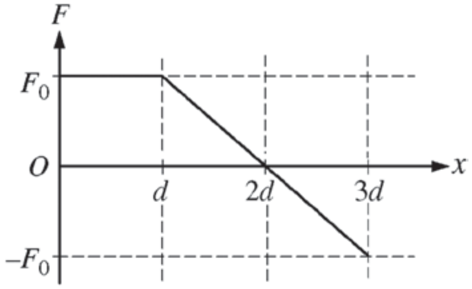
Sample Questions for the AP Physics 1 Exam

Multiple-Choice Questions

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

Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.



1. An object is moving in the positive *x*-direction while a net force directed along the *x*-axis is exerted on the object. The figure above shows the force as a function of position. What is the net work done on the object over the distance shown?

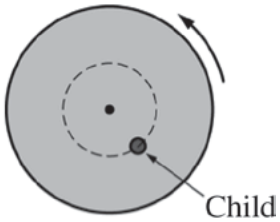
   (A) $F_0 d$

   (B) $3F_0 d/2$

   (C) $2F_0 d$

   (D) $4F_0 d$

Essential Knowledge	**5.B.5:** Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance. This process is called doing work on a system. The amount of energy transferred by this mechanical process is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system.
Learning Objectives	**5.B.5.3:** The student is able to predict and calculate from graphical data the energy transfer to or work done on an object or system from information about a force exerted on the object or system through a distance.
Science Practices	**1.4:** The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively. **2.2:** The student can *apply mathematical routines* to quantities that describe natural phenomena.



Top View

2. The diagram above shows a top view of a child of mass M on a circular platform of mass $2M$ that is rotating counterclockwise. Assume the platform rotates without friction. Which of the following describes an action by the child that will increase the angular speed of the platform-child system and gives the correct reason why?

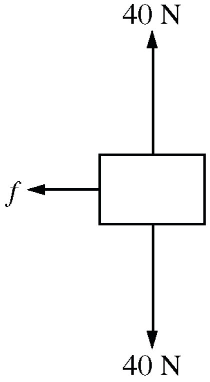
   (A) The child moves toward the center of the platform, increasing the total angular momentum of the system.

   (B) The child moves toward the center of the platform, decreasing the rotational inertia of the system.

   (C) The child moves away from the center of the platform, increasing the total angular momentum of the system.

   (D) The child moves away from the center of the platform, decreasing the rotational inertia of the system.

Essential Knowledge	**5.E.1:** If the net external torque exerted on the system is zero, the angular momentum of the system does not change.
Learning Objectives	**5.E.1.1:** The student is able to make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque.
Science Practices	**6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models.



3. The figure above shows the forces exerted on a block that is sliding on a horizontal surface: the gravitational force of 40 N, the 40 N normal force exerted by the surface, and a frictional force exerted to the left. The coefficient of friction between the block and the surface is 0.20. The acceleration of the block is most nearly

