AAPT UNITED STATES PHYSICS TEAM
AIP 2026

# 2026 $F = ma$ Exam

25 QUESTIONS - 75 MINUTES

## INSTRUCTIONS

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

- Use $g = 10$ N/kg throughout, unless otherwise specified.
- You may write in this question booklet and the scratch paper provided by the proctor.
- This test has 25 multiple choice questions. Select the best response to each question, and use a No.2 pencil to completely fill the box corresponding to your choice. If you change an answer, completely erase the previous mark. Only use the boxes numbered 1 through 25 on the answer sheet.
- All questions are equally weighted, but are not necessarily equally difficult.
- You will receive one point for each correct answer, and zero points for each incorrect or blank answer. There is no additional penalty for incorrect answers.
- You may use a hand-held calculator. 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 external references, such as books or formula sheets.
- The question booklet, answer sheet and scratch paper will be collected at the end of this exam.
- **To maintain exam security, do not communicate any information about the questions or their solutions until after February 13, 2026.**

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

We acknowledge The US Physics Team coaches and other contributors to this year's exams:

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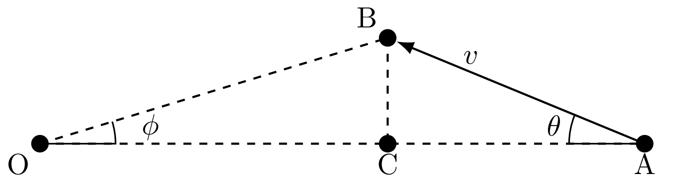
1. In astronomy, some galactic objects appear to sweep across the sky faster than light speed, $c$. This effect, called superluminal motion, comes purely from geometry and the finite travel time of light, and it has nothing to do with special relativity.

A jet moves from point $A$ to $B$ at speed $v = \beta c$. The jet emits a pulse of light at $A$, and a second pulse a time $\delta t$ later at $B$. An observer sees these pulses at point $O$. The angle between the jet and the line of sight is $\theta$. Assume the angle $\phi$ is small, so the distances from $O$ to points $B$ and $C$ can be treated as equal.




Find the apparent transverse velocity, $v_T$, along $CB$ as measured by the observer, in terms of $\beta$ and $\theta$. Express your answer as $\beta_T \equiv \frac{v_T}{c}$

(A) $\beta_T = \frac{\beta \sin\theta}{1-\beta\cos\theta}$

(B) $\beta_T = \beta \sin\theta(1 - \beta\cos\theta)$

(C) $\beta_T = \frac{\beta \sin\theta}{1+\beta\cos\theta}$

(D) $\beta_T = \frac{\beta \sin\theta}{\sqrt{1-\beta^2}}$

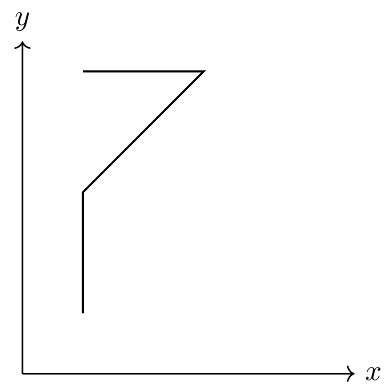
(E) $\beta_T = \beta \tan\theta$

2. A series of dominoes are stood upright in a line. The dominoes have mass density $\rho$, height $h$, and spacing $d$ between them. When the first domino is knocked over, a wave of falling dominoes propagates down the line with speed $v$.

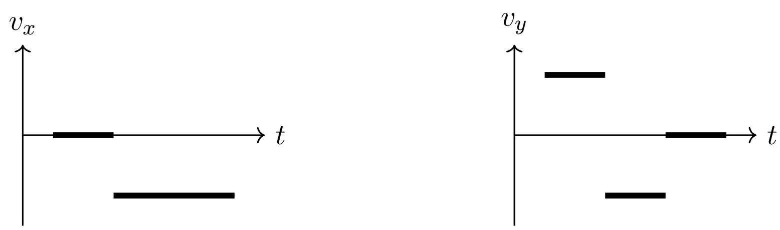
   Now, a second set of dominoes is set up identically, but with all dimensions ($h$ and $d$) scaled by $\lambda$. The mass density is the same. Let $v'$ denote the wave speed of the scaled system. Which of the following best describes how $v'$ depends on $\lambda$?

