AAPT UNITED STATES PHYSICS TEAM
AIP 2019

2019 $F = ma$ Exam

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. You may only use the scratch paper provided by the proctor.
- This test contains 25 multiple choice questions. Select the 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. 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 of the same level of difficulty.
- Correct answers will be awarded one point; incorrect answers or 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.
- The question booklet, the answer sheet and the scratch paper will be collected at the end of this exam.
- **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 1, 2019.**

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We acknowledge the following people for their contributions to this year's exams (in alphabetical order):

JiaJia Dong, Mark Eichenlaub, Matthew Huang, David Jones, Abijith Krishnan, Daniel Longenecker, Marianna Mao, Joon Pahk, Kye Shi, Brian Skinner, Alex Small, Paul Stanley, Elena Yudovina, and Kevin Zhou.

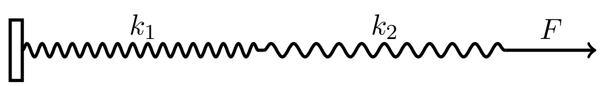
1. A uniform block of mass 10 kg is released at rest from the top of an incline of length 10 m and inclination 30°. The coefficients of static and kinetic friction between the incline and the block are $\mu_s = 0.15$ and $\mu_k = 0.1$. The end of the incline is connected to a frictionless horizontal surface. After a long time, how much energy is dissipated due to friction?

   (A) 75 J
   (B) 87 J
   (C) 130 J
   (D) 147 J
   (E) 500 J

2. Three cubical blocks of the same volume are made out of wood, styrofoam, and plastic. When the plastic block is placed in water, half of its volume is submerged. If the wooden block is placed in water with the plastic block on top, the wooden block is just fully submerged. Similarly, if the styrofoam block is placed in oil with the plastic block on top, the styrofoam block is just fully submerged. The density of oil is 0.7 times that of the water. What is the ratio of the density of wood to the density of styrofoam, $\rho_{\text{wood}}/\rho_{\text{styrofoam}}$?

   (A) 2.5
   (B) 0.5
   (C) 0.7
   (D) 1.4
   (E) 1

3. Two springs of spring constants k_1 and k_2, respectively, are connected in series and stretched, as shown below. What is the ratio of their potential energies, U_1/U_2?



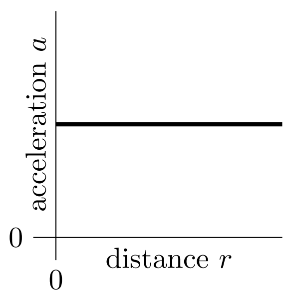
   (A) 1
   (B) k_1/k_2
   (C) k_2/k_1
   (D) $(k_1/k_2)^2$
   (E) $(k_2/k_1)^2$

4. Consider two identical masses that interact only by gravitational attraction to each other. If one mass is fixed in place and the other is released from rest, then the two masses collide in time T. If both masses are released from rest, they collide in time

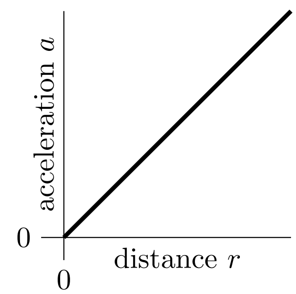
   (A) $T/4$
   (B) $T/(2\sqrt{2})$
   (C) $T/2$
   (D) $T/\sqrt{2}$
   (E) T

5. The density of the Earth increases gradually from around 3 g/cm^3 at the crust to about 13 g/cm^3 at the core. Which one of these plots could show local gravitational acceleration as a function of distance from Earth's center?

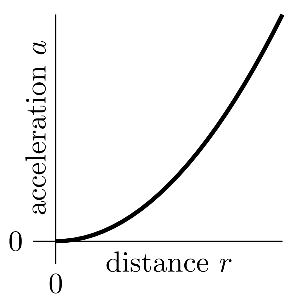
(A)



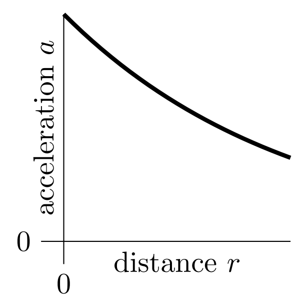
(B)



