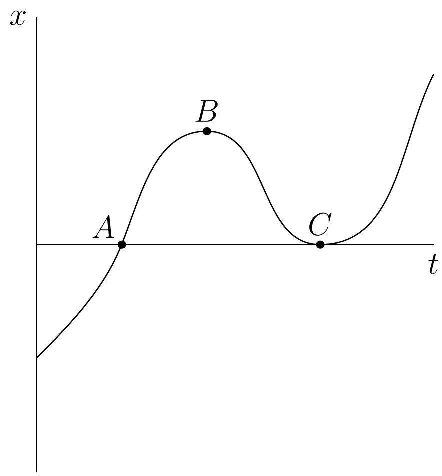
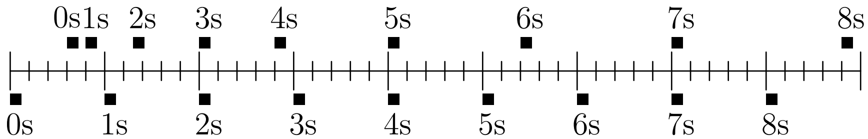
1. A particle moves in one dimension according to the position vs time plot shown below. At which point(s) is the velocity of the particle zero?



(A) A only
(B) B only
(C) C only
(D) A and C
(E) B and C

2. Two people are running. Their positions at different times are shown via boxes in the diagram below. Did the two runners ever have the same velocity?



(A) No
(B) Yes, at 7s
(C) Yes, around 4s.
(D) Yes, at 2s, 4s, and 7s.
(E) Yes, at 3s, 5s, and 7s.

3. A small insect flying at $3\ \text{m/s}$ hits the windshield of a large truck traveling at $30\ \text{m/s}$. If the average force from the windshield on the insect is $F_{w\to i}$ and the average force from the insect on the windshield is $F_{i\to w}$, then which is true of $\dfrac{|F_{i\to w}|}{|F_{w\to i}|}$?

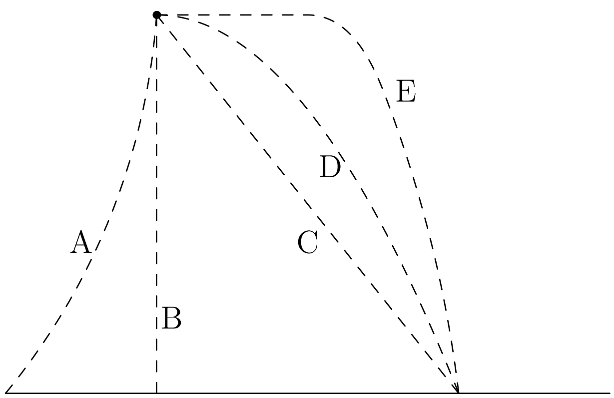
(A) $\dfrac{|F_{w\to i}|}{|F_{i\to w}|} > 1000$
(B) $1000 > \dfrac{|F_{w\to i}|}{|F_{i\to w}|} > 10$
(C) $10 > \dfrac{|F_{w\to i}|}{|F_{i\to w}|} > 1$

(D) $\dfrac{|F_{w\to i}|}{|F_{i\to w}|} = 1$
(E) $\dfrac{|F_{w\to i}|}{|F_{i\to w}|} < 1$

4. You can swim at velocity $\vec{v} = 2\ \mathrm{m/s}$ in still water. The water in a river flows at velocity $\vec{w} = 1\ \mathrm{m/s}$. When you swim in a river, your net velocity $\vec{u}$ relative to the shore is the vector sum of your velocity $\vec{v}$ relative to the water and the water flow velocity $\vec{w}$. You choose to swim in such a way that your net velocity $\vec{u}$ relative to the shore is perpendicular to the shore. At what speed do you move relative to the shore?

(A) $1\ \mathrm{m/s}$
(B) $1.41\ \mathrm{m/s}$
(C) $1.5\ \mathrm{m/s}$
(D) $1.73\ \mathrm{m/s}$
(E) $2\ \mathrm{m/s}$

5. An airplane is moving sideways in level flight. A ball is attached to the bottom of the airplane by a claw. The claw opens, releasing the ball without giving it a push. The ball falls from the airplane to the ground. Ignoring air resistance on the ball, which path below best illustrates the path of the ball as observed from someone stationary on the ground?