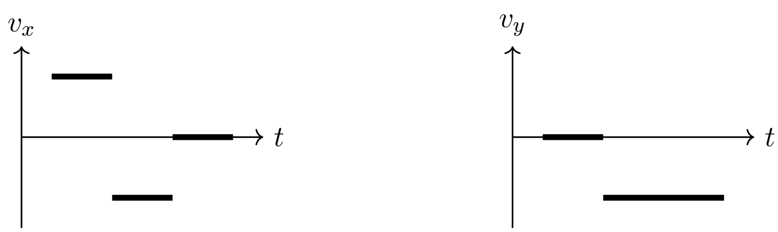
   (A) $v' \sim \frac{1}{\sqrt{\lambda}}$
   (B) $v' \sim \lambda$
   (C) $v' \sim \frac{1}{\lambda}$
   (D) $v' \sim \sqrt{\lambda}$
   (E) $v'$ is independent of $\lambda$

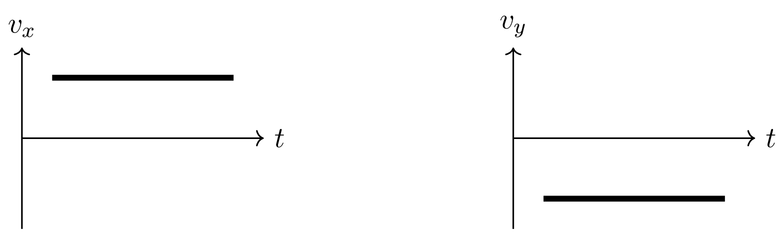
3. A point moves in the $xy$ plane, and its trajectory is shown in the figure below.

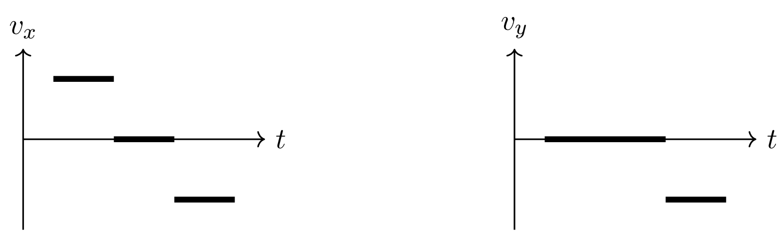


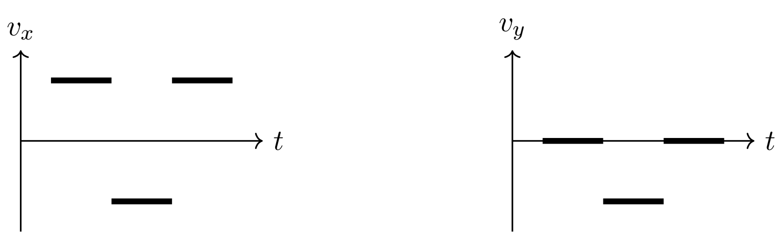

One of the following *pairs* of graphs shows the time dependence of $v_x$ and $v_y$ for this motion. Select the correct pair.

(A)



(B)



(C)



(D)



(E)


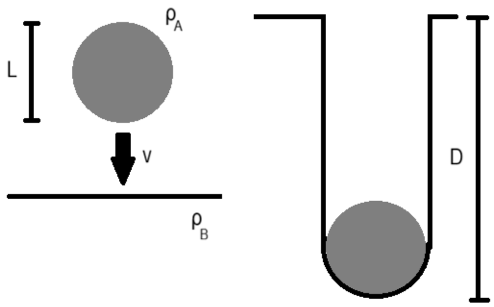
4. Two small balls are launched simultaneously from the same point at some height above horizontal ground. One ball is launched vertically upward with speed $3\,\text{m/s}$, while the other is launched horizontally with speed $4\,\text{m/s}$ and lands on the ground at a horizontal distance of $20\,\text{m}$ from the launch point. Neglect air resistance. At the moment the second ball lands, how far is it from the first ball?

