AAPT UNITED STATES PHYSICS TEAM
AIP 2018

# 2018 $F = ma$ Contest

## 25 QUESTIONS - 75 MINUTES

## INSTRUCTIONS

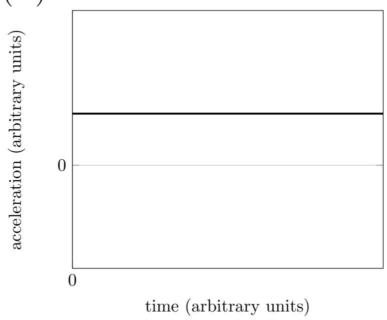
**DO NOT OPEN THIS TEST UNTIL YOU ARE TOLD TO BEGIN**

- Use $g = 10$ N/kg throughout this contest.
- You may write in this booklet of questions. However, you will not receive any credit for anything written in this booklet.
- Your answer to each question must be marked on the optical mark answer sheet.
- Select the single answer that provides the best response to each question. Please be sure to use a No. 2 pencil and completely fill the box corresponding to your choice. If you change an answer, the previous mark must be completely erased.
- Correct answers will be awarded one point; incorrect answers and leaving an answer blank will be awarded zero points. There is no additional penalty for incorrect answers.
- A hand-held calculator may be used. Its memory must be cleared of data and programs. You may use only the basic functions found on a simple scientific calculator. Calculators may not be shared. Cell phones may not be used during the exam or while the exam papers are present. You may not use any tables, books, or collections of formulas.
- This test contains 25 multiple choice questions. Your answer to each question must be marked on the optical mark answer sheet that accompanies the test. Only the boxes preceded by numbers 1 through 25 are to be used on the answer sheet.
- All questions are equally weighted, but are not necessarily the same level of difficulty.
- **In order to maintain exam security, do not communicate any information about the questions (or their answers or solutions) on this contest until after February 20, 2018.**
- The question booklet and answer sheet will be collected at the end of this exam. You may not use scratch paper.

**DO NOT OPEN THIS TEST UNTIL YOU ARE TOLD TO BEGIN**

1. A large lump of clay is dropped off of a wall and lands on the ground. Which graph best represents the acceleration of the center of mass of the clay as a function of time?

(A)

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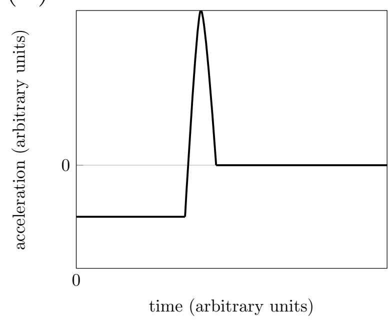


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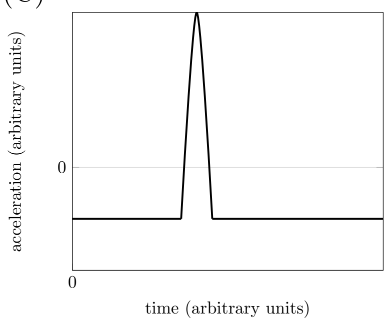


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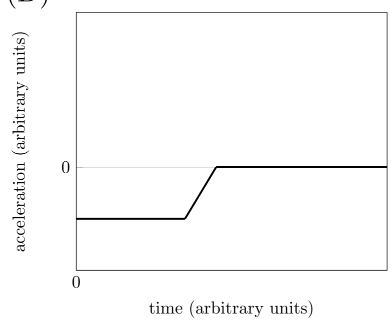


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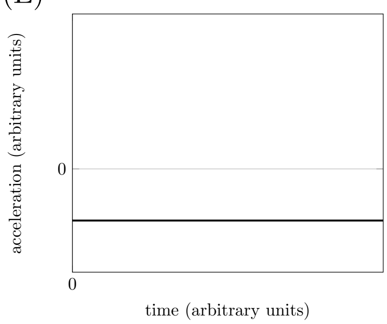



2. A uniform block of mass 10 kg is released at rest from the top of an incline with length 10 m and inclination 30°, and slides to the bottom. The coefficients of static and kinetic friction are $\mu_s = \mu_k = 0.1$. How much energy is dissipated due to friction?