(A)
(B)
(C)
(D)
(E)

6. What are the dimensions of angular momentum?

(A) $\mathrm{MLT^{-1}}$
(B) $\mathrm{ML^2T^{-1}}$
(C) M
(D) $\mathrm{ML^2T^{-2}}$
(E) $\mathrm{L^2T^{-2}}$

7. A box of mass $3\ \mathrm{kg}$ sits on a floor with coefficient of kinetic friction $\mu = 0.2$. A force of $12\ \mathrm{N}$ is

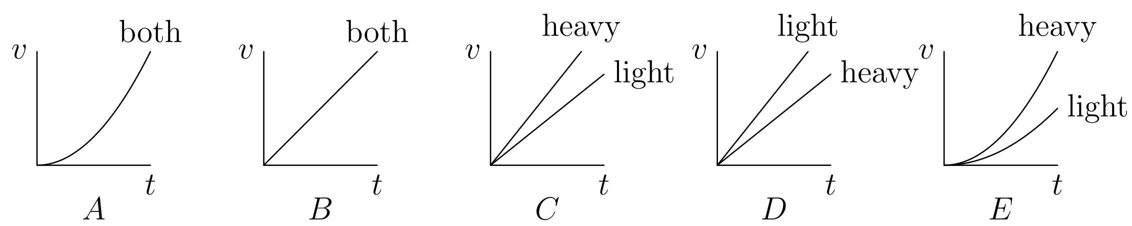
applied horizontally to the box. This force is large enough to overcome static friction. How long does it take the box to move $2\ \mathrm{m}$? Use $g = 10\ \mathrm{m/s^2}$.

(A) $1\ \mathrm{s}$
(B) $1.41\ \mathrm{s}$
(C) $1.88\ \mathrm{s}$
(D) $2\ \mathrm{s}$
(E) $4\ \mathrm{s}$

8. A star system has two planets. The first planet orbits once every 4.3 Earth years. The second planet is 3.3 times as far out from the star as the first planet. How long does it take to make an orbit?

(A) There isn't enough information to solve the problem.
(B) $4.3\ \mathrm{y}$
(C) $7.8\ \mathrm{y}$
(D) $14.2\ \mathrm{y}$
(E) $25.8\ \mathrm{y}$
(F) $46.8\ \mathrm{y}$

9. A heavy stone and a light stone are dropped at the same time from a balcony. Neglecting air resistance, which graph below shows the speed v vs. time t of the stones?



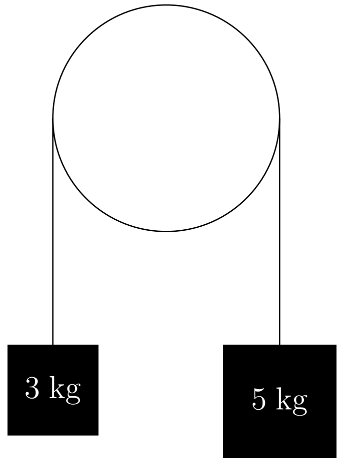
10. A mass on a spring obeying Hooke's law oscillates back and forth. A second identical mass on an identical spring oscillates with twice the amplitude. Compared to the first oscillator, the second oscillator...

(A) has twice the energy and oscillates with twice the frequency
(B) has four times the energy and oscillates with the same frequency
(C) has the same energy and oscillates with half the frequency
(D) has twice the energy and oscillates with the same frequency
(E) has the same energy and oscillates with four times the frequency

11. A ball of mass $5\ \mathrm{kg}$ moves to the right at $3\ \mathrm{m/s}$ until it collides with a stationary ball. After the collision, the balls stick and move together at speed $1\ \mathrm{m/s}$. What is the mass of the second ball?

(A) $5\ \mathrm{kg}$
(B) $10\ \mathrm{kg}$
(C) $15\ \mathrm{kg}$
(D) $1.67\ \mathrm{kg}$
(E) $125\ \mathrm{kg}$

12. What is the acceleration of the left mass in the Atwood machine shown?



(A) $0.6g$
(B) $0.4g$
(C) $0.25g$
(D) $0.625g$
(E) $0.375g$

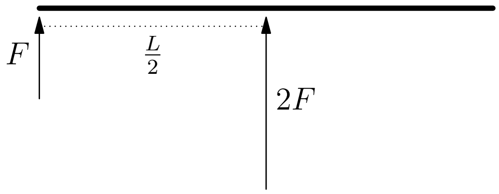
13. A box of mass $10\ \mathrm{kg}$ sits on a floor with coefficient of static friction $\mu = 0.25$. You attach a rope to the box and pull on the box at an angle 30° above the horizontal. What is the minimum tension in the rope for the box to move? Use $g = 10.0\ \mathrm{m/s^2}$.