(A) 25 m (B) 36 m (C) 60 m (D) 80 m (E) 240 m

5. A helicopter flies at constant height $h$ along a *circular* trajectory of radius $R$ with constant angular velocity $\omega$, continuously dropping sand. Ignore air resistance. What is the radius of the curve traced by the sand on the ground?

(A) $R$ (B) $R\sqrt{1+h^2}$ (C) $R\sqrt{1+2h^2}$ (D) $R\sqrt{1+\frac{h\omega^2}{g}}$ (E) $R\sqrt{1+\frac{2h\omega^2}{g}}$

6. Newton's Impact Depth Approximation provides an estimate on how far a projectile will penetrate a material at high speeds. If a projectile of length $L$ and density $\rho_A$ impacts a wall of density $\rho_B$, Newton's approximation states that the projectile will penetrate to a depth of $D = L\frac{\rho_A}{\rho_B}$. Assuming this is true for all velocities, how does the average force the wall exerts on the projectile $F$ scale with the initial projectile speed $v$?




(A) $F \propto v^{1/2}$ (B) $F \propto v$ (C) $F \propto v^{3/2}$ (D) $F \propto v^2$ (E) $F \propto v^{5/2}$

7. The James Webb telescope lies at a point called the Lagrange Point 2 or L2. This is a point where the telescope would remain stationary in a frame rotating with Earth's orbit around the sun, so a telescope placed exactly at L2 would be in an equilibrium position relative to Earth's orbit. What is the stability of this equilibrium point with respect to radial and tangential perturbations?


(A) Stable to both radial and tangential perturbations.

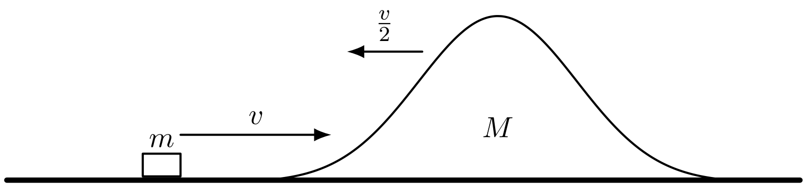
(B) Stable to radial perturbations. Unstable to tangential perturbations.

(C) Stable to tangential perturbations. Unstable to radial perturbations.

(D) Unstable to both radial and tangential perturbations.

(E) None of the listed. L2 is not a real equilibrium point because the centrifugal force is a fictitious force.

8. A puck of mass $m$ moves with speed $v$ toward a heavy bump of mass $M$, where $M \gg m$. Both the puck and the bump slide without friction. The bump moves toward the puck with speed $\frac{v}{2}$ and provides a smooth transition from the horizontal surface onto the bump. The bump is tall enough that the puck slides back down. Find the maximum height $h$ the puck reaches.




(A) $\frac{v^2}{2g}$ (B) $\frac{9v^2}{8g}$ (C) $\frac{3v^2}{8g}$ (D) $\frac{7v^2}{4g}$ (E) $\frac{3v^2}{4g}$

9. A vertical cylindrical pipe with a sealed bottom contains no air and is tall enough that its top is open to outer space (no atmosphere). A heavy plate is mounted at the bottom of the cylinder and vibrates vertically. A small ball inside the pipe undergoes elastic collisions with the plate.

The plate vibrates in such a way that, during each collision, it is moving upward with a constant speed equal to $\frac{v}{1000}$, where $v$ is the orbital speed at zero altitude above the Earth. The plate moves downward sufficiently fast that the ball collides with the plate only while the plate is moving upward. The ball is initially dropped from rest from a height equal to the Earth's radius above the plate.

