TABLE OF INFORMATION FOR 2004 and 2005

| CONSTANTS AND CONVERSION FACTORS | |
|---|---|
| 1 unified atomic mass unit, | $1 \text{ u} = 1.66 \times 10^{-27}$ kg |
| | $= 931 \text{ MeV}/c^2$ |
| 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, | $R = 8.31 \text{ J}/(\text{mol} \cdot \text{K})$ |
| 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, | $h = 6.63 \times 10^{-34} \text{ J} \cdot \text{s}$ |
| | $= 4.14 \times 10^{-15} \text{ eV} \cdot \text{s}$ |
| | $hc = 1.99 \times 10^{-25} \text{ J} \cdot \text{m}$ |
| | $= 1.24 \times 10^3 \text{ eV} \cdot \text{nm}$ |
| 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, | $\mu_0 = 4\pi \times 10^{-7} (\text{T} \cdot \text{m})/\text{A}$ |
| Magnetic constant, | $k' = \mu_0/4\pi = 10^{-7} (\text{T} \cdot \text{m})/\text{A}$ |
| 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, | $1 \text{ atm} = 1.0 \times 10^5 \text{ N/m}^2$ |
| | $= 1.0 \times 10^5 \text{ Pa}$ |
| 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 | $\Omega$ |
| 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 | $\mu$ |
| $10^{-9}$ | nano | n |
| $10^{-12}$ | pico | p |

| VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES | | | |
|---|---|---|---|
| $\theta$ | $\sin \theta$ | $\cos \theta$ | $\tan \theta$ |
| 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 | $\infty$ |

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.

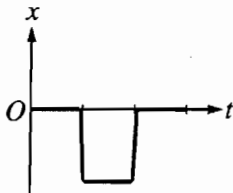**Note:** To simplify calculations, you may use $g = 10 \text{ m/s}^2$ in all problems.
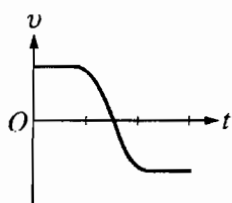


1. The graph above shows velocity $v$ *versus* time $t$ for an object in linear motion. Which of the following is a possible graph of position $x$ *versus* time $t$ for this object?
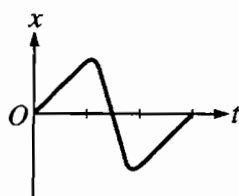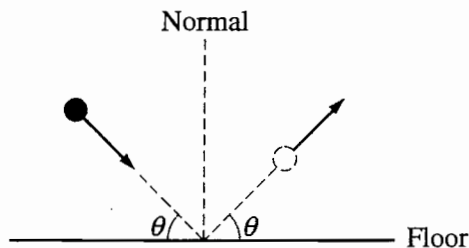
(A)
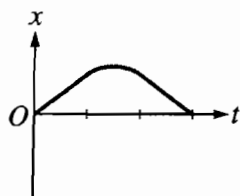

(B)


(C)
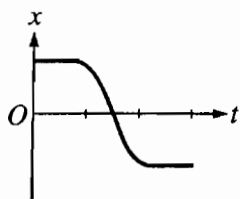

(D)
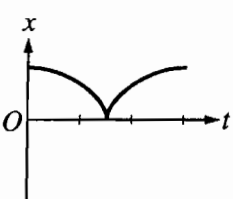

(E)


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

**GO ON TO THE NEXT PAG**

3. A 2 kg ball collides with the floor at an angle $\theta$ 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) 
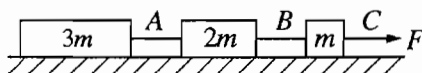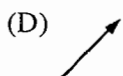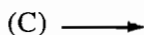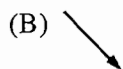


4. Three blocks of masses $3m$, $2m$, and $m$ are connected to strings $A$, $B$, and $C$ as shown above. The blocks are pulled along a rough surface by a force of magnitude $F$ exerted by string $C$. The coefficient of friction between each block and the surface is the same. Which string must be the 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**
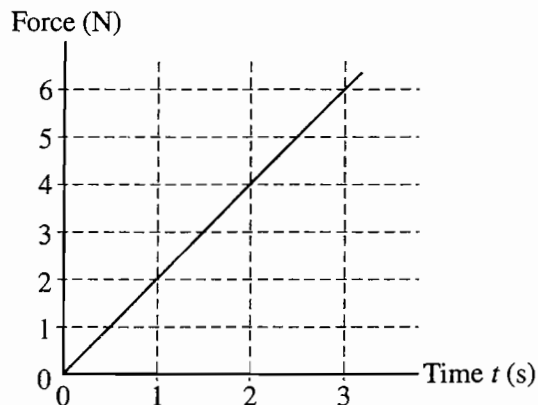