(A) $25.0\ \mathrm{N}$
(B) $28.9\ \mathrm{N}$
(C) $50.0\ \mathrm{N}$
(D) $21.65\ \mathrm{N}$
(E) $25.2\ \mathrm{N}$

14. A ball is tied to the end of a string and swung in a circle at constant speed. A second identical ball is on an identical string, but is swung twice as fast. Gravity can be ignored for both balls. Compared the first ball, the second ball...

(A) experiences twice the net force and has twice the angular momentum.
(B) experiences four times the net force and has twice the angular momentum.
(C) experiences four times the net force and has four times the angular momentum.
(D) experiences the same force and has the same angular momentum.
(E) experiences twice the net force and has four times the angular momentum.

15. A board of length L sits stationary in deep space. A force F is applied to the left hand side of the board, at $x = 0$, as shown. A second force $2F$ is applied to the center of the board at $x = \frac{L}{2}$ as shown. At what x value can a third force be applied to the board so that it remains stationary?



(A) at $x = 0$
(B) at $x = \frac{1}{6}L$
(C) at $x = \frac{1}{3}L$
(D) at $x = \frac{1}{2}L$
(E) at $x = \frac{2}{3}L$
(F) at $x = L$

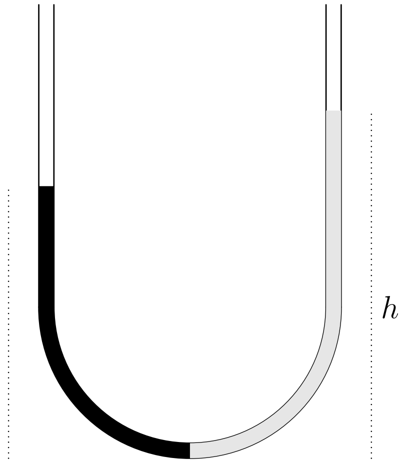
16. A disk rolls without slipping. The center of the disk moves at speed v. What is the speed of the point at the top of the disk?

    (A) 0
    (B) $v/2$
    (C) v
    (D) $2v$
    (E) $4v$

17. A cable on top of an elevator car pulls the elevator upward at a constant speed. All friction effects are negligible. In this situation, the forces on the elevator are such that

    (A) the upward force exerted by the cable is greater than the downward force of gravity.
    (B) the upward force exerted by the cable is equal to the downward force of gravity.
    (C) the upward force exerted by the cable is smaller than the downward force of gravity.
    (D) the upward force exerted by the cable is greater than the sum of the downward force of gravity and the downward force due to the air.
    (E) none of the above - the elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable.

18. A U-shaped tube contains liquid of density $2\ \mathrm{g/cm^3}$ on the left and $1\ \mathrm{g/cm^3}$ on the right. The fluids meet at the bottom of the tube. If the height of the fluid of density $1\ \mathrm{g/cm^3}$ is h, what is the height of the fluid of density $2\ \mathrm{g/cm^3}$?



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

19. Ball A, with mass $2m$, moves to the right at speed $2v$. It collides elastically with ball B, of mass m, moving left at speed v. What is the final speed of ball A?

(A) 0
(B) v
(C) $2v$
(D) $3v$
(E) $4v$

20. A object moving in one dimension experiences a force $f = -f_0 \frac{x}{|x|}$. Assume $f_0 > 0$. Describe the motion of the object.

(A) harmonic oscillation
(B) oscillation, but not harmonic
(C) oscillation when the initial velocity is sufficiently small only
(D) oscillation when the initial velocity is sufficiently large only
(E) motion in a straight line

Don't look at the next page until you've attempted all the problems!

The answers to Are You Ready for F=ma Problem Series are below.

Solution Scoring Guide:

- **15+ questions correct:** You are well-prepared for F=ma. We hope to see you in class!
- **9–14 questions correct:** You'll need to work extra diligently to keep up if you enroll in F=ma. Be sure to review the questions you got wrong, and read the appropriate sections of your textbook.
- **0–8 questions correct:** F=ma is probably not for you at this stage.

1. **(E)** B and C

   The velocity is slope of the position vs time graph, so the velocity is zero when the graph has slope zero. Slope zero means the graph is flat. This occurs at points $\boxed{\text{B and C}}$.

2. **(C)** Yes, around 4 s.

   Velocity is distance traveled per unit time, $v = \frac{\Delta x}{\Delta t}$. The gap in time Δt between successive boxes is always 1 s, so we want places where Δx is the same for the two runners. The runner depicted below the line always has about the same Δx, indicating that they run at constant speed. The runner above the line has increasing Δx, indicating they're running faster and faster. The Δx for the top runner is lower than that of the bottom runner before 4 s and higher after 4 s, so the top runner must have achieved the same speed some time near $\boxed{4\text{ s}}$.