After how many collisions with the plate will the ball escape the Earth's gravitational field?

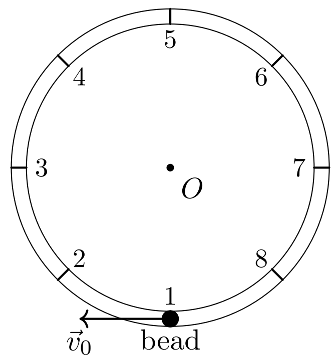
(A) 207 (B) 208 (C) 414 (D) 415 (E) 1000

10. Consider the following three solid objects, each of mass $M$ and uniform density:
(i) a half-ball of radius $a$;
(ii) a cylinder of radius $a$ and height $a$;
(iii) a cylinder of radius $a$ and height $2a$.

For each object, consider the gravitational acceleration at the center of its flat circular face. Let $g_{\text{ball}}$, $g_a$, and $g_{2a}$ denote these accelerations for the half-ball, the cylinder of height $a$, and the cylinder of height $2a$, respectively. Which of the following is correct?

(A) $g_a > g_{\text{ball}} > g_{2a}$
(B) $g_{\text{ball}} > g_{2a} > g_a$
(C) $g_{\text{ball}} > g_a > g_{2a}$
(D) $g_{2a} > g_{\text{ball}} > g_a$
(E) $g_{2a} > g_a > g_{\text{ball}}$

11. A circular track of mass $m$ lies flat horizontally on a frictionless table and is free to move on it. A bead also of mass $m$ can slide without friction on the track. The track is initially at rest, and it is labeled every 45° with tick marks. The bead is placed on tick 1 and is given an initial velocity $\vec{v}_0$ tangential to the track as shown below.




What is the speed of the track's center $O$ when the bead reaches tick 3?

(A) $v_0$ (B) $\frac{v_0}{2}$ (C) $\frac{\sqrt{3}v_0}{2}$ (D) $\frac{v_0}{\sqrt{2}}$ (E) $\frac{v_0}{2\sqrt{2}}$

12. A wake surfer of total mass $M$ (surfer plus board) is being towed at a constant horizontal velocity $v$ across a flat lake. The wakeboard has a specific geometry such that, at this speed, it is partially submerged and provides a static buoyant force $F_B$ (where $F_B < Mg$).

To support the remainder of the weight, the board moves with an angle of attack $\theta$ relative to the horizontal water surface. Assume that the water exerts a reaction force strictly normal to the bottom surface of the board. Which of the following expressions represents the horizontal tension $T$ in the tow rope required to maintain this constant velocity?

(A) $T = Mg \tan\theta$ (B) $T = (Mg - F_B)\tan\theta$ (C) $T = (Mg - F_B)\sin\theta$
(D) $T = Mg \sin\theta$ (E) $T = F_B \cos\theta$

13. A block of mass $m$ slides along a surface with a coefficient of kinetic friction $\mu_k$. The block is confined to move between two walls separated by a distance $L$. Attached to each wall is an ideal, perfectly elastic spring with a very large force constant $k$.

The block is launched from the midpoint between the walls with an initial speed $v_0$ directed toward one of the springs. It bounces back and forth between the springs, losing speed only due to friction with the surface.

Assume the time spent in contact with the springs is negligible compared to the travel time between them. Which of the following expressions correctly gives the total time $T$ required for the block to come to a permanent rest?