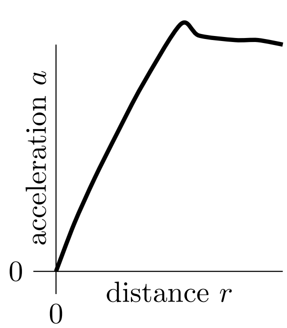
(C)



(D)



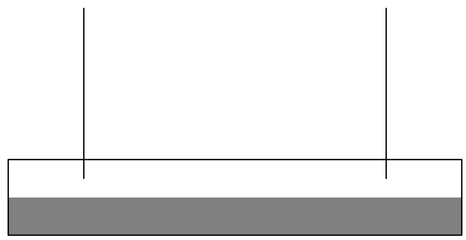
(E)



6. A very long cylinder of dust is spinning about its axis with angular velocity ω at steady state. Let r be the distance from the axis. If the dust is only held together by gravity, the density of the dust is proportional to:

   (A) r^{-2}
   (B) r^{-1}
   (C) the density does not depend on r.
   (D) r
   (E) r^2

7. A trough half-filled with water is suspended from wires, as shown. The tension is initially the same in each wire.



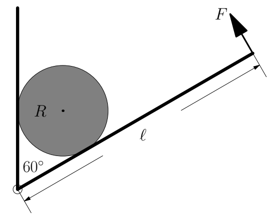
A boat is placed in the trough directly under the left wire. It floats without touching the sides of the trough or overflowing the water. How does the tension in the wires change as a result?

   (A) The tension is not affected in either wire.
   (B) The tension increases equally in both wires.
   (C) The tension increases in the left wire and decreases in the right wire.
   (D) The tension increases in the left wire and stays the same in the right wire.
   (E) The tension increases in the left wire and increases by a smaller amount in the right wire.

8. A scale is calibrated so that it gives a correct reading when sitting on the ground. A person holds the scale and presses it on both sides with their hands, pushing up on the bottom with the left hand and pushing down on the top with the right. The scale has a mass of 5 kg, and their left hand exerts a force of 200 N. The reading on the scale is:

   (A) 15 kg
   (B) 20 kg
   (C) 35 kg
   (D) 40 kg
   (E) 45 kg

9. A light board of length ℓ is hinged to a vertical wall. A solid ball of weight G and radius R is held between the wall and the board by a force F applied perpendicular at the end of the board, as shown in the figure below. Both the wall and the board are frictionless. The angle between the board and the wall is $60°$. What is the magnitude of F?



(A) $\dfrac{2}{\sqrt{3}}G$

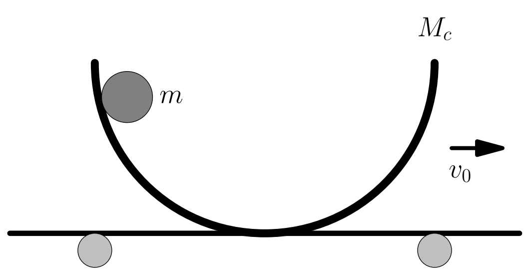
(B) $\dfrac{2R}{\ell}G$

(C) $\dfrac{2R}{\sqrt{3}\ell}G$

(D) $\dfrac{4R}{\sqrt{3}\ell}G$

(E) $\dfrac{\sqrt{3}R}{\ell}G$

10. A ball of mass m rolls in a bowl bolted on a cart. The bowl and cart move together and have a combined mass M_c, as shown in the figure. Initially, the cart moves to the right with speed v_0 with respect to the ground, while the ball is at rest with respect to the cart. The ball then slides down to the bottom of the bowl. When it reaches the bottom of the bowl, it moves with velocity v_b with respect to the cart. At this instant, how fast is the cart moving with respect to the ground?



(A) $v_0 - v_b$

(B) $v_0 - \dfrac{m}{M_c}v_b$

(C) $\dfrac{M_c v_0 - m v_b}{M_c + m}$

(D) $\dfrac{(m + M_c)v_0 - m v_b}{m + M_c}$

(E) The answer depends on the coefficient of friction between the ball and bowl.

11. Consider a flat uniform square of mass M and side length L. Cut a circle out of the square that has a diameter equal to the length of the side of the square, with the same center as the square. Determine the moment of inertia of the remaining shape about an axis through the center and perpendicular to the plane of the square.