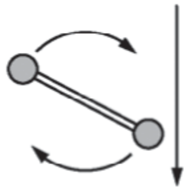
   (A) 1.0 m/s^2 to the right

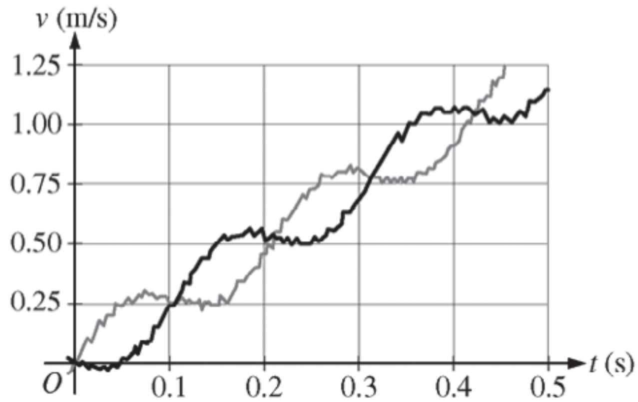
   (B) 1.0 m/s^2 to the left

   (C) 2.0 m/s^2 to the right

   (D) 2.0 m/s^2 to the left

Essential Knowledge	**2.B.1:** A gravitational field g at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field. **3.A.1:** An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. **3.B.1:** If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. **3.B.2:** Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.
Learning Objectives	**2.B.1.1:** The student is able to apply $\vec{F} = m\vec{g}$ to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems. **3.A.1.1:** The student is able to express the motion of an object using narrative, mathematical, and graphical representations. **3.B.1.3:** The student is able to reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. **3.B.2.1:** The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.
Science Practices	**1.4:** The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively. **1.5:** The student can *reexpress key elements of natural phenomena across multiple representations* in the domain. **2.2:** The student can *apply mathematical routines* to quantities that describe natural phenomena. **7.2:** The student can *connect concepts* in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.





4. A student on another planet has two identical spheres, each of mass 0.6 kg, attached to the ends of a rod of negligible mass. The student gives the assembly a rotation in the vertical plane and then releases it so it falls, as shown in the top figure above. Sensors record the vertical velocity of the two spheres, and the data is shown in the graph of velocity v as a function of time t. Another student wants to calculate the assembly's angular speed and the change in the linear momentum of the center of mass of the assembly between 0 s and 0.3 s. Which of these quantities can be determined using the graph?

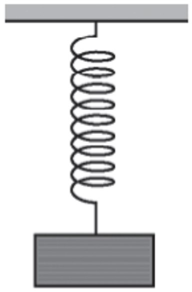
   (A) Angular speed only

   (B) Change in linear momentum only

   (C) Angular speed and change in linear momentum

   (D) Neither of these quantities can be determined using the graph.

Essential Knowledge	**3.F.2:** The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis. **4.B.1:** The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass.
Learning Objectives	**3.F.2.2:** The student is able to plan data collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis. **4.B.1.2:** The student is able to analyze data to find the change in linear momentum for a constant-mass system using the product of the mass and the change in velocity of the center of mass.
Science Practices	**5.1:** The student can *analyze data* to identify patterns or relationships.



5. A block of known mass hanging from an ideal spring of known spring constant is oscillating vertically. A motion detector records the position, velocity, and acceleration of the block as a function of time. Which of the following indicates the measured quantities that are sufficient to determine whether the net force exerted on the block equals the vector sum of the individual forces?

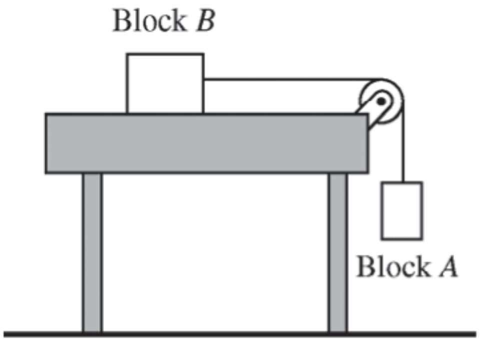
(A) Acceleration only

(B) Acceleration and position only

(C) Acceleration and velocity only

(D) Acceleration, position, and velocity

Essential Knowledge	**3.B.1:** If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. **3.B.3:** Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples should include gravitational force exerted by the Earth on a simple pendulum and mass-spring oscillator.
Learning Objectives	**3.B.1.2:** The student is able to design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces. **3.B.3.3:** The student can analyze data to identify qualitative or quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion to use that data to determine the value of an unknown.
Science Practices	**5.1:** The student can *analyze data* to identify patterns or relationships.



6. Block A hangs from a light string that passes over a light pulley and is attached to block B, which is on a level horizontal frictionless table, as shown above. Students are to determine the mass of block B from the motion of the two-block system after it is released from rest. They plan to measure the time block A takes to reach the floor. The students must also take which of the following measurements to determine the mass of block B?

   (A) Only the mass of block A

   (B) Only the distance block A falls to reach the floor

   (C) Only the mass of block A and the distance block A falls to reach the floor

   (D) The mass of block A, the distance block A falls to reach the floor, and the radius of the pulley

Essential Knowledge	**3.A.1:** An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. **4.A.2:** The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.
Learning Objectives	**3.A.1.2:** The student is able to design an experimental investigation of the motion of an object. **4.A.2.1:** The student is able to make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time.
Science Practices	**4.2:** The student can *design a plan* for collecting data to answer a particular scientific question. **6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models.

