TABLE OF INFORMATION FOR 2004 and 2005

CONSTANTS AND CONVERSION FACTORS

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

UNITS

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

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

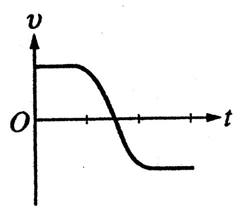
The following conventions are used in this examination.

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
Section I, MECHANICS
Time—45 minutes
35 Questions

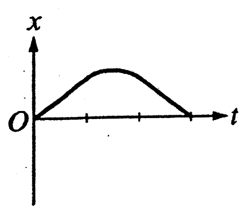
Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding oval on the answer sheet.

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

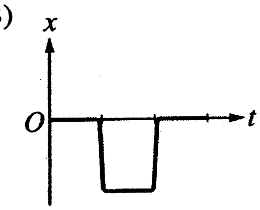


1. The graph above shows velocity v *versus* time t for an object in linear motion. Which of the following is a possible graph of position x *versus* time t for this object?

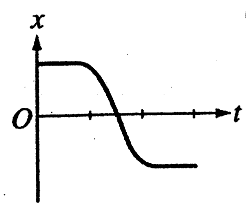
(A)



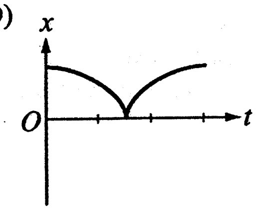
(B)



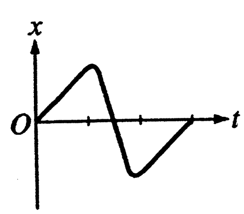
(C)



(D)

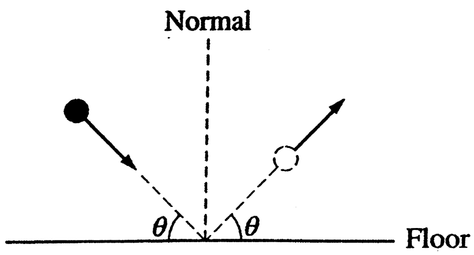


(E)



2. An object is dropped from rest from the top of a 400 m cliff on Earth. If air resistance is negligible, what is the distance the object travels during the first 6 s of its fall?

(A) 30 m
(B) 60 m
(C) 120 m
(D) 180 m
(E) 360 m



3. A 2 kg ball collides with the floor at an angle θ and rebounds at the same angle and speed as shown above. Which of the following vectors represents the impulse exerted on the ball by the floor?

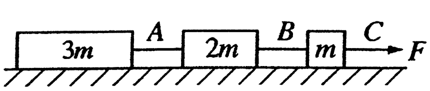
(A) 

(B) 

(C)

(D) 

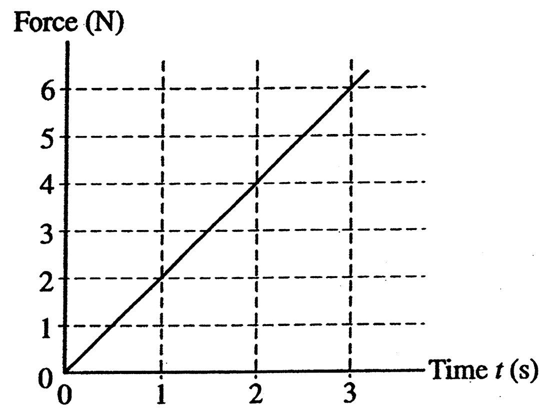
(E) 



4. Three blocks of masses $3m$, $2m$, and m are connected to strings A, B, and C as shown above. The blocks are pulled along a rough surface by a force of magnitude F exerted by string C. The coefficient of friction between each block and the surface is the same. Which string must be the strongest in order not to break?

(A) A
(B) B
(C) C
(D) They must all be the same strength.
(E) It is impossible to determine without knowing the coefficient of friction.

Questions 5-6



A block of mass 3 kg, initially at rest, is pulled along a frictionless, horizontal surface with a force shown as a function of time t by the graph above.