   (A) 0 J
   (B) 22 J
   (C) 43 J
   (D) 87 J
   (E) 164 J

3. A 3.0 kg mass moving at 40 m/s to the right collides with and sticks to a 2.0 kg mass traveling at 20 m/s to the right. After the collision, the kinetic energy of the system is closest to

   (A) 600 J
   (B) 1200 J
   (C) 2600 J
   (D) 2800 J
   (E) 3400 J

4. A basketball is released from rest and bounces on the ground. Considering only the ball just before and just after the bounce, which of the following statements must be true?

   (A) The momentum and the total energy of the ball are conserved.
   (B) The momentum of the ball is conserved, but not the kinetic energy.
   (C) The total energy of the ball is conserved, but not the momentum.
   (D) The kinetic energy of the ball is conserved, but not the momentum.
   (E) Neither the kinetic energy of the ball nor the momentum is conserved.

5. The hard disk in a computer will spin up to speed within 10 rotations, but when turned off will spin through 50 rotations before coming to a stop. Assuming the hard disk has constant angular acceleration $\alpha_1$ and angular deceleration $\alpha_2$, the ratio $\alpha_1/\alpha_2$ is

   (A) $1/5$
   (B) $1/\sqrt{5}$
   (C) $\sqrt{5}$
   (D) 5
   (E) 25

6. A massless beam of length $L$ is fixed on one end. A downward force $F$ is applied to the free end of the beam, deflecting the beam downward by a distance $x$. The deflection $x$ is linear in $F$ and is inversely proportional to the cross-section moment $I$, which has units $\mathrm{m}^4$. The deflection is also dependent on Young's modulus $E$, which has units $\mathrm{N/m}^2$. Then $x$ depends on $L$ according to

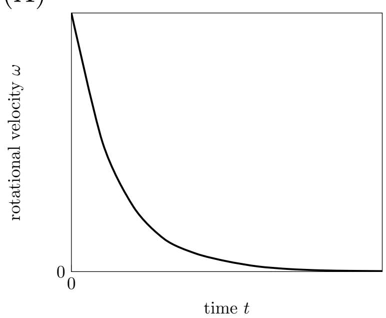
   (A) $x \propto \sqrt{L}$
   (B) $x \propto L$
   (C) $x \propto L^2$
   (D) $x \propto L^3$
   (E) $x \propto L^4$

7. A pendulum of length $L$ oscillates inside a box. A person picks up the box and gently shakes it vertically with frequency $\omega$ and a fixed amplitude for a fixed time. To maximize the final amplitude of the pendulum, $\omega$ should satisfy

   (A) $\omega = \sqrt{4g/L}$
   (B) $\omega = \sqrt{2g/L}$
   (C) $\omega = \sqrt{g/L}$
   (D) $\omega = \sqrt{g/4L}$
   (E) there will be no significant effect on the pendulum amplitude for any value of $\omega$

8. The coefficients of static and kinetic friction between a ball and a horizontal plane are $\mu_s = \mu_k = \mu$. The ball is given a horizontal speed but no rotational velocity about its center of mass. Which of the following graphs best shows the rotational velocity of the ball about its center of mass as a function of time?

(A)

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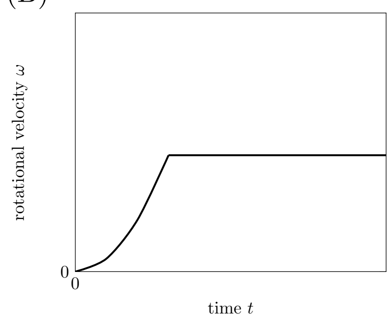


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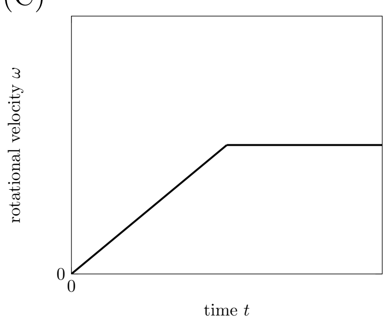