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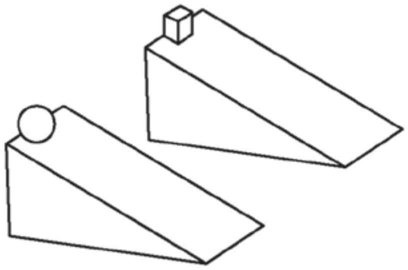


7. Two objects are released from rest at the top of ramps with the same dimensions, as shown in the figure above. The sphere rolls down one ramp without slipping. The small block slides down the other ramp without friction. Which object reaches the bottom of its ramp first, and why?

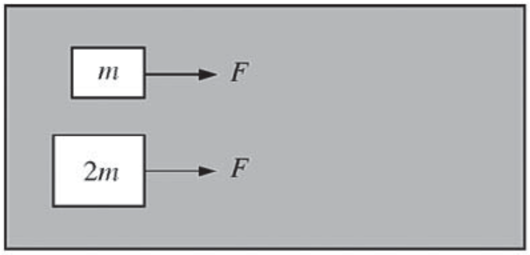
   (A) The sphere, because it gains rotational kinetic energy, but the block does not

   (B) The sphere, because it gains mechanical energy due to the torque exerted on it, but the block does not

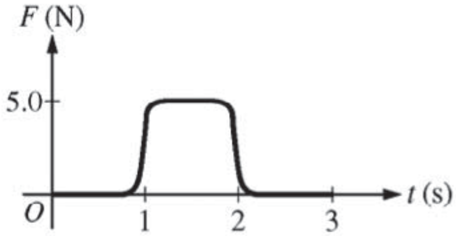
   (C) The block, because it does not lose mechanical energy due to friction, but the sphere does

   (D) The block, because it does not gain rotational kinetic energy, but the sphere does

Essential Knowledge	**5.B.4:** The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system. **5.B.5:** Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance. This process is called doing work on a system. The amount of energy transferred by this mechanical process is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system.
Learning Objectives	**5.B.4.2:** The student is able to calculate changes in kinetic energy and potential energy of a system using information from representations of that system. **5.B.5.4:** The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy).
Science Practices	**1.4:** The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively. **6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models.



Top View



8. Two blocks, of mass m and $2m$, are initially at rest on a horizontal frictionless surface. A force F is exerted individually on each block, as shown above. The graph shows how F varies with time t. Which block has the greatest average power provided to it between $t = 0$ s and $t = 3$ s?

(A) The block of mass m

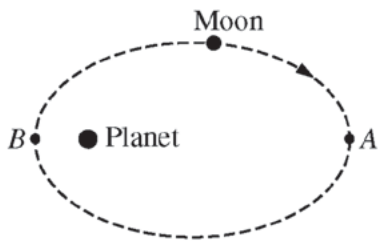
(B) The block of mass $2m$

(C) Both blocks have the same power provided to them.

(D) It cannot be determined without knowing the ratio of the maximum force to the mass m.

Essential Knowledge	**3.A.1:** An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. **3.E.1:** The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the time interval that the force is exerted. **5.B.5:** Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance. This process is called doing work on a system. The amount of energy transferred by this mechanical process is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system.
Learning Objectives	**3.A.1.1:** The student is able to express the motion of an object using narrative, mathematical, and graphical representations. **3.E.1.4:** The student is able to apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object. **5.B.5.3:** The student is able to predict and calculate from graphical data the energy transfer to or work done on an object or system from information about a force exerted on the object or system through a distance. **5.B.5.5:** The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance.

Science Practices	**1.4:** The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively. **1.5:** The student can *reexpress key elements of natural phenomena across multiple representations* in the domain. **2.2:** The student can *apply mathematical routines* to quantities that describe natural phenomena. **6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models.



9. A moon is in an elliptical orbit about a planet as shown above. At point A the moon has speed u_A and is at distance R_A from the planet. At point B the moon has speed u_B. Which of the following explains a correct method for determining the distance of the moon from the planet at point B in terms of the given quantities?