5. The acceleration of the block at $t = 2$ s is

(A) 3/4 m/s^2
(B) 4/3 m/s^2
(C) 2 m/s^2
(D) 8 m/s^2
(E) 12 m/s^2

6. The speed of the block at $t = 2$ s is

(A) 4/3 m/s
(B) 8/3 m/s
(C) 4 m/s
(D) 8 m/s
(E) 24 m/s

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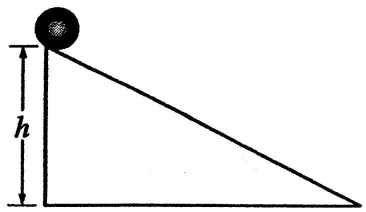
Questions 7-8



A sphere of mass M, radius r, and rotational inertia I is released from rest at the top of an inclined plane of height h as shown above.

7. If the plane is frictionless, what is the speed v_{cm} of the center of mass of the sphere at the bottom of the incline?

   (A) $\sqrt{2gh}$

   (B) $\frac{2Mgh}{I}$

   (C) $\frac{2Mghr^2}{I}$

   (D) $\sqrt{\frac{2Mghr^2}{I}}$

   (E) $\sqrt{\frac{2Mghr^2}{I + Mr^2}}$

8. If the plane has friction so that the sphere rolls without slipping, what is the speed v_{cm} of the center of mass at the bottom of the incline?

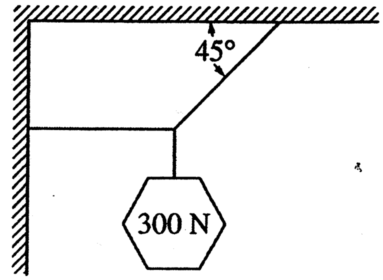
   (A) $\sqrt{2gh}$

   (B) $\frac{2Mgh}{I}$

   (C) $\frac{2Mghr^2}{I}$

   (D) $\sqrt{\frac{2Mghr^2}{I}}$

   (E) $\sqrt{\frac{2Mghr^2}{I + Mr^2}}$



9. An object weighing 300 N is suspended by means of two cords, as shown above. The tension in the horizontal cord is

   (A) 0 N
   (B) 150 N
   (C) 210 N
   (D) 300 N
   (E) 400 N

Questions 10-12

A small box is on a ramp tilted at an angle θ above the horizontal. The box may be subject to the following forces: frictional (f), gravitational (mg), pulling or pushing (F_p) and normal (N). In the following free-body diagrams for the box, the lengths of the vectors are proportional to the magnitudes of the forces.

Figure A

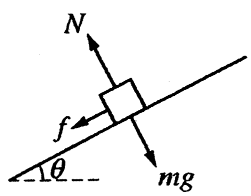


Figure B

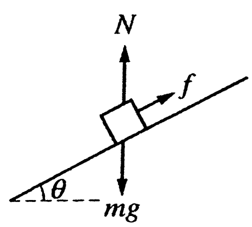


Figure C

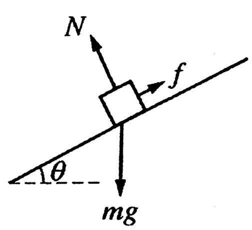


Figure D

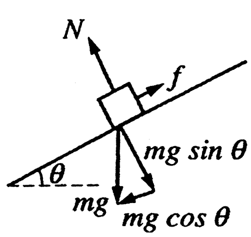
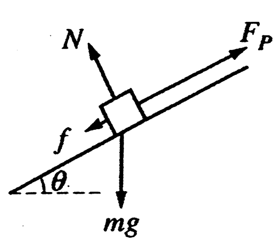


Figure E



10. Which figure best represents the free-body diagram for the box if it is accelerating up the ramp?
    (A) Figure A
    (B) Figure B
    (C) Figure C
    (D) Figure D
    (E) Figure E

11. Which figure best represents the free-body diagram for the box if it is at rest on the ramp?
    (A) Figure A
    (B) Figure B
    (C) Figure C
    (D) Figure D
    (E) Figure E

12. Which figure best represents the free-body diagram for the box if it is sliding down the ramp at constant speed?
    (A) Figure A
    (B) Figure B
    (C) Figure C
    (D) Figure D
    (E) Figure E