A block of mass 3 kg, initially at rest, is pulled along a frictionless, horizontal surface with a force shown as a function of time $t$ by the graph above.
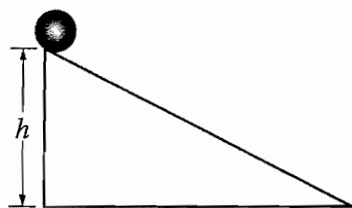
5. The acceleration of the block at $t = 2$ s is

(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

**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) $\dfrac{2Mgh}{I}$

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

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

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

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) $\dfrac{2Mgh}{I}$

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

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

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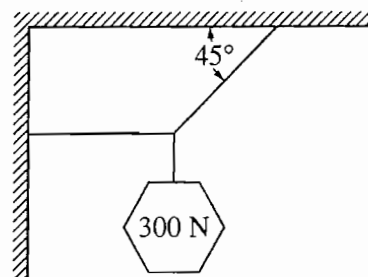


9. An object weighing 300 N is suspended by means of two cords, as shown above. The tension in the horizontal cord is

   (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 $\theta$ 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.
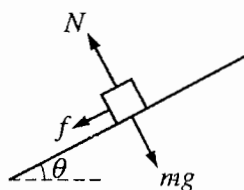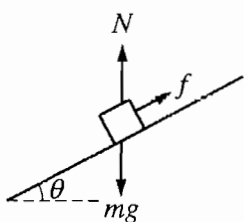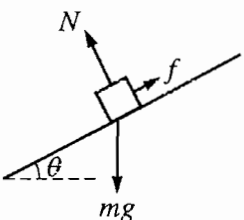
Figure A



Figure B



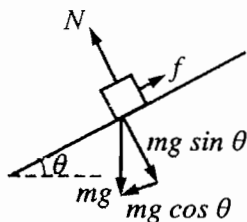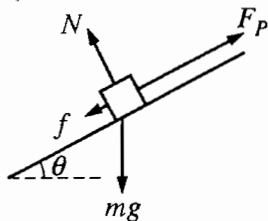Figure C



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) $\dfrac{3kt^2}{2}$

    (C) $\dfrac{kt^2}{3}$

    (D) $kt^4$

    (E) $\dfrac{kt^4}{4}$
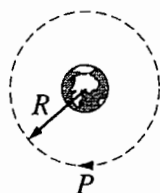
14. A spacecraft orbits Earth in a circular orbit of radius $R$, as shown above. When the spacecraft is at position $P$ shown, a short burst of the ship's engines results in a small increase in its speed. The new orbit is best shown by the solid curve in which of the following diagrams?
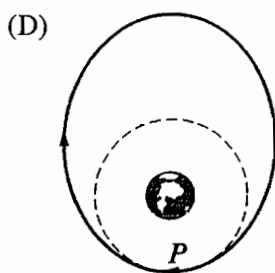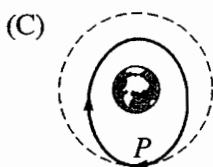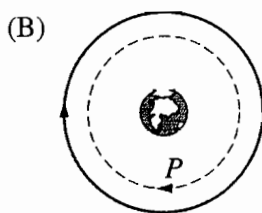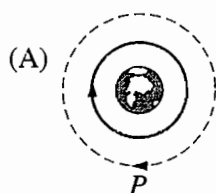
(A)



(B)



(C)



(D)



(E)
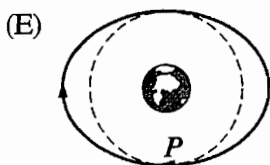


15. A student holds one end of a string in a fixed position. A ball of mass 0.2 kg attached to the other end of the string moves in a horizontal circle of radius 0.5 m with a constant speed of 5 m/s. How much work is done on the ball by the string during each revolution?

(A) 0 J
(B) 0.5 J
(C) 1.0 J
(D) $2\pi$ J
(E) $5\pi$ 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$^{-1}$
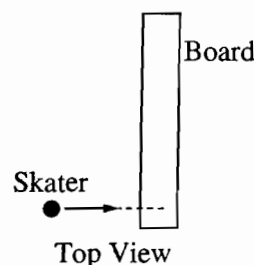


Top View

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 $\theta$ that the pendulum makes with the vertical as a function of time $t$ ?