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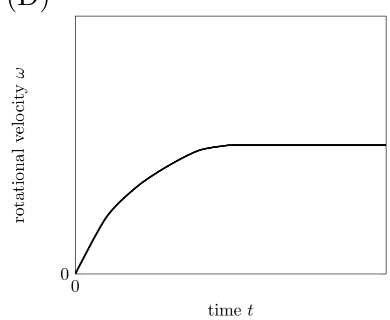
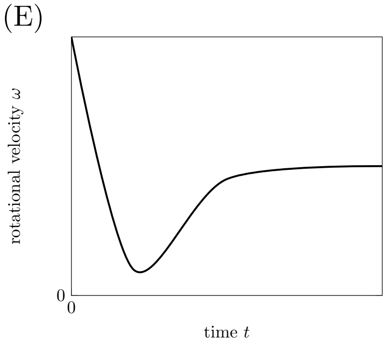



(E)



9. A 3.0 kg ball moving at 10 m/s east collides elastically with a 2.0 kg ball moving 15 m/s west. Which of the following statements could be true after the collision?

   (A) The two balls are both moving directly east.
   (B) The 3.0 kg ball moves directly west at 15 m/s.
   (C) The 2.0 kg ball moves directly north at 10 m/s.
   (D) The 3.0 kg ball is at rest.
   (E) The 2.0 kg ball moves directly south at 15 m/s.

10. A balloon filled with air submerged in water at a depth $h$ experiences a buoyant force $B_0$. The balloon is moved to a depth of $2h$, where it experiences a buoyant force $B$. Assuming the water is incompressible and the balloon and air are compressible, the buoyant force $B$ satisfies

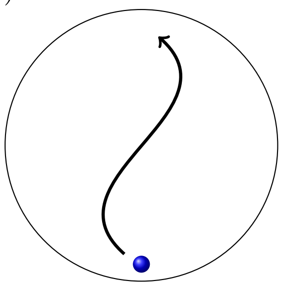
    (A) $B \geq 2B_0$
    (B) $B_0 < B < 2B_0$
    (C) $B = B_0$
    (D) $B < B_0$
    (E) it depends on the compressibility of the balloon and air

11. A circle of rope is spinning in outer space with an angular velocity $\omega_0$. Transverse waves on the rope have speed $v_0$, as measured in a rotating reference frame where the rope is at rest. If the angular velocity of the rope is doubled, the new speed of transverse waves, as measured in a rotating reference frame where the rope is at rest, will be

    (A) $v_0$
    (B) $\sqrt{2}v_0$
    (C) $2v_0$
    (D) $4v_0$
    (E) $8v_0$

12. A child in a circular, rotating space station tosses a ball in such a way so that once the station has rotated through one half rotation, the child catches the ball. From the child's point of view, which plot shows the trajectory of the ball? The child is at the bottom of the space station in the diagrams below, but only the initial location of the ball is shown.

(A)



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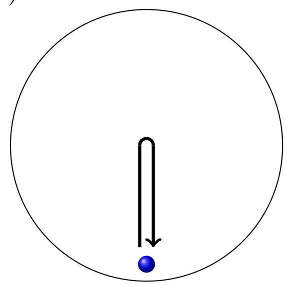

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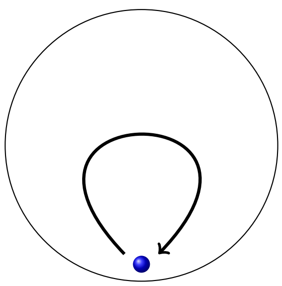
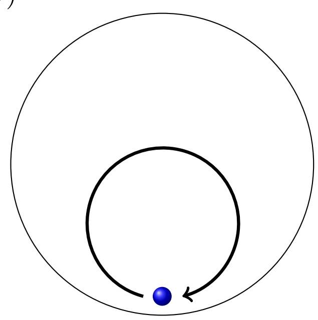
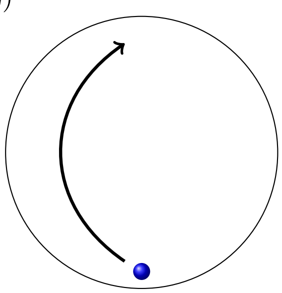