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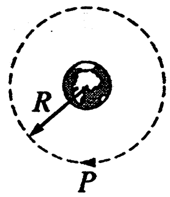
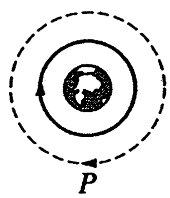
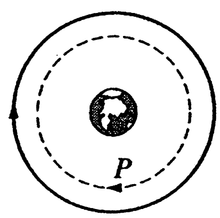
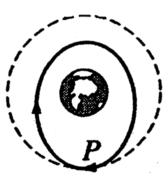
13. The momentum p of a moving object as a function of time t is given by the expression $p = kt^3$, where k is a constant. The force causing this motion is given by the expression
    (A) $3kt^2$
    (B) $\frac{3kt^2}{2}$
    (C) $\frac{kt^2}{3}$
    (D) kt^4
    (E) $\frac{kt^4}{4}$

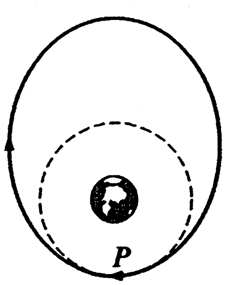


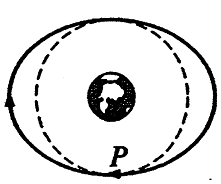
14. A spacecraft orbits Earth in a circular orbit of radius R, as shown above. When the spacecraft is at position P shown, a short burst of the ship's engines results in a small increase in its speed. The new orbit is best shown by the solid curve in which of the following diagrams?

(A)


(B)


(C)


(D)


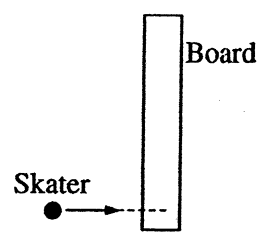
(E)


15. A student holds one end of a string in a fixed position. A ball of mass 0.2 kg attached to the other end of the string moves in a horizontal circle of radius 0.5 m with a constant speed of 5 m/s. How much work is done on the ball by the string during each revolution?

(A) 0 J
(B) 0.5 J
(C) 1.0 J
(D) 2π J
(E) 5π J

16. A wheel of 0.5 m radius rolls without slipping on a horizontal surface. The axle of the wheel advances at constant velocity, moving a distance of 20 m in 5 s. The angular speed of the wheel about its point of contact on the surface is

(A) 2 radians $\cdot$ s^{-1}
(B) 4 radians $\cdot$ s^{-1}
(C) 8 radians $\cdot$ s^{-1}
(D) 16 radians $\cdot$ s^{-1}
(E) 32 radians $\cdot$ s^{-1}



Top View

17. A long board is free to slide on a sheet of frictionless ice. As shown in the top view above, a skater skates to the board and hops onto one end, causing the board to slide and rotate. In this situation, which of the following occurs?

(A) Linear momentum is converted to angular momentum.
(B) Kinetic energy is converted to angular momentum.
(C) Rotational kinetic energy is conserved.
(D) Translational kinetic energy is conserved.
(E) Linear momentum and angular momentum are both conserved.

Questions 18-19

A simple pendulum has a period of 2 s for small amplitude oscillations.

18. The length of the pendulum is most nearly

(A) 1/6 m
(B) 1/4 m
(C) 1/2 m
(D) 1 m
(E) 2 m

19. Which of the following equations could represent the angle θ that the pendulum makes with the vertical as a function of time t ?

(A) $\theta = \theta_{max} \sin \frac{\pi}{2} t$

(B) $\theta = \theta_{max} \sin \pi t$

(C) $\theta = \theta_{max} \sin 2\pi t$

(D) $\theta = \theta_{max} \sin 4\pi t$

(E) $\theta = \theta_{max} \sin 8\pi t$

20. Two blocks of masses M and m, with $M > m$, are connected by a light string. The string passes over a frictionless pulley of negligible mass so that the blocks hang vertically. The blocks are then released from rest. What is the acceleration of the block of mass M ?

(A) g

(B) $\frac{M - m}{M} g$

(C) $\frac{M + m}{M} g$

(D) $\frac{M + m}{M - m} g$

(E) $\frac{M - m}{M + m} g$

21. For a particular nonlinear spring, the relationship between the magnitude of the applied force F and the resultant displacement x from equilibrium is given by the equation $F = kx^2$. What is the amount of work done by stretching the spring a distance x_0 ?