(A) $\left(\frac{1}{6} - \frac{\pi}{32}\right) ML^2$

(B) $\left(\frac{1}{12} - \frac{\pi}{64}\right) ML^2$

(C) $\left(\frac{\pi}{24} - \frac{1}{3\pi}\right) ML^2$

(D) $\left(\frac{1}{2\pi} - \frac{1}{16}\right) ML^2$

(E) $\left(\frac{1}{2\pi} - \frac{1}{8}\right) ML^2$

12. Two planets A and B have masses $m_A = 2m_B$. They orbit a star in circular orbits of radius $r_A = 3r_B$. Let E_i and L_i be the kinetic energy and the magnitude of the angular momentum of planet i, respectively. Which of the following is true?

(A) $E_A > E_B$ and $L_A > L_B$

(B) $E_A > E_B$ and $L_A < L_B$

(C) $E_A < E_B$ and $L_A > L_B$

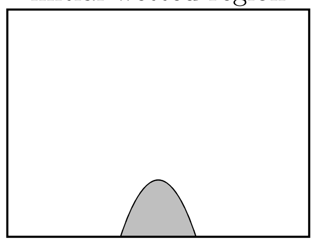
(D) $E_A < E_B$ and $L_A < L_B$

(E) $E_A = E_B$ and $L_A > L_B$

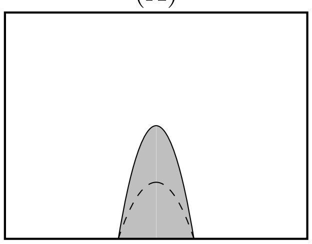
13. A water hose is at ground level against the base of a large wall. By aiming the hose at some angle, and squirting water at a speed v, one wets a region on the wall, as shown below. If the speed of the water is doubled, what is the new region that can be wetted? Ignore the effect of water splashing beyond the point of contact.

In the answer choices, the dotted line marks the initial wetted region.

initial wetted region

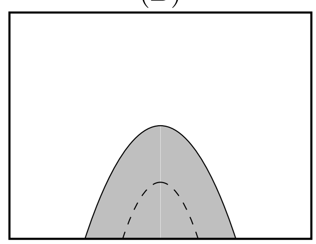


(A)



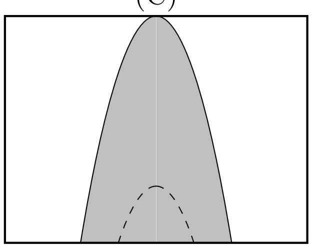
double height, same width

(B)



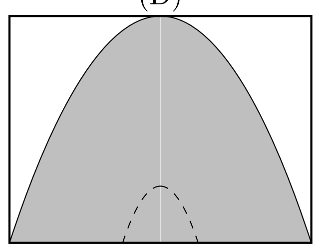
double height, double width

(C)



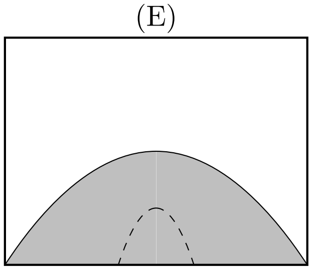
four times height, double width

(D)



four times height, four times width

(E)



double height, four times width

14. A ball is launched at speed v at angle θ above the horizontal toward a vertical wall a distance L away. It bounces elastically off the wall and falls back to its launch point. What was its initial speed?

    (A) $\dfrac{\sqrt{Lg}}{\tan\theta}$

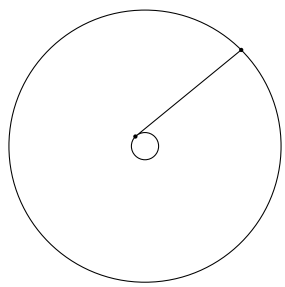
    (B) $\dfrac{\sqrt{Lg}}{\sqrt{\tan\theta}}$

    (C) $\dfrac{\sqrt{Lg}}{\sin\theta}$

    (D) $\dfrac{\sqrt{Lg}}{\sqrt{\sin\theta}}$

    (E) $\dfrac{\sqrt{2Lg}}{\sqrt{\sin 2\theta}}$

15. A mass of $M = 100$ g is attached to the end of a string of length $R = 2$ m. A person swings the mass overhead such that their hand traverses a circle of radius $r = 3$ cm at angular velocity $\omega = 10$ rad/s, ahead of the mass M by an angle of $\pi/2$. Estimate the force of air resistance on the object.