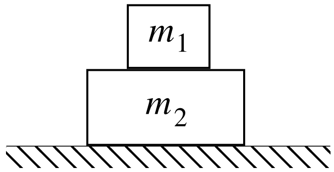
(D)



(E)

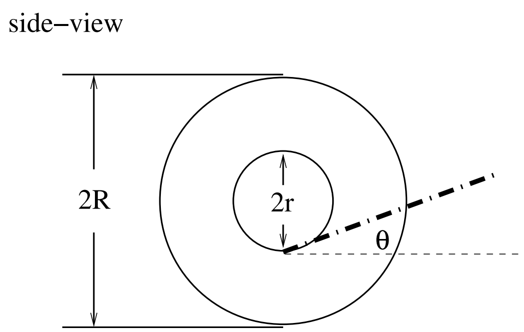


13. Two blocks of masses $m_1 = 2.0$ kg and $m_2 = 1.0$ kg are stacked together on top of a frictionless table as shown. The coefficient of static friction between the blocks is $\mu_s = 0.20$. What is the minimum horizontal force that must be applied to the top block to make it slide across the bottom block?




(A) 4.0 N
(B) 6.0 N
(C) 8.0 N
(D) 12.0 N
(E) The top block will not slide across the bottom block

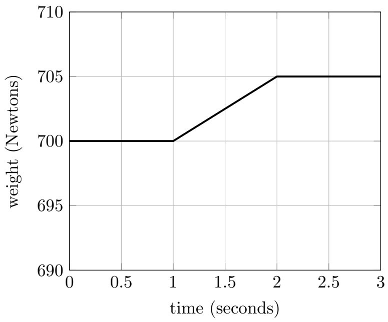
14. A spool is made of a cylinder with a thin disc attached to either end of the cylinder, as shown. The cylinder has radius $r = 0.75$ cm and the discs each have radius $R = 1.00$ cm. A string is attached to the cylinder and wound around the cylinder a few times. At what angle above the horizontal can the string be pulled so that the spool will slip without rotating?



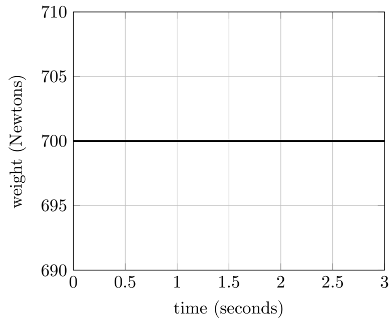

(A) 31.2°
(B) 41.4°
(C) 54.0°
(D) 60.8°
(E) 81.5°

15. You are standing on a weight scale that reads 700 Newtons while holding a large physics textbook that is originally at rest. At time $t = 1$ seconds you begin moving the textbook upward so that by time $t = 2$ seconds the textbook is now half a meter higher and once again at rest. Which of the following graphs best illustrates how the reading on the scale might vary with time?

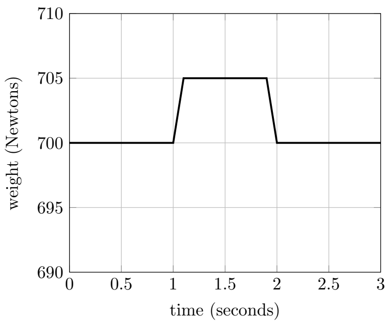
(A)



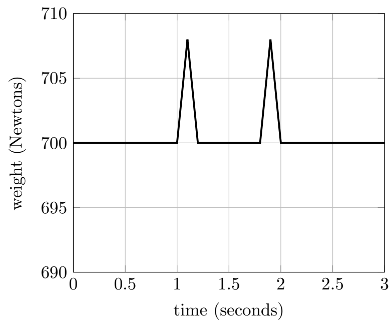

(B)