(A) kx_0^3

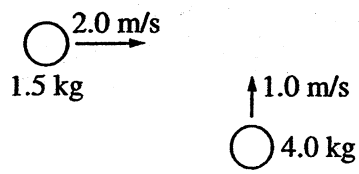
(B) $\frac{1}{2} kx_0$

(C) $\frac{1}{2} kx_0^3$

(D) $\frac{1}{3} kx_0^2$

(E) $\frac{1}{3} kx_0^3$

Questions 22-23



Two pucks moving on a frictionless air table are about to collide, as shown above. The 1.5 kg puck is moving directly east at 2.0 m/s. The 4.0 kg puck is moving directly north at 1.0 m/s.

22. What is the total kinetic energy of the two-puck system before the collision?

(A) $\sqrt{13}$ J
(B) 5.0 J
(C) 7.0 J
(D) 10 J
(E) 11 J

23. What is the magnitude of the total momentum of the two-puck system after the collision?

(A) 1.0 kg·m/s
(B) 3.5 kg·m/s
(C) 5.0 kg·m/s
(D) 7.0 kg·m/s
(E) $5.5\sqrt{5}$ kg·m/s

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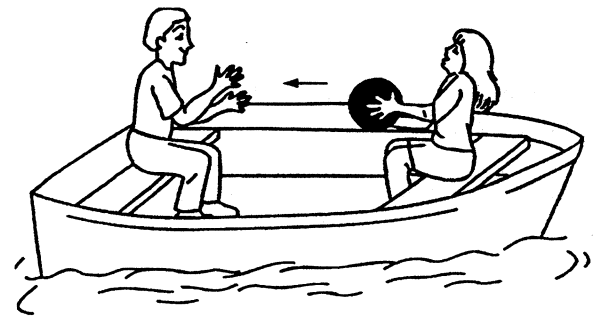
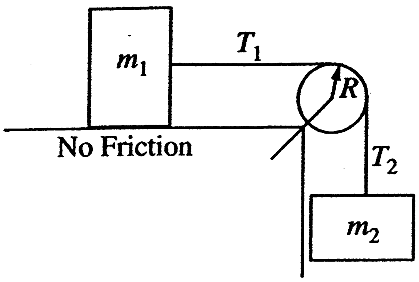
24. The position of an object is given by the equation $x = 3.0t^2 + 1.5t + 4.5$, where x is in meters and t is in seconds. What is the instantaneous acceleration of the object at $t = 3.0$ s?

(A) 3.0 m/s^2
(B) 6.0 m/s^2
(C) 9.0 m/s^2
(D) 19.5 m/s^2
(E) 36 m/s^2



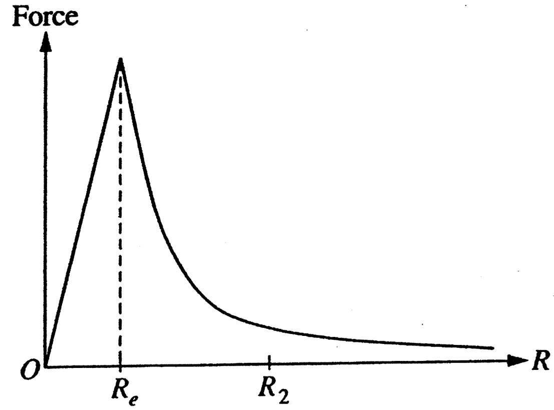
25. As shown above, two students sit at opposite ends of a boat that is initially at rest. The student in the front throws a heavy ball to the student in the back. What is the motion of the boat at the time immediately after the ball is thrown and, later, after the ball is caught? (Assume that air and water friction are negligible.)

	Immediately After the Throw	After the Catch
(A)	Boat moves forward	Boat moves forward
(B)	Boat moves forward	Boat moves backward
(C)	Boat moves forward	Boat does not move
(D)	Boat moves backward	Boat does not move
(E)	Boat moves backward	Boat moves forward



26. Two blocks are joined by a light string that passes over the pulley shown above, which has radius R and moment of inertia I about its center. T_1 and T_2 are the tensions in the string on either side of the pulley and α is the angular acceleration of the pulley. Which of the following equations best describes the pulley's rotational motion during the time the blocks accelerate?

