential energy when the displacement is

(A) zero
(B) $\pm A/4$
(C) $\pm A/2$
(D) $\pm A/\sqrt{2}$
(E) $\pm A$

19. Examples of simple harmonic motion include which of the following?

I. A mass, hanging from a spring, moves up and down in a uniform gravitational field.
II. A puck on an air table bounces back and forth between the walls of the table.
III. A ball bounces up and down on a table.

(A) I only
(B) III only
(C) I and II only
(D) II and III only
(E) I, II, and III

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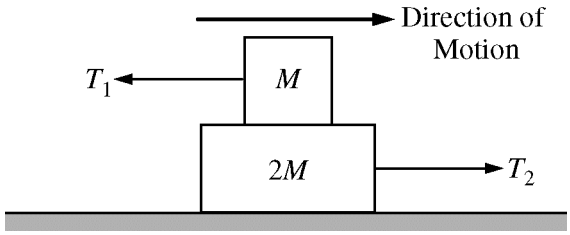
Questions 20-21



Two blocks are stacked on top of each other, as shown in the figure above. The top block, of mass M, is attached to a rope that pulls to the left with tension T_1. The bottom block, of mass $2M$, is attached to a rope that pulls to the right with tension T_2. The coefficient of friction between the blocks is μ. The blocks are at rest relative to each other and move to the right at constant speed relative to the frictionless surface.

20. What is the relationship between T_1 and T_2?

(A) $T_1 = 2T_2$

(B) $T_1 = \frac{1}{2}T_2$

(C) $T_1 = \mu T_2$

(D) $T_1 = \frac{1}{\mu}T_2$

(E) $T_1 = T_2$

21. The force of friction experienced by the top block is f_1, and the force of friction experienced by the bottom block is f_2. What is the relationship between f_1 and f_2?

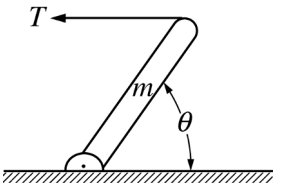
(A) $f_1 = 2f_2$

(B) $f_1 = \frac{1}{2}f_2$

(C) $f_1 = \mu f_2$

(D) $f_1 = \frac{1}{\mu}f_2$

(E) $f_1 = f_2$



22. A uniform beam of mass m is pivoted at one end and held in equilibrium at an angle θ by a horizontal wire, as shown above. The tension T in the wire is

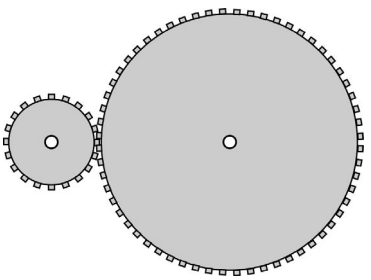
(A) $\frac{1}{2}mg\cot\theta$

(B) $mg\cot\theta$

(C) $mg\tan\theta$

(D) $2mg\tan\theta$

(E) mg



23. A gear containing 20 teeth on its circumference is meshed with a gear containing 60 teeth on its circumference, as shown above. If the angular speed of the 20-tooth gear is ω, what is the angular speed of the 60-tooth gear?

(A) $\frac{\omega}{60}$

(B) $\frac{\omega}{20}$

(C) $\frac{\omega}{3}$

(D) ω

(E) 3ω

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24. The angular displacement θ of a rotating wheel is described by the equation $\theta = \theta_0 + at^2 - bt^3$, where t is time and θ_0, a, and b are positive constants. The angular acceleration of the wheel as a function of time t is

(A) equal to a positive constant

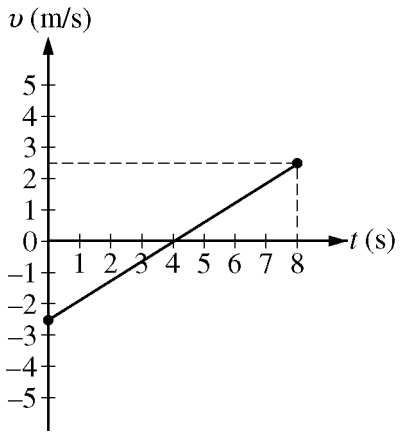
(B) zero

(C) $2a - 6bt$

(D) $2at - 3bt^2$

(E) $\theta_0 t + \frac{1}{3}at^3 - \frac{1}{4}bt^4$

Questions 25-27



The motion of an object moving along a straight line is described by the graph of velocity v versus time t above.