    (A) 0.02 N
    (B) 0.03 N
    (C) 0.2 N
    (D) 0.3 N
    (E) 2 N

The following information applies to 16 and 17.

A hoop of radius r is launched to the right at initial speed v_0 at ground-level. As it is launched, it is also spun counterclockwise at angular velocity $3v_0/r$. The coefficient of kinetic friction between the ground and the hoop is μ_k.

16. How long does it take the hoop to return to its starting position?

    (A) $\dfrac{v_0}{2\mu_k g}$

    (B) $\dfrac{2v_0}{\mu_k g}$

    (C) $\dfrac{\mu_k v_0}{2g}$

    (D) $\dfrac{\mu_k v_0}{g}$

    (E) $\dfrac{2\mu_k v_0}{g}$

17. Would the answer to the previous question, namely the amount of time to return to the starting position, be the same for a uniform disk with the same coefficient of friction launched with the same initial conditions?

    (A) Yes.

    (B) No, because the torque due to friction is larger for the hoop.

    (C) No, because the disk never returns to its starting position.

    (D) No, because the disk stops slipping too soon.

    (E) There is not enough information to decide.

18. You are predicting the time for a car to complete a race. The car begins with an initial speed v_0 and maintains a constant acceleration a throughout the race. Both v_0 and a have independent uncertainties of 10%. Which contributes greater uncertainty to your estimate of the time for the car to complete the race?

    (A) The uncertainty in v_0 for sufficiently short races and the uncertainty in a for sufficiently long races.

    (B) The uncertainty in v_0 for sufficiently long races and the uncertainty in a for sufficiently short races.

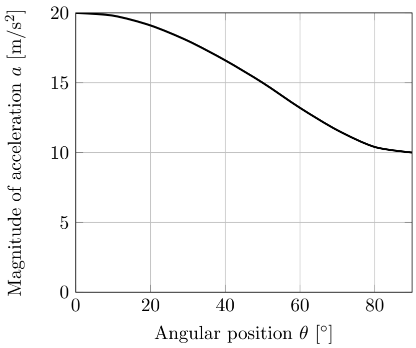
    (C) The uncertainty in v_0.

    (D) The uncertainty in a.

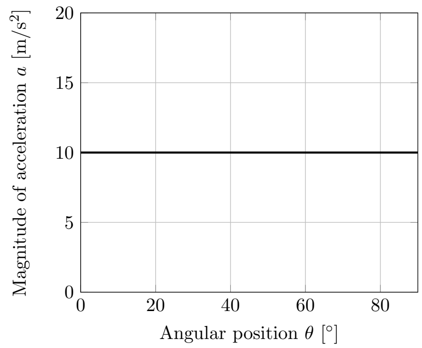
    (E) They contribute equally in the uncertainty.

19. A physical pendulum consists of a mass on one end of a massless rigid rod that can pivot about the opposite end. Assuming the oscillations have an amplitude of 90°, which of the following graphs best shows the total acceleration of the mass as a function of the angular position θ, measured between the pendulum and the vertical direction?

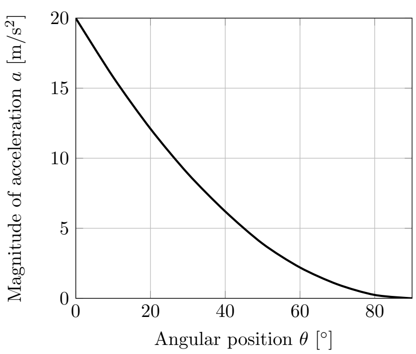
(A)



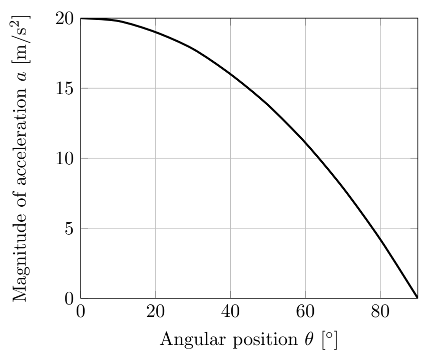
(B)