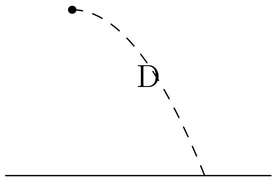
3. **(D)** $\frac{|F_{w\to i}|}{|F_{i\to w}|} = 1$

   By Newton's third law, the forces from the windshield on the insect and from the insect on the windshield are the same. Therefore their ratio is $\boxed{\text{equal to } 1}$.

4. **(D)** 1.73 m/s

   The vertical component of your velocity (the component in the direction against the current) must be 1 m/s, meaning $v\sin\theta = 1\text{ m/s}$, where θ is the angle between the direction you swim relative to the water and the direction you move relative to the shore. This implies $\sin\theta = \frac{1}{2}$ or $\theta = 30°$. Then the component of your velocity across the river is $v\cos\theta = \frac{\sqrt{3}}{2}v \approx \boxed{1.73\text{ m/s}}$.

5. **(D)**



   Initially, the ball is moving along with the airplane, so it has a large horizontal velocity. Because we ignore air resistance, the only force on the ball is a gravitational force downwards. This force tells us the change in the velocity of the ball - the ball's y-velocity increases in time. The result is a parabolic trajectory, choice $\boxed{\text{D}}$.

6. **(B)** $\mathrm{ML^2T^{-1}}$

   Angular momentum is $\vec{L} = \vec{p} \times \vec{r}$, with $\vec{p}$ the momentum and $\vec{r}$ the position. Momentum is $\vec{p} = m\vec{v}$. So $\vec{L} = m\vec{v} \times \vec{r}$. The dimensions of the mass m are mass, M. The dimensions of velocity $\vec{v}$ are length over time, $\frac{\mathrm{L}}{\mathrm{T}}$. The dimensions of position $\vec{r}$ are length, L. So the dimensions of angular momentum are $|\vec{L}| = \mathrm{M \cdot LT^{-1} \cdot L} = \boxed{\mathrm{ML^2T^{-1}}}$.

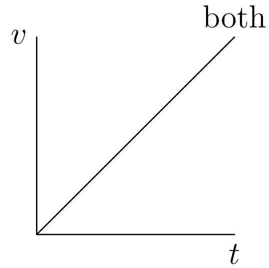
7. **(B)** $1.41\ \mathrm{s}$

   The gravitational force on the box is $30\ \mathrm{N}$. The friction force when the box is moving is therefore $\mu N = 6\ \mathrm{N}$. Then the net force on the box is $12\ \mathrm{N} - 6\ \mathrm{N} = 6\ \mathrm{N}$. This makes the acceleration of the box $a = \frac{F}{m} = 2\ \mathrm{m/s^2}$. The distance the box travels in a given time is $x = \frac{1}{2}at^2$, so $t = \sqrt{\frac{2x}{a}} = \sqrt{2}\ \mathrm{s} \approx \boxed{1.41\ \mathrm{s}}$.

8. **(E)** $25.8\ \mathrm{y}$

   Kepler's third law states that the period of an orbit scales as the $3/2$ power of the distance from the star. So $\frac{T_2}{T_1} = \left(\frac{R_2}{R_1}\right)^{3/2}$ where T_1 is the orbital period of the first planet and R_1 is the orbital radius of the first planet, etc. Putting in the numbers, we get $T_2 = 4.3\ \mathrm{y} \cdot (3.3)^{3/2} = \boxed{25.8\ \mathrm{y}}$.

9. **(B)**



   Gravity accelerates heavy and light objects with the same acceleration. Also, the acceleration due to gravity is constant, meaning the slope of a v vs t plot is constant. This leaves only choice $\boxed{B}$.

10. **(B)** has four times the energy and oscillates with the same frequency.

    The frequency of a harmonic oscillator is independent of the amplitude. However, the energy stored in a spring is $\frac{1}{2}kx^2$, so doubling the amplitude means the system has $\boxed{\text{four times the energy.}}$

11. **(B)** $10\ \mathrm{kg}$.