25. Which of the following is true about the speed of the object during the time interval from 0 to 8 s?

(A) It increases during the entire interval.
(B) It decreases during the entire interval.
(C) It remains the same.
(D) It first increases and then decreases.
(E) It first decreases and then increases.

26. Which of the following is true about the acceleration of the object during the time interval from 0 to 8 s?

(A) It increases during the entire interval.
(B) It decreases during the entire interval.
(C) It remains the same.
(D) It first increases and then decreases.
(E) It first decreases and then increases.

27. What is the net displacement of the object for the time interval from 0 to 8 s?

(A) 0 m
(B) 5 m
(C) 10 m
(D) 20 m
(E) It cannot be determined without knowing the initial position of the object.

---

28. An object starts from rest and accelerates uniformly in the horizontal direction, moving 32 m during the first 4 s. What are the magnitudes of the object's displacement and velocity after it accelerates for the first 3 s

	Magnitude of Displacement	Magnitude of Velocity
(A)	24 m	24 m/s
(B)	24 m	18 m/s
(C)	18 m	18 m/s
(D)	18 m	12 m/s
(E)	8 m	12 m/s

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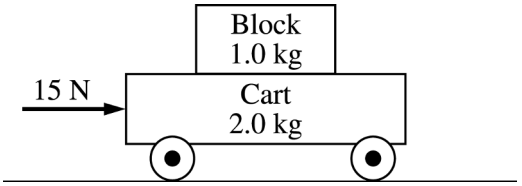

29. A 2.0 kg cart rolls with negligible friction on a horizontal surface, as shown in the figure above. The coefficient of static friction between the cart and the 1.0 kg block on top of the cart is 0.7. If a horizontal 15 N force is applied to the cart as shown and the block does not slide on the cart, the magnitude of the horizontal component of the force that the block exerts on the cart is most nearly

(A) 2 N
(B) 5 N
(C) 8 N
(D) 10 N
(E) 15 N

30. A car rounds a flat curve of radius R with a speed of v_0. The coefficient of friction between the tires and the road is μ. For the car not to slide on the road, which of the following statements must be true?

(A) The car's speed v_0 cannot be greater than μgR.
(B) The car's speed v_0 cannot be less than μgR.
(C) The radius R of the car's path cannot be greater than $v_0^2/\mu g$.
(D) The radius R of the car's path cannot be less than $v_0^2/\mu g$.
(E) The centripetal acceleration must be less than g.

31. If two balls collide and there are no external forces acting on the balls, quantities that must be the same for the two-ball system before and after the collision include which of the following?

I. Total kinetic energy
II. Total momentum
III. Momentum in the x-direction

(A) I only
(B) III only
(C) I and II only
(D) II and III only
(E) I, II, and III

32. Two objects, X and Y, are released from rest at the same height. Object X has three times the mass of object Y. Just before reaching the ground, object Y has momentum p_Y and kinetic energy K_Y. If air resistance is negligible, what are the momentum and kinetic energy of object X just before it reaches the ground?

	Momentum	Kinetic Energy
(A)	p_Y	K_Y
(B)	$3p_Y$	$3K_Y$
(C)	$3p_Y$	$6K_Y$
(D)	$6p_Y$	$3K_Y$
(E)	$6p_Y$	$6K_Y$

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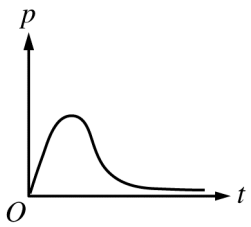
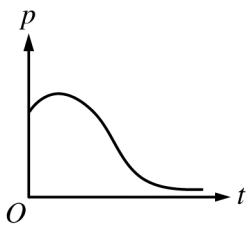
GO ON TO THE NEXT PAGE.