(A) Conservation of angular momentum, because the gravitational force exerted by the moon on the planet is the same as that exerted by the planet on the moon

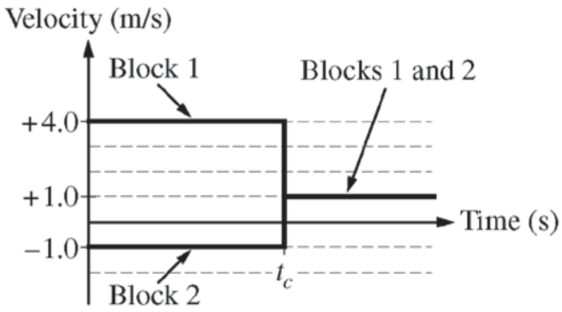
(B) Conservation of angular momentum, because the gravitational force exerted on the moon is always directed toward the planet

(C) Conservation of energy, because the gravitational force exerted on the moon is always directed toward the planet

(D) Conservation of energy, because the gravitational force exerted by the moon on the planet is the same as that exerted by the planet on the moon

Essential Knowledge	**5.B.5:** Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance. This process is called doing work on a system. The amount of energy transferred by this mechanical process is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. **5.E.1:** If the net external torque exerted on the system is zero, the angular momentum of the system does not change.
Learning Objectives	**5.B.5.4:** The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). **5.E.1.1:** The student is able to make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque.
Science Practices	**6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models. **7.2:** The student can *connect concepts* in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

Questions 10–12 refer to the following material.



Block 1 of mass m_1 and block 2 of mass m_2 are sliding along the same line on a horizontal frictionless surface when they collide at time t_c. The graph above shows the velocities of the blocks as a function of time.

10. Which block has the greater mass, and what information indicates this?

(A) Block 1, because it had a greater speed before the collision.

(B) Block 1, because the velocity after the collision is in the same direction as its velocity before the collision.

(C) Block 2, because it had a smaller speed before the collision.

(D) Block 2, because the final velocity is closer to the initial velocity of block 2 than it is to the initial velocity of block 1.

Essential Knowledge	**4.A.2:** The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. **5.D.2:** In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.
Learning Objectives	**4.A.2.3:** The student is able to create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system. **5.D.2.5:** The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values.
Science Practices	**1.4:** The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively. **2.2:** The student can *apply mathematical routines* to quantities that describe natural phenomena.

11. How does the kinetic energy of the two-block system after the collision compare with its kinetic energy before the collision, and why?

(A) It is less, because the blocks have the same velocity after the collision, so some of their kinetic energy was transformed into internal energy.

(B) It is less, because the blocks have velocities in opposite directions before the collision, so some of their kinetic energy cancels.

(C) It is the same, because the collision was instantaneous, so the effect of external forces during the collision is negligible.

(D) It is the same, because the blocks have the same velocity after the collision, and there is no friction acting on them.

Essential Knowledge	**5.D.2:** In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.
Learning Objectives	**5.D.2.3:** The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy.
Science Practices	**6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models. **7.2:** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

12. Which of the following is true of the motion of the center of mass of the two-block system during the time shown?

(A) The center of mass does not move because the blocks are moving in opposite directions before the collision.

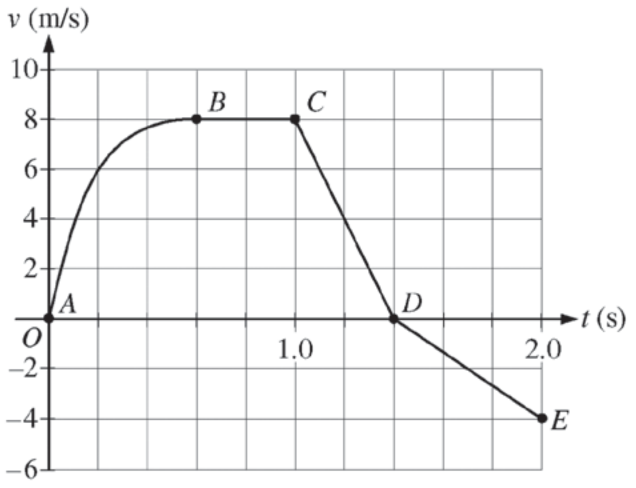
(B) The center of mass moves at a constant velocity of +1.0 m/s because there is no friction acting on the system.