(A) $T = \frac{v_0}{2\mu_k g L}$

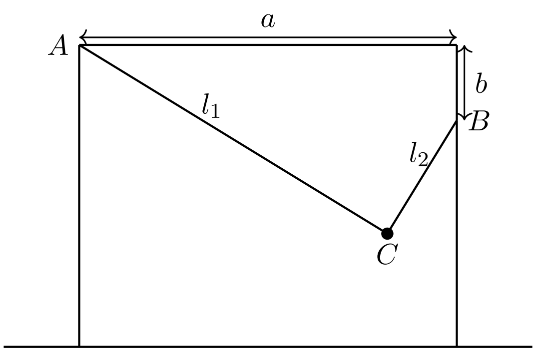
(B) $T = \frac{v_0}{\mu_k g}\left(1 - e^{-\frac{\mu_k g}{v_0}}\right)$

(C) $T = \frac{v_0}{\mu_k g}$

(D) $T = \frac{v_o}{\mu_k g L}\sum_{n=0}^{\infty}\left(\frac{1}{2}\right)^n$

(E) $T = \sqrt{\frac{2L}{\mu_k g}}$

14. In the following swing, all lines are rigid rods and their lengths satisfy the relation $l_1^2 + l_2^2 = a^2 + b^2$. What is the period of small oscillation of the mass at point C?




(A) $2\pi\sqrt{\frac{l_1^2+l_2^2}{ga}}$ (B) $2\pi\sqrt{\frac{l_1 l_2}{ga}}$ (C) $2\pi\sqrt{\frac{l_1 l_2}{g\sqrt{a^2+b^2}}}$ (D) $2\pi\sqrt{\frac{a l_1 l_2}{g(l_1^2+l_2^2)}}$ (E) $2\pi\sqrt{\frac{b l_1 l_2}{g(l_1^2+l_2^2)}}$

15. A ball launcher fires balls along the floor at some initial speed, applying no rotation to them. The balls initially slip along the floor, then start rolling without slipping. Ignore the potential deformation of the ball and flooring during this process, as well as air resistance. How does the final speed of the rolling ball depend on the coefficient of friction $\mu$ between the ball and the floor?

(A) The final speed is larger when $\mu$ is large

(B) The final speed is the same regardless of $\mu$

(C) The final speed is larger when $\mu$ is small

(D) The final speed is larger when $\mu$ is small for high launch speeds, and when $\mu$ is large for low launch speeds

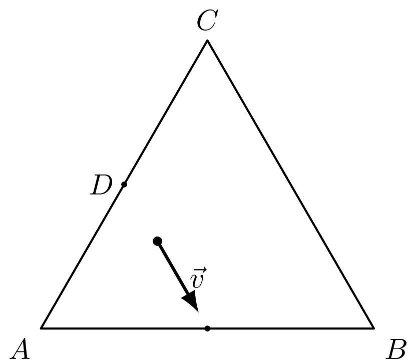
(E) The final speed is larger when $\mu$ is large for high launch speeds, and when $\mu$ is small for low launch speeds

16. A small puck of mass $m$ slides without friction inside a rigid, uniform *triangle rack* of mass $5m$, whose inner boundary is an equilateral triangle $ABC$. The rack is initially at rest and can move freely on a frictionless horizontal table. All collisions between the puck and the rack are perfectly elastic.

At some instant, the puck strikes the midpoint of side $AB$ from inside the rack. Just before this collision, the puck's velocity is parallel to side $BC$.

After the collision at the midpoint of $AB$, the puck collides with the rack again, and then collides once more. At which part of the triangle does this second collision after the initial one occur?

(Some answer choices refer to the midpoint $D$ of side $AC$.)




(A) a point in the interior of segment $AB$

(B) a point in the interior of segment $BC$

(C) a point in the interior of segment $AD$

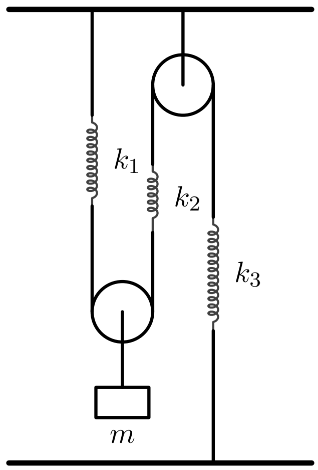
(D) a point in the interior of segment $DC$

(E) the point $D$

17. A ladder is leaning against a vertical wall. The ladder is a uniform rod of mass $M$ and length $L$, and both the wall and the ground are frictionless. The ladder is released from rest from an almost-vertical position and begins to slide. What is the speed of the point of the ladder that is in contact with the floor when it is a horizontal distance $\frac{\sqrt{3}L}{2}$ away from the wall?