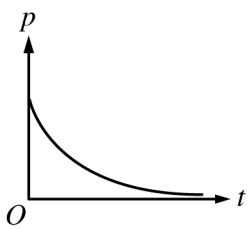
Questions 33-34

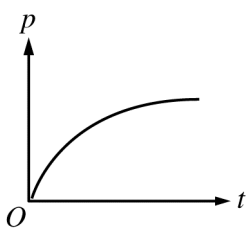
A very light ball is released from rest at time $t = 0$ and falls through the air, which provides significant resistance.

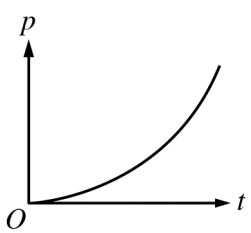
33. Which graph best represents the magnitude of the momentum of the ball?

(A)


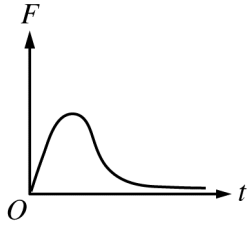
(B)


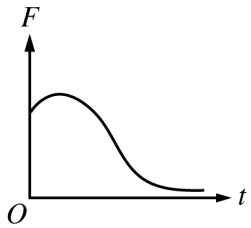
(C)


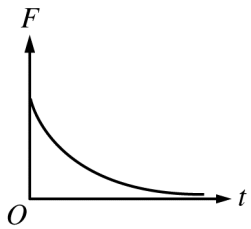
(D)


(E)


34. Which graph best represents the magnitude of the net force on the ball?

(A)


(B)


(C)


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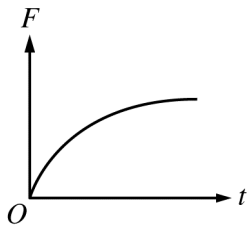
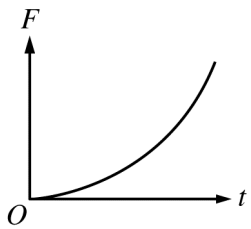


(E)


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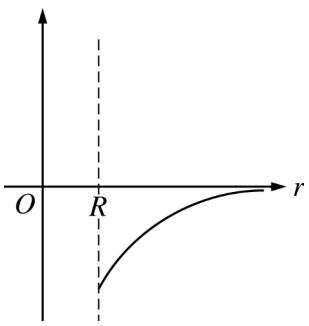
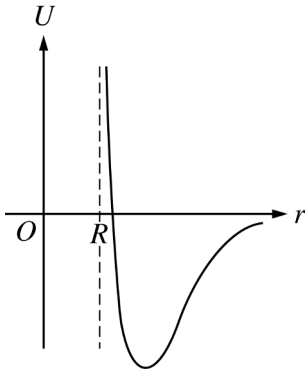
35. A satellite can move in a circular orbit about a massive planet of radius R. Which of the following graphs could represent the gravitational potential energy U of this satellite as a function of the radius r of the orbit?

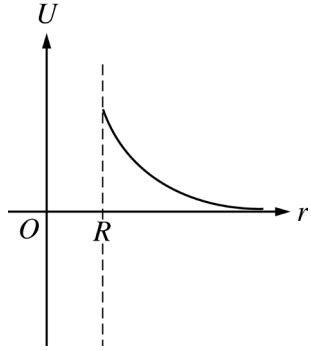
(A)



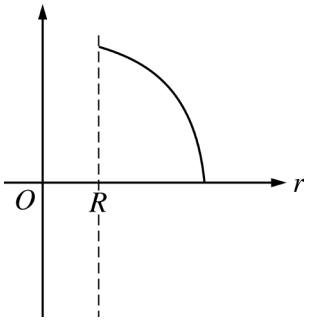
(B)