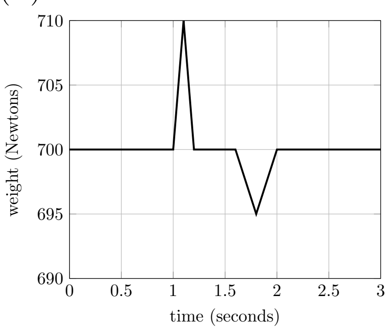

(C)




(D)




(E)

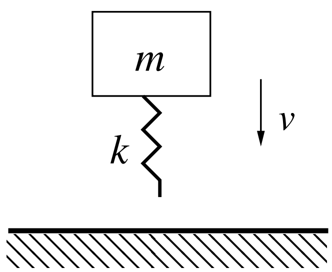


16. A plane can fly by tilting the trailing edge of the wings downward by a small angle $\theta$, called the angle of attack. In still air, a plane with ground speed $v$ will have a lift force proportional to $v^2\theta$ and a drag force is proportional to $v^2$.

Consider a plane initially in level flight in still air with constant ground speed $v$. If the plane enters a region with a tailwind with speed $w < v$ (the wind is blowing in the same direction that the plane wants to fly), how must the engine power and the angle of attack change for the plane to maintain level flight at the same ground speed?

(A) The engine power decreases and the angle of attack decreases
(B) The engine power decreases and the angle of attack stays the same
(C) The engine power decreases and the angle of attack increases
(D) The engine power increases and the angle of attack decreases
(E) The engine power increases and the angle of attack increases

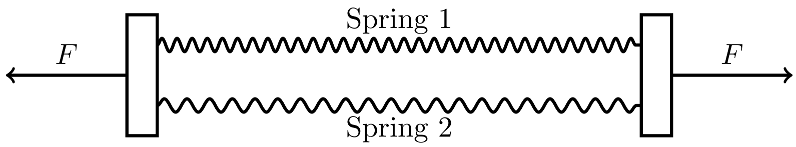
17. A pogo stick is modeled as a massless spring of spring constant $k$ attached to the bottom of a block of mass $m$. The pogo stick is dropped with the spring pointing downward and hits the ground with speed $v$. At the moment of the collision, the free end of the spring sticks permanently to the ground.




During the subsequent oscillations, the maximum speed of the block is

(A) $v$
(B) $v + 2mg^2/kv$
(C) $v + mg^2/kv$
(D) $\sqrt{v^2 + 2mg^2/k}$
(E) $\sqrt{v^2 + mg^2/k}$

18. A spring of relaxed length $\ell_1$ and spring constant $k_1$ is placed 'in parallel' with a spring of relaxed length $\ell_2$ and spring constant $k_2$. A force $F$ is applied to each end.




The combination of the springs acts like a single spring with spring constant $k$ and relaxed length $\ell$ where

(A) $k = k_1 + k_2$ and $\ell = \ell_1\ell_2/(\ell_1 + \ell_2)$
(B) $k = k_1 + k_2$ and $\ell = (\ell_1 k_1 + \ell_2 k_2)/(k_1 + k_2)$
(C) $k = k_1 + k_2$ and $\ell = (\ell_1 k_2 + \ell_2 k_1)/(k_1 + k_2)$
(D) $k = (\ell_1 k_1 + \ell_2 k_2)/(\ell_1 + \ell_2)$ and $\ell = (\ell_1 k_1 + \ell_2 k_2)/(k_1 + k_2)$
(E) $k = (\ell_2 k_1 + \ell_1 k_2)/(\ell_1 + \ell_2)$ and $\ell = (\ell_1 k_2 + \ell_2 k_1)/(k_1 + k_2)$

19. In an experiment to determine the speed of sound, a student measured the distance that a sound wave traveled to be $75.0 \pm 2.0$ cm, and found the time it took the sound wave to travel this distance to be $2.15 \pm 0.10$ ms. Assume the uncertainties are Gaussian. The computed speed of sound should be recorded as

(A) $348.8 \pm 0.5$ m/s
(B) $348.8 \pm 0.8$ m/s
(C) $349 \pm 8$ m/s
(D) $349 \pm 15$ m/s
(E) $349 \pm 19$ m/s

20. A massive, uniform, flexible string of length $L$ is placed on a horizontal table of length $L/3$ that has a coefficient of friction $\mu_s = 1/7$, so equal lengths $L/3$ of string hang freely from both sides of the table. The string passes over the edges of the table on smooth, frictionless, curved surfaces.