(A) $0.46\sqrt{gL}$ (B) $0.51\sqrt{gL}$ (C) $0.56\sqrt{gL}$ (D) $0.61\sqrt{gL}$ (E) $0.66\sqrt{gL}$

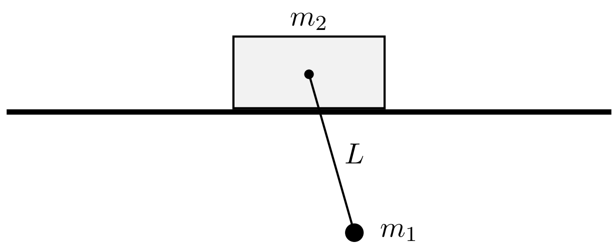
18. Three springs and a block of mass $m$ are connected as shown in the figure below. The spring constants are $k_1 = k$, $k_2 = k/5$, and $k_3 = k/3$. All pulleys and ropes are massless, and there is no friction anywhere in the system. Find the ratio of the period of oscillations of this system, $T$, to the period $T_0$ of a simple mass–spring system with mass $m$ and spring constant $k$. The value of $\dfrac{T}{T_0}$ is:




The value of $\frac{T}{T_0}$ is:

(A) $\frac{2}{3}$ (B) $\frac{3}{2}$ (C) $\frac{\sqrt{2}}{\sqrt{3}}$ (D) $\frac{\sqrt{7}}{6}$ (E) $\frac{\sqrt{6}}{7}$

19. A point mass $m_1$ is attached to a box of mass $m_2$ by a massless, inextensible rope of fixed length $L$, attached to the *center* of the box. The box can slide without friction on a horizontal surface. The mass $m_1$ swings freely under gravity, and *all motion occurs in the plane of the picture.* Neglect air resistance. Find the angular frequency $\omega$ of small oscillations about the stable equilibrium.




In case you need the small-angle approximation, you may use

$$\cos\theta = 1 - \frac{1}{2}\theta^2 + \cdots, \qquad \sin\theta = \theta - \frac{1}{6}\theta^3 + \cdots.$$

(A) $\omega = \sqrt{\frac{m_1 + m_2}{m_2}\frac{g}{L}}$

(B) $\omega = \sqrt{\frac{m_1 + m_2}{m_1}\frac{g}{L}}$

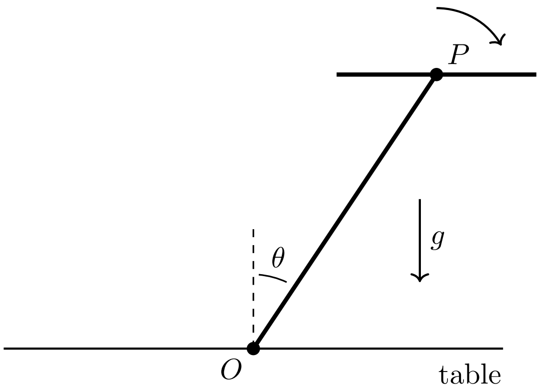
(C) $\omega = \sqrt{\frac{m_1}{m_1 + m_2}\frac{g}{L}}$

(D) $\omega = \sqrt{\frac{m_2}{m_1 + m_2}\frac{g}{L}}$

(E) $\omega = \sqrt{\frac{g}{L}}$

20. Two uniform rigid rods lie in a vertical plane. The lower rod rests on a rough horizontal table at a single point $O$ and makes angle $\theta \neq 0$ with the vertical. The rod can pivot about point $O$ without slipping.

The second rod is rigidly attached at its center of mass to the top of the lower rod at point $P$. A motor causes the second rod to rotate in the plane about $P$. The motor is rigidly attached to the lower rod and does not exert forces or torques on the table.