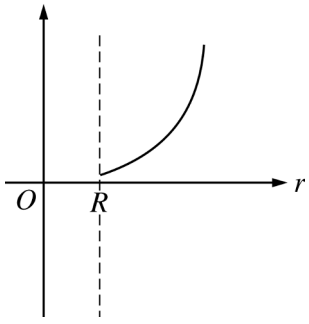
(C)



(D)



(E)



S T O P

END OF MECHANICS SECTION I

IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON MECHANICS SECTION I ONLY.

DO NOT TURN TO ANY OTHER TEST MATERIALS.

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**

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AP® Physics C: Mechanics Exam

SECTION II: Free Response

2014

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

At a Glance

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

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

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

Instructions

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

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

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

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

Form I
Form Code 4JBP6-S

TABLE OF INFORMATION, EFFECTIVE 2012

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1 \text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

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

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

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

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

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

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

ADVANCED PLACEMENT PHYSICS C EQUATIONS, EFFECTIVE 2012

MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0^2 + 2a(x - x_0)$

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

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

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

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

$F_{fric} \le \mu N$

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

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

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

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

$\Delta U_g = mgh$

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

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

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

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

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

$\upsilon = r\omega$

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

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

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

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

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

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

$C_p = \sum_i C_i$

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

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

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

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

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

$I = Ne\upsilon_d A$

$V = IR$

$R_s = \sum_i R_i$

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

$P = IV$

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

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

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

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

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

$B_s = \mu_0 nI$

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

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

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

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

ADVANCED PLACEMENT PHYSICS C EQUATIONS, EFFECTIVE 2012

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

Rectangular Solid

$V = \ell wh$

Cylinder

$V = \pi r^2 \ell$

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

Sphere

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

$S = 4\pi r^2$

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

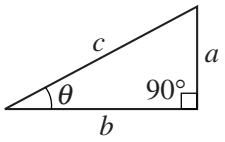
Right Triangle

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

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

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

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



CALCULUS

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

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

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

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

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

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

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

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

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

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

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

PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

Mech 1.

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

(a)

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

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

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

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

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GO ON TO THE NEXT PAGE.

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

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

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

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

i. The magnitude of the frictional force

__ Increases __ Decreases __ Remains the same

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

__ Increases __ Decreases __ Remains the same

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

__ Increases __ Decreases __ Remains the same

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Mech 2.

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

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

i. The orbital speed v_1 of the satellite

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

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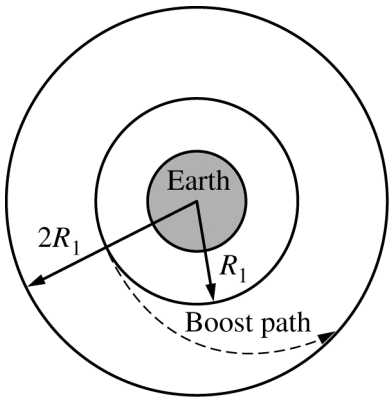
GO ON TO THE NEXT PAGE.

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



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

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

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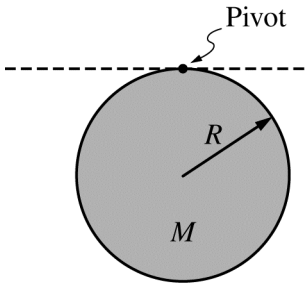

Figure 1

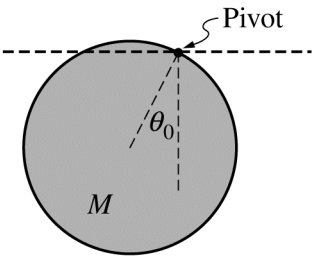

Figure 2

Mech 3.

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

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

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

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

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GO ON TO THE NEXT PAGE.

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

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

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

__ There is not enough information to determine the period.

Justify your answer.

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END OF EXAM

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