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

(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) $\dfrac{M - m}{M} g$

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

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

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

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) $\dfrac{1}{2} kx_0$

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

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

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

Questions 22-23
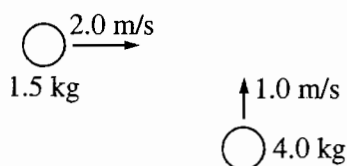


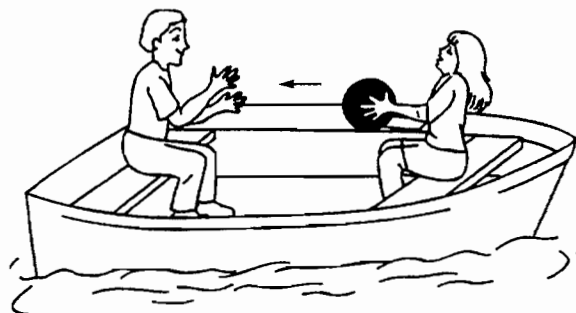Two pucks moving on a frictionless air table are about to collide, as shown above. The 1.5 kg puck is moving directly east at 2.0 m/s. The 4.0 kg puck is moving directly north at 1.0 m/s.
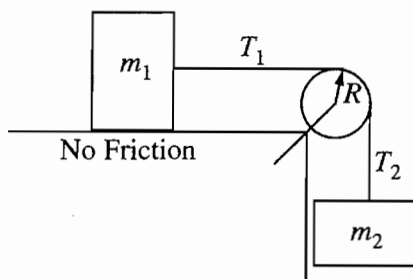
22. What is the total kinetic energy of the two-puck system before the collision?

(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

24. The position of an object is given by the equation $x = 3.0\,t^2 + 1.5\,t + 4.5$, 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 |

No Friction

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 $\alpha$ 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) $m_2 g R = I\alpha$

(B) $(T_1 + T_2)R = I\alpha$

(C) $T_2 R = I\alpha$

(D) $(T_2 - T_1)R = I\alpha$

(E) $(m_2 - m_1)gR = I\alpha$
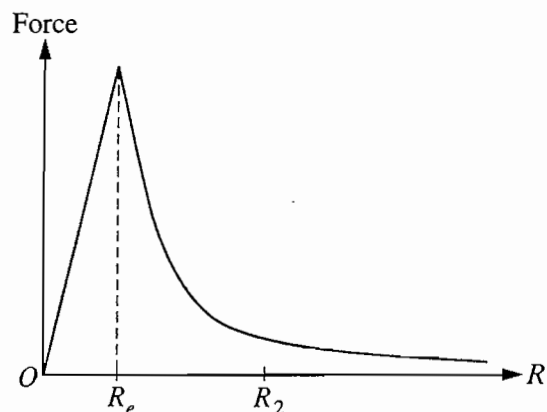


Force

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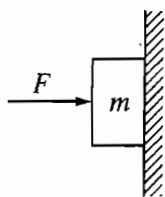
28. A horizontal force $F$ pushes a block of mass $m$ against a vertical wall. The coefficient of friction between the block and the wall is $\mu$. What value of $F$ is necessary to keep the block from slipping down the wall?

    (A) $mg$

    (B) $\mu mg$

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

    (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 $\dfrac{1}{9}$ and radius $\dfrac{1}{2}$ that of Earth, is most nearly

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

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

    (C) $T$

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

    (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 $\text{m}/\text{s}^2$ 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 $\text{m}/\text{s}^2$ at this location.
    (B) The acceleration due to gravity is 70% less than 9.80 $\text{m}/\text{s}^2$ 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.
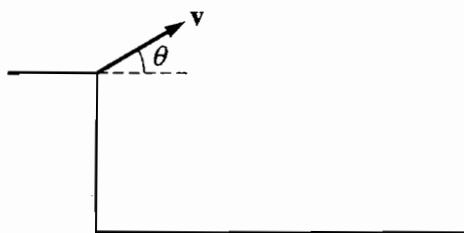
Note: Figure not drawn to scale.

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 $\theta$ 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) $\dfrac{v_e}{\sqrt{2}}$
   (E) $\dfrac{v_e}{2}$

**END OF SECTION I, MECHANICS**