Which of the following types of motion of the second rod could keep the angle $\theta$ fixed in time?

(A) The second rod rotates with constant angular velocity

(B) The second rod rotates with angular velocity that varies periodically in time

(C) The system cannot remain at constant $\theta$ because only internal torques are produced by the motor

(D) The second rod rotates with angular velocity that increases linearly in time

(E) $\theta$ changes because the moment of inertia of the second rod about point $O$ varies during the motion

21. A student stands on a large horizontal merry-go-round ($R = 2.0\,\text{m}$) at an initial radius of $r_0 = 1.0\,\text{m}$. Both rotate at constant angular speed $\omega = 1.2$ rad/s. The student wants to get off without walking and performs a sequence of identical vertical jumps of height $h = 0.31\,\text{m}$. Ignore air resistance.

    What is the minimum number of jumps needed for the student to land off the platform? You may assume that the merry-go-round is much more massive than the student and that friction instantly brings the student back into co-rotation with the platform.

    (A) 3

    (B) 4

    (C) 5

    (D) 6

    (E) It is impossible to move outward by purely vertical jumps

22. A tricycle of mass $m = 100\,\text{kg}$ is traveling north on a horizontal surface. The geometry of the tricycle is defined as follows:

- Wheelbase (distance from front axle to rear axle): $L = 1.0\,\text{m}$
- Rear track width (distance between rear wheels): $d = 1.0\,\text{m}$
- Center of mass (CM) location: on the longitudinal symmetry axis, a distance $b = 0.4\,\text{m}$ forward of the rear axle
- Radius of gyration about the CM: $k = 0.5\,\text{m}$

(The radius of gyration $k$ is defined by $I_{\text{CM}} = mk^2$, where $I_{\text{CM}}$ is the moment of inertia of the tricycle about a vertical axis through its center of mass.)

Seeing a patch of ice on their right side ahead, the rider panics and slams on the brakes. The front wheel and the left rear wheel slide on dry pavement with a coefficient of kinetic friction $\mu_k = 0.5$, while the right rear wheel slides on frictionless ice ($\mu = 0$).

This asymmetry in friction forces produces a net torque about the center of mass, causing the tricycle to begin rotating. Calculate the initial angular acceleration $\alpha$ of the tricycle.

(A) 3.0 rad/s$^2$, Counter-Clockwise

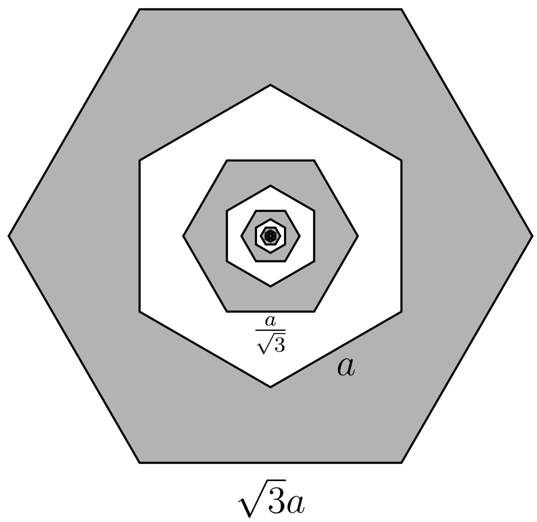
(B) 3.0 rad/s$^2$, Clockwise

(C) 3.3 rad/s$^2$, Counter-Clockwise

(D) 6.0 rad/s$^2$, Counter-Clockwise

(E) 3.3 rad/s$^2$ Clockwise

23. Consider the infinitely repeating hexagonal sequence where the largest hexagon has side length $\sqrt{3}a$ and is filled with mass. Inside it, a smaller hexagon of side length $a$ is rotated 30° clockwise and cut out. Then, an even smaller hexagon of side length $a/\sqrt{3}$ is rotated again by 30° clockwise and filled. This pattern continues infinitely. Let $I_1$ be the moment of inertia of this 2D figure about an axis through its center of mass, perpendicular to its plane and $I_2$ be the moment of inertia of a regular hexagon with side length $\sqrt{3}a$. What is $I_1/I_2$ equal to? ($\sum_{n=0}^{\infty} r^n = \frac{1}{1-r}$ for $|r| < 1$)