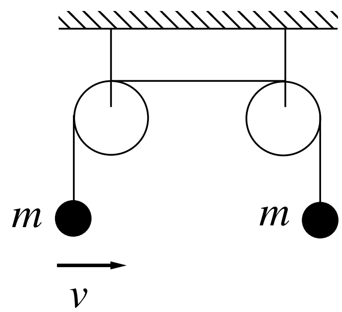
Now suppose that one of the hanging ends of the string is pulled a distance $x$ downward, then released at rest. Neither end of the string ever touches the ground in this problem. The maximum value of $x$ so that the string does not slip off of the table is

(A) $L/42$
(B) $L/21$
(C) $L/14$
(D) $2L/21$
(E) $3L/14$

21. A uniform bar of length $L$ and mass $M$ is supported by a fixed pivot a distance $x$ from its center. The bar is released from rest from a horizontal position. The period of the resulting oscillations is minimal when

(A) $x = L/2$
(B) $x = L/2\sqrt{3}$
(C) $x = L/4$
(D) $x = L/4\sqrt{3}$
(E) $x = L/12$

22. Two particles of mass $m$ are connected by pulleys as shown.



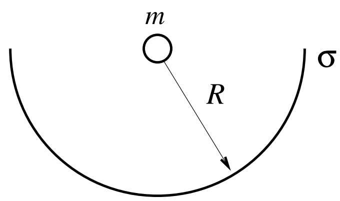

The mass on the left is given a small horizontal velocity, and oscillates back and forth. The mass on the right

(A) remains at rest
(B) oscillates vertically, and with a net upward motion
(C) oscillates vertically, and with a net downward motion
(D) oscillates vertically, with no net motion
(E) oscillates horizontally, with no net motion

23. Two particles with mass $m_1$ and $m_2$ are connected by a massless rigid rod of length $L$ and placed on a horizontal frictionless table. At time $t = 0$, the first mass receives an impulse perpendicular to the rod, giving it speed $v$. At this moment, the second mass is at rest. The next time the second mass is at rest is

(A) $t = 2\pi L/v$
(B) $t = \pi(m_1 + m_2)L/m_2 v$
(C) $t = 2\pi m_2 L/(m_1 + m_2)v$
(D) $t = 2\pi m_1 m_2 L/(m_1 + m_2)^2 v$
(E) $t = 2\pi m_1 L/(m_1 + m_2)v$

24. A particle of mass $m$ is placed at the center of a hemispherical shell of radius $R$ and mass density $\sigma$, where $\sigma$ has dimensions of kg/m$^2$.




The gravitational force of the shell on the particle is

(A) $(1/3)(\pi G m \sigma)$
(B) $(2/3)(\pi G m \sigma)$
(C) $(1/\sqrt{2})(\pi G m \sigma)$
(D) $(3/4)(\pi G m \sigma)$
(E) $\pi G m \sigma$

25. A student is measuring the surface area of a cylindrical wire. The student measures the radius of the wire to be $1 \pm 0.1$ cm using a ruler and the length of the wire to be $1.00 \pm 0.01$ m using a meter-stick. The precision of their result can be increased in several ways.

1: Upgrade the ruler to a caliper with uncertainty 0.01 cm.
2: Upgrade the meter-stick to a tape measure with uncertainty 0.001 m.
3: Repeat the measurement independently ten times and average the results.

How do the resulting uncertainties of the measurements compare?

(A) Method 3 has the lowest uncertainty, while methods 1 and 2 have the same uncertainty
(B) Method 3 has the highest uncertainty, while methods 1 and 2 have the same uncertainty
(C) Method 1 has the highest uncertainty, and method 2 has the lowest
(D) Method 2 has the highest uncertainty, and method 1 has the lowest
(E) Method 2 has the highest uncertainty, and method 3 has the lowest