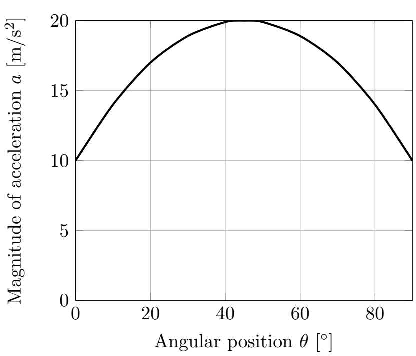
(C)



(D)

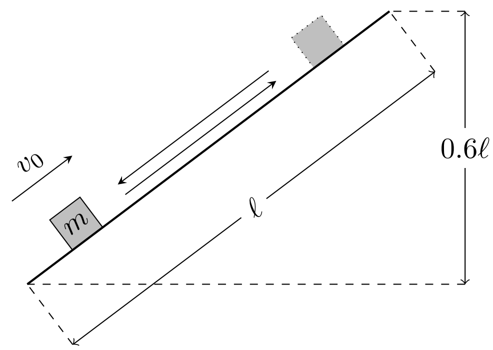


(E)



20. A block on a ramp is given an initial velocity v_0 upward along the ramp. It slides upward for a time t_u, traveling some distance, and then slides downward for a time t_d until it returns to its original position. What is t_d in terms of t_u?

    The height of the incline is 0.6 times its length and the coefficient of kinetic friction between the block and the incline is 0.5.



    (A) $t_0/5$
    (B) $t_0/\sqrt{5}$
    (C) $\sqrt{5}t_0$
    (D) $2t_0$
    (E) $5t_0$

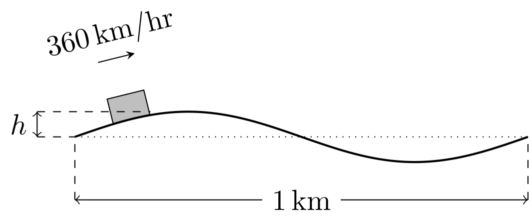
21. An empty freight car on a level railroad track has a mass M. A chute above the freight car opens and grain falls down into the car at a rate of r, measured in kilograms per second. The grain falls a vertical distance h before hitting the bed of the freight car without bouncing up. How much normal force is exerted on the freight car from the rails at a time t after the grain begins to hit the bed of the car? Assume the grain starts from rest.

    (A) $Mg + rtg$
    (B) $Mg + r\sqrt{gh}$
    (C) $Mg + r\sqrt{2gh}$
    (D) $Mg + r\sqrt{gh} + rtg$
    (E) $Mg + r\sqrt{2gh} + rtg$

22. The bruise threshold for a fruit is the largest height it can be dropped from rest without bruising. The bruise threshold of a 0.2 kg apple on steel is 10 cm. Suppose that it always takes 0.1 seconds after impact for the apple to fully stop and that 4 cm^2 of the apple comes into contact with the surface during the impact. What minimum average pressure is required to cause the apple to bruise?

    (A) 67 Pa
    (B) 210 Pa
    (C) 7100 Pa
    (D) 23 000 Pa
    (E) 67 000 Pa

23. A train travels at 360 km/hr on an almost straight track. The track is slightly sinusoidal, with a vertical amplitude of h over a 1 km distance, as shown in the figure. If the maximum tolerable vertical acceleration of the train is set at 0.1 m/s^2, what is the maximum allowable size of h?



(A) 12.5 cm
(B) 25 cm
(C) 50 cm
(D) 100 cm
(E) 1000 cm

24. A uniform rope of length L and mass M passes over a frictionless pulley, and hangs with both ends at equal heights. If one end is pulled down a distance x and the rope is released, the acceleration of that end at this instant will be:

(A) $xg/4L$
(B) $xg/3L$
(C) $xg/2L$
(D) xg/L
(E) $2xg/L$

25. A student makes an estimate of the acceleration due to gravity, g, by dropping a rock from a known height h and measuring the time, t, it takes to hit the ground. Neglecting air resistance, which one of the following situations will lead to the smallest value of the relative uncertainty, $(\Delta g)/g$, in the estimate?

(A) There is no uncertainty in t, and h has a 10% uncertainty.
(B) There is no uncertainty in h, and t has a 10% uncertainty.
(C) Both t and h have a 5% uncertainty.
(D) (A) and (B) yield the same uncertainty, which is smaller than in (C).
(E) (A), (B), and (C) all yield the same uncertainty.