(A) $m_2 gR = I\alpha$
(B) $(T_1 + T_2)R = I\alpha$
(C) $T_2 R = I\alpha$
(D) $(T_2 - T_1)R = I\alpha$
(E) $(m_2 - m_1)gR = I\alpha$



27. The graph above shows the force of gravity on a small mass as a function of its distance R from the center of the Earth of radius R_e, if the Earth is assumed to have a uniform density. The work done by the force of gravity when the small mass approaches Earth from far away and is placed into a circular orbit of radius R_2 is best represented by the area under the curve between

(A) $R = 0$ and $R = R_e$
(B) $R = 0$ and $R = R_2$
(C) $R = R_e$ and $R = R_2$
(D) $R = R_e$ and $R = \infty$
(E) $R = R_2$ and $R = \infty$

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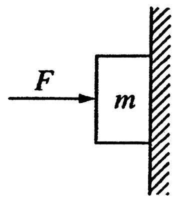

28. A horizontal force F pushes a block of mass m against a vertical wall. The coefficient of friction between the block and the wall is μ. What value of F is necessary to keep the block from slipping down the wall?

(A) mg

(B) μmg

(C) $\frac{mg}{\mu}$

(D) $mg(1-\mu)$

(E) $mg(1+\mu)$

29. A mass M suspended by a spring with force constant k has a period T when set into oscillation on Earth. Its period on Mars, whose mass is about $\frac{1}{9}$ and radius $\frac{1}{2}$ that of Earth, is most nearly

(A) $\frac{1}{3}T$

(B) $\frac{2}{3}T$

(C) T

(D) $\frac{3}{2}T$

(E) $3T$

30. A 1000 W electric motor lifts a 100 kg safe at constant velocity. The vertical distance through which the motor can raise the safe in 10 s is most nearly

(A) 1 m
(B) 3 m
(C) 10 m
(D) 32 m
(E) 100 m

31. A 1.0 kg mass is attached to the end of a vertical ideal spring with a force constant of 400 N/m. The mass is set in simple harmonic motion with an amplitude of 10 cm. The speed of the 1.0 kg mass at the equilibrium position is

(A) 2 m/s
(B) 4 m/s
(C) 20 m/s
(D) 40 m/s
(E) 200 m/s

32. A student is testing the kinematic equations for uniformly accelerated motion by measuring the time it takes for light-weight plastic balls to fall to the floor from a height of 3 m in the lab. The student predicts the time to fall using g as $9.80\ m/s^2$ but finds the measured time to be 35% greater. Which of the following is the most likely cause of the large percent error?

(A) The acceleration due to gravity is 70% greater than $9.80\ m/s^2$ at this location.
(B) The acceleration due to gravity is 70% less than $9.80\ m/s^2$ at this location.
(C) Air resistance increases the downward acceleration.
(D) The acceleration of the plastic balls is not uniform.
(E) The plastic balls are not truly spherical.

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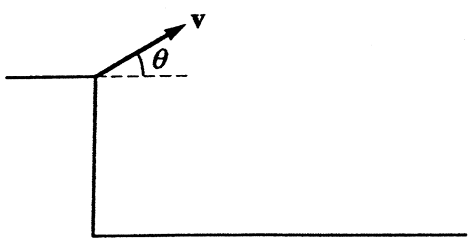

Note: Figure not drawn to scale.

33. An object is thrown with velocity **v** from the edge of a cliff above level ground. Neglect air resistance. In order for the object to travel a maximum horizontal distance from the cliff before hitting the ground, the throw should be at an angle θ with respect to the horizontal of

(A) greater than 60° above the horizontal
(B) greater than 45° but less than 60° above the horizontal
(C) greater than zero but less than 45° above the horizontal
(D) zero
(E) greater than zero but less than 45° below the horizontal

34. A car travels forward with constant velocity. It goes over a small stone, which gets stuck in the groove of a tire. The initial acceleration of the stone, as it leaves the surface of the road, is

(A) vertically upward
(B) horizontally forward
(C) horizontally backward
(D) zero
(E) upward and forward, at approximately 45° to the horizontal

35. The escape speed for a rocket at Earth's surface is v_e. What would be the rocket's escape speed from the surface of a planet with twice Earth's mass and the same radius as Earth?