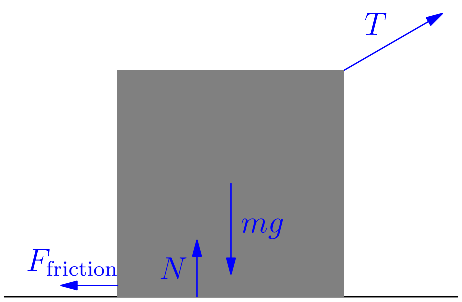
In the collision, the balls conserve momentum, $p = mv$. Because the speed of the balls is reduced by a factor of three in the collision, the mass of the two balls combined must be three times the mass of the first ball. That means the second ball has twice the mass of the first ball, or $\boxed{10 \text{ kg}}$.

12. **(C)** $0.25g$

The system would be balanced if the right mass had mass 3 kg. So there are 2 kg on the right hand side that are unbalanced. These two unbalanced kilograms accelerate 8 kg of mass, so the acceleration of the system is $\frac{2 \text{ kg}}{8 \text{ kg}} g = \boxed{0.25g}$.

13. **(E)** 25.2 N

There are four forces on the box: a tension force, a friction force, a normal force, and gravity.



The gravitational force on the box is mg The vertical component of tension pulls up on the box with a magnitude $T\sin(\theta)$ with θ the angle above the horizontal of the rope. Setting the net vertical force equal to zero, the normal force on the box is $mg - T\sin\theta$. The maximum friction force on the box is $\mu N = \mu(mg - T\sin\theta)$. This is equal to the minimum horizontal force to move the box, so $\mu(mg - T_m\sin\theta) = T_m\cos\theta$ where T_m is the minimum tension to move the box. Solving for T_m, we get $T_m = \frac{\mu mg}{\cos\theta + \mu\sin\theta}$. Putting in the given values, $\boxed{T_m = 25.2 \text{ N}}$.

14. **(B)** experiences four times the net force and has twice the angular momentum.

The acceleration of an object moving in a circle is $a = v^2/r$. Because the second string is identical, r is the same. The second ball moves twice as fast, so its acceleration, and therefore the $\boxed{\text{net force it experiences, is four times as great}}$. The angular momentum is $L = pr = mvr$. This is $\boxed{\text{twice as great for the second ball}}$.

15. **(C)** at $x = \frac{1}{3}L$

There must be no net force on the rod. This means the applied force must be magnitude $3F$ and point downward. There must also be no net torque on the rod. We can calculate the torque about any point, but let us choose the center of the rod for convenience. The force $2F$ does not exert torque about this point. The force F exerts a torque $F\frac{L}{2}$, so the second force must exert a torque of the same magnitude, so $3F \cdot d = F\frac{L}{2}$, where d is the distance between where the second force is applied and the center of the rod. Solving, $d = \frac{L}{6}$, which means $x = \frac{L}{2} - \frac{L}{6} = \boxed{\frac{L}{3}}$.

16. **(D)** $2v$

    Imagine moving alongside the disk at speed v. In this frame, the disk is simply spinning and not moving. The bottom of the disk must be moving at speed $-v$ to keep up with the ground, which is moving at speed $-v$. So the top of the disk, which moves the opposite direction, moves at speed v in this frame. Back in the original frame of the ground, the top of the disk moves at speed $v + v = \boxed{2v}$.

17. **(B)** the upward force exerted by the cable is equal to the downward force of gravity.

    Because the elevator is moving at constant speed, its acceleration is zero. This means the net force on the elevator is zero, so the upward force from the cable must be equal in magnitude to the downward force from gravity.

18. **(A)** $h/2$

    By Newton's third law, the two columns of fluid exert equal and opposite forces on each other at their interface. If the situation is static, the forces they exert are simply pressure forces, so the pressure must be the same between the two fluids at the bottom of the tube. That pressure is $P = P_0 + \rho g h$ where P_0, the atmospheric pressure, is the same on each side. Then because ρ is twice as much for the heavier fluid, h must be half as much. The answer is $\boxed{h/2}$.

19. **(A)** 0

    Analyze the situation in a reference frame moving to the right at speed v. In this frame, the initial speeds of the balls are v and $2v$ respectively, and the net momentum of the system of both balls is zero. In this reference frame, in order to conserve both momentum and energy, the balls simply reverse directions without changing speeds. So the final velocity of ball A is v in the frame, moving to the left. In the original frame, the final velocity of ball A is zero.

20. **(B)** oscillation, but not harmonic.

    As long as the x value does not change sign, the object experiences a constant force, so its motion is a parabola with acceleration pointed towards the origin. There is no escape velocity associated with parabolic motion; eventually the object will return to the origin. After passing through the origin, the object's acceleration will change directions to again point towards the origin. So the object oscillates, but because its motion is a series of partial parabolas pasted together instead of a sinusoidal oscillation, it is not harmonic oscillation.