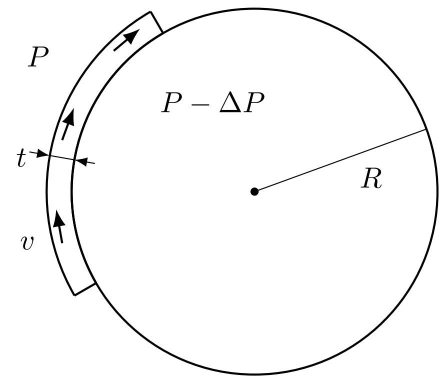



(A) $\frac{1}{4}$ (B) $\frac{2\sqrt{3}+3}{9\sqrt{3}+9}$ (C) $\frac{9}{10}$ (D) $\frac{3\sqrt{3}+6}{9\sqrt{3}+6}$ (E) none of the listed

24. A thin sheet of air with density $\rho$ is blown at a uniform speed $v$ toward a smooth, convex cylindrical surface of radius $R$. The sheet has uniform thickness $t \ll R$ and remains everywhere tangent to the cylinder while it stays attached. Neglect gravity and viscosity.

The pressure on the outer side of the air sheet is constant and equal to $P$. The pressure on the side adjacent to the cylinder is lower by an amount $\Delta P$. The air sheet follows the curvature of the cylinder until it can no longer remain attached.

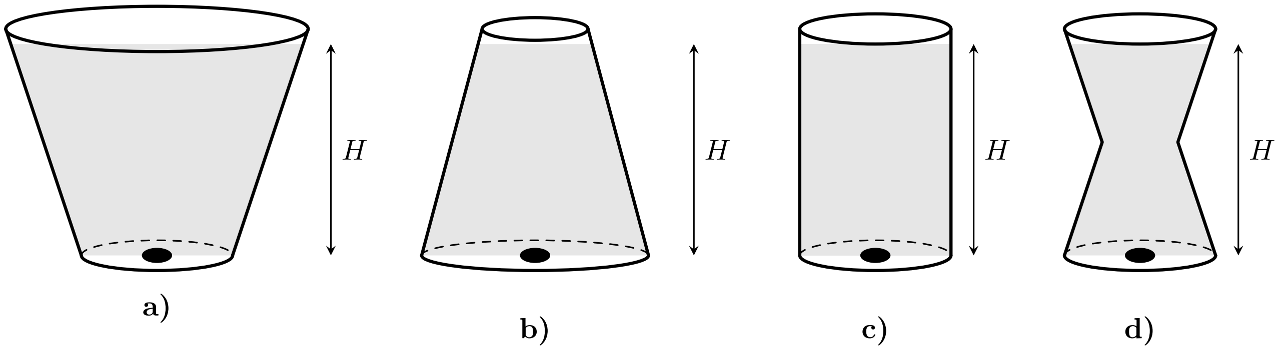
Given the parameters below, what is the *maximum integer speed* $v_{\text{max}}$ for which the sheet can remain attached to the surface?




$$\rho = 1.2 \text{ kg/m}^3, \qquad t = 5.0 \text{ mm}, \qquad R = 5.0 \text{ cm}, \qquad \Delta P_{\text{max}} = 120 \text{ Pa}.$$

(A) 8 m/s (B) 22 m/s (C) 31 m/s (D) 44 m/s (E) 60 m/s

25. The five vases below are filled with water to the same initial volume and initial height $H$. Each vase has an identical drainage hole at the bottom.




Which vase will drain completely in the shortest amount of time?

(A) Vase a
(B) Vase b
(C) Vase c
(D) Vase d
(E) All vases drain in the same amount of time.