(A) $2v_e$
(B) $\sqrt{2}v_e$
(C) v_e
(D) $\frac{v_e}{\sqrt{2}}$
(E) $\frac{v_e}{2}$

END OF SECTION I, MECHANICS

Chapter V: Answers to the 2004 AP Physics C Exam

- Section I: Multiple Choice
    - Section I Answer Key and Percent Answering Correctly
    - Analyzing Your Students' Performance on the Multiple-Choice Section
    - Diagnostic Guide for the 2004 AP Physics C Released Exam
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    - Comments from the Chief Reader
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Section I: Multiple Choice

Listed below are the correct answers to the multiple-choice questions, the percent of AP students who answered each question correctly by AP grade, and the total percent answering correctly.

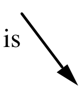
Section I Answer Key and Percent Answering Correctly

Mechanics

Item No.	Correct Answer	Percent Correct by Grade 5	4	3	2	1	Total Percent Correct
1	A	96	93	89	82	64	87
2	D	97	92	87	71	41	82
3	E	88	75	68	62	52	71
4	C	80	70	66	63	54	68
5	B	97	95	91	84	63	88
6	A	68	37	21	11	7	33
7	A	93	79	64	47	23	66
8	E	76	42	23	14	11	38
9	D	85	62	42	25	14	51
10	E	99	98	98	96	82	96
11	C	69	57	51	47	35	54
12	C	61	46	42	36	26	44
13	A	87	75	64	52	34	66
14	D	45	32	29	27	22	33
15	A	81	61	47	37	17	53
16	C	88	75	60	42	21	62
17	E	58	39	34	27	18	38
18	D	75	52	36	27	17	46
19	B	57	27	17	12	10	28
20	E	78	62	50	37	19	54
21	E	88	70	58	48	30	63
22	B	90	85	80	75	50	79
23	C	40	22	17	14	12	23
24	B	98	97	94	89	63	91
25	C	56	42	34	31	26	40
26	D	73	49	33	24	17	43
27	E	92	75	58	39	17	62
28	C	93	75	50	30	19	59
29	C	48	21	12	8	6	22
30	C	81	61	45	34	30	54
31	A	70	41	23	11	6	35
32	D	63	45	37	32	26	43
33	C	55	41	34	31	26	39
34	A	48	30	21	16	13	28
35	B	61	33	23	18	12	33

Electricity and Magnetism

Item No.	Correct Answer	Percent Correct by Grade 5	4	3	2	1	Total Percent Correct
36	E	86	80	74	64	37	71
37	C	87	76	65	50	26	65
38	A	66	55	49	43	25	50
39	B	84	62	49	35	17	54
40	C	73	40	22	12	6	36
41	C	78	42	23	13	9	39
42	B	83	61	40	24	11	49
43	C	63	28	16	10	8	30
44	B	81	53	37	29	23	49
45	E	94	82	74	62	38	73
46	A	65	43	30	26	17	40
47	B	83	65	54	42	24	58
48	B	71	47	33	21	10	41
49	C	85	64	52	38	20	56
50	C	81	69	61	55	43	64
51	A	71	32	18	12	10	33
52	C	44	29	20	15	11	27
53	B	81	60	47	36	26	54
54	A	48	24	16	12	10	25
55	C	83	57	45	32	24	53
56	D	99	97	94	91	67	91
57	A	96	90	81	70	49	80
58	D	63	36	28	23	15	36
59	A	71	46	35	25	16	43
60	B	65	43	36	29	20	42
61	B	61	39	31	22	16	37
62	A	85	64	48	34	16	54
63	D	82	66	53	43	27	58
64	E	77	48	34	23	14	44
65	E	68	38	25	16	5	35
66	C	88	71	59	49	36	64
67	A	79	55	40	27	15	48
68	D	73	47	37	27	16	44
69	D	44	33	30	27	17	32
70	B	28	13	11	8	8	15

	BASIC IDEA	SOLUTION	ANSWER
36.	$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + ... + \frac{1}{C_n}$	capacitors in series.	E
37.	$P = IV = \frac{V^2}{R}$	$1200 = \frac{(120)^2}{R}$	C
38.	Gauss' Law	No field within the walls of the conducting shell.	A
39.	$\int_{V_a}^{V_b} dV = -\int_a^b \vec{E} \cdot d\vec{s}$	$\Delta V = -\int_0^5 (ax+b)dx = -\left[a\frac{x^2}{2} + bx \right]_0^5 = -[(40)(0.125) + 4(0.5) - (0)] = -7 Volts$	B
40.	$\vec{F} = q\vec{v} \times \vec{B}$ $F = ma = m\frac{v^2}{r}$	In order for the positive q to experience a centripetal force the rhr indicates counterclockwise for its motion. $+evB = m\frac{v^2}{r}$ so we have $eBr = mv$	C
41.	vt=distance	$v = \frac{eBr}{m}$ and the distance during one period is $2\pi r$ so we have $\frac{eBr}{m} T = 2\pi r$ and then $T = \frac{2\pi m}{eB}$	C
42.	$W = \frac{1}{2}CV^2$	$W = \frac{1}{2}(20\mu)(30)^2 = 9 \times 10^{-3} J$	B
43.	Cons. Of Energy $K = \frac{1}{2}mv^2$ $\Delta U = q\Delta V$	$\Delta U + \Delta K = -qV + \frac{1}{2}mv^2 = 0$; $-eV + \frac{1}{2}m_e v^2 = 0$ $v = \sqrt{\frac{2eV}{m_e}}$	C
44.	$\oint \vec{B} \cdot d\vec{s} = \mu_o i$	$\oint \vec{B} \cdot d\vec{s} = B2\pi r = \mu_o \frac{\pi r^2}{\pi R^2} I$	B
45.	vector addition of E's	The field caused by the Q is  . That of the -4Q is  . The vector sum is clearly to the right and downward.	E
46.	vector addition of E's $E = \frac{1}{4\pi\varepsilon_o}\frac{Q}{r^2}$	To yield zero they must be in the opposite direction. That rules out the region between the two charges where both fields are to the right. To the right of the -4Q all places are closer to this larger charge so the field is non-zero and to the left. This brings us to A or B. Since one charge is four times as great as the other and the field is a function of the inverse square of the distance, the larger charge must be twice as far away. This gives us A.	A
47.	V=IR $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + ...$ $R_{eq} = R_1 + R_2 + ...$	Since adding a parallel resistor always reduces the equivalent resistance of the parallel resistors below the smallest of them, the total resistance of the circuit is less so the current will increase. In order to double the current the total resistance would have to be half of the original 35Ω or 17.5Ω meaning that the pair would have to be the equivalent of 2.5Ω, where as, from $\frac{1}{R_{eq}} = \frac{1}{20} + \frac{1}{60}$ it is 15Ω.	B
48.	$R = \rho\frac{L}{A}$	$\frac{R_x}{R_y} = \frac{\rho\frac{2L_y}{\pi\left(\frac{2d_y}{2}\right)^2}}{\rho\frac{L_y}{\pi\left(\frac{d_y}{2}\right)^2}} = 0.5$	B

49.	$V = \frac{1}{4\pi\varepsilon_o}\frac{q}{r}$ $E = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}$ $\varepsilon_o \oint \vec{E} \cdot d\vec{A} = q_{inside}$	Field within the shell is zero (Gauss's Law). Outside the shell not the field weakens with the inverse square so at 2R the field is one fourth as great as it is at R.	C
50.	$\frac{F}{L} = \frac{\mu_o}{2\pi}\frac{I_1 I_2}{d}$	doubling both currents adds a factor of 4 to the right side.	C
51.	$\Phi_B = \vec{B} \cdot \vec{A}$ $\mathcal{E} = -\frac{d\Phi}{dt}$	$A = \pi r^2 = \pi(at)^2 = \pi a^2 t^2$ therefore $\Phi_B = B\pi a^2 t^2$. $\mathcal{E} = -\frac{d\Phi}{dt} = -2B\pi a^2 t$	A
52.	V=IR	Add the change in potential from bottom to top for each circuit. Left circuit: -Ir + $\mathcal{E}$ = 10volts. Right circuit: +Ir + + $\mathcal{E}$ = 20volts Adding the two equations gives 2e = 30volts so e = 15volts	C
53.	$\vec{F} = q\vec{v} \times \vec{B}$ $\vec{F} = q\vec{E}$	Because the forces caused by the two fields must be in opposite directions in order to add to zero, and since the force of the magnetic field is perpendicular to the magnetic field and the force of the electric field is in the same line as that of the field, the two fields must be perpendicular.	B
54.	Lenz's Law right hand rule	Induced current opposes the change that caused it. The force on the magnet opposes the withdrawal, that is, the force is to the right. The flux to the right through the loop is decreasing so the induced current will try to maintain it so the magnetic field due to the induced current is to the right as well.	A
55.	$\vec{\tau} = \vec{p} \times \vec{B}$ **or** $\vec{F} = I\vec{\ell} \times \vec{B}$ right hand rule	The torque tends to align the dipole moment with the magnetic field. The force on the top wire is out of the page and on the bottom wire is into the page.	C
56.	if necessary $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$ $R_{eq} = R_1 + R_2 + \ldots$	The quickest solution is to note that because the 35Ω resistor is in series with the parallel branch the equivalent resistance must be > 35Ω. Because the 60Ω and 20Ω resistors are in parallel their combination must Be < 20Ω. This gives us that the answer is between 35Ω and 55Ω.	D
57.	Symmetry	The field vectors will negate each other for the diametrically opposed pairs.	A
58.	$V = \frac{1}{4\pi\varepsilon_o}\frac{q}{r}$ ΔU=qΔV	The potential at the center of the circle is $V = \frac{1}{4\pi\varepsilon_o}\frac{6Q}{R}$ so the potential energy of a sixth charge will be $U = \frac{1}{4\pi\varepsilon_o}\frac{6Q^2}{R} = \frac{3}{2\pi\varepsilon_o}\frac{Q^2}{R}$ so this equals the work required to bring it from "infinity" where the U = 0.	D
59.	$E = -\frac{dV}{dr}$	The field points down slope.	A
60.	$E = -\frac{dV}{dr}$	Where the slope is the greatest, that is, where the equipotential lines are closest together.	B
61.	W=ΔU=qΔV	W= $q(V_E - V_C)$ = -1μC(20V-10V) = -10μJ	B

62.	alternate statement Faraday's Law of Induction.	$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi}{dt}$ ⇦ Rate of change of magnetic flux ⮤ Line integral of non-electrostatic field	A
63.	$C = \frac{\kappa \varepsilon_o A}{d}$	The equation for the capacitance of a parallel plate capacitor indicates that C will increase if d is decreased.	D
64.	$\frac{F}{L} = \frac{\mu_o}{2\pi}\frac{I_1 I_2}{d}$	The force decreases with distance. Parallel wires with currents in the same direction appear to attract, and those with currents in the opposite direction seem to repel. (See $\vec{F} = I\vec{\ell} \times \vec{B}$ to explain the direction.)	E
65.	free electrons in a metal	In a static situation the charges will move about until the net field in the conductor is zero.	E
66.	$i = \frac{\varepsilon}{R}\left(1 - e^{-\frac{Rt}{L}}\right)$	As t → ∞ I approaches 12/6 = 2A	C
67.	V=iR	Since $i = 0$ (see equation in #66) $V_R = 0$ at t = 0.	A
68.	$\varepsilon_o \oint \vec{E} \cdot d\vec{A} = q_{inside}$	Inside the sphere: $\varepsilon_o E 4\pi r^2 = \frac{\frac{4}{3}\pi r^3}{\frac{4}{3}\pi R^3}$ yielding E proportional to r. This fact alone eliminates the other choices.	D
69.	charging by induction	In I the electrons are driven onto the leaves. In II the electrons are allowed to go to ground, so in III the leaves have a net positive charge.	D
70.	The Hall Effect $\vec{F} = q\vec{v} \times \vec{B}$	Negative charge will shift to the left causing the right side to be at a higher potential, since potential is defined in terms of the positive charge.	B