(C) The center-of-mass velocity starts out greater than +1.0 m/s but decreases to +1.0 m/s during the collision because the collision is inelastic.

(D) The center-of-mass velocity increases as the blocks get closer together, and then becomes constant after the collision.

Essential Knowledge	**4.A.2:** The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.
Learning Objectives	**4.A.2.3:** The student is able to create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system.
Science Practices	**1.4:** The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively. **2.2:** The student can *apply mathematical routines* to quantities that describe natural phenomena.

Questions 13–15 refer to the following information.



A cart is constrained to move along a straight line. A varying net force along the direction of motion is exerted on the cart. The cart's velocity v as a function of time t is shown in the graph above. The five labeled points divide the graph into four sections.

13. Which of the following correctly ranks the magnitude of the average acceleration of the cart during the four sections of the graph?

(A) $a_{CD} > a_{AB} > a_{BC} > a_{DE}$

(B) $a_{BC} > a_{AB} > a_{CD} > a_{DE}$

(C) $a_{AB} > a_{BC} > a_{DE} > a_{CD}$

(D) $a_{CD} > a_{AB} > a_{DE} > a_{BC}$

Essential Knowledge	**3.A.1:** An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.
Learning Objectives	**3.A.1.1:** The student is able to express the motion of an object using narrative, mathematical, and graphical representations. **3.A.1.3:** The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical, and graphical representations.
Science Practices	**1.5:** The student can *reexpress key elements of natural phenomena across multiple representations* in the domain. **2.2:** The student can *apply mathematical routines* to quantities that describe natural phenomena.

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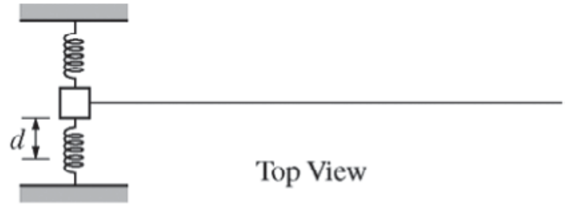
14. For which segment does the cart move the greatest distance?
    (A) *AB*
    (B) *BC*
    (C) *CD*
    (D) *DE*

Essential Knowledge	**3.A.1:** An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.
Learning Objectives	**3.A.1.1:** The student is able to express the motion of an object using narrative, mathematical, and graphical representations.
Science Practices	**1.5:** The student can *reexpress key elements of natural phenomena across multiple representations* in the domain. **2.2:** The student can *apply mathematical routines* to quantities that describe natural phenomena.

15. During some part of the motion, the work done on the cart is negative. What feature of the motion indicates this?
    (A) The speed is increasing.
    (B) The speed is decreasing.
    (C) The acceleration is positive.
    (D) The acceleration is negative.

Essential Knowledge	**3.E.1:** The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the time interval that the force is exerted. **5.B.5:** Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance. This process is called doing work on a system. The amount of energy transferred by this mechanical process is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system.
Learning Objectives	**3.E.1.3:** The student is able to use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether kinetic energy of that object would increase, decrease, or remain unchanged. **5.B.5.4:** The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy).
Science Practices	**1.4:** The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively. **2.2:** The student can *apply mathematical routines* to quantities that describe natural phenomena. **6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models. **7.2:** The student can *connect concepts* in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.



16. The figure above shows a block on a horizontal surface attached to two springs whose other ends are fixed to walls. A light string attached to one side of the block initially lies straight across the surface, as shown. The other end of the string is free to move. There is significant friction between the block and the surface but negligible friction between the string and the surface. The block is displaced a distance *d* and released from rest. Which of the following best represents the shape of the string a short time later?

(A)

(B)

(C)

(D)

Essential Knowledge	**3.B.3:** Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples should include gravitational force exerted by the Earth on a simple pendulum and mass-spring oscillator. **4.C.2:** Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the force is parallel to its displacement. The process through which the energy is transferred is called work. **6.A.3:** The amplitude is the maximum displacement of a wave from its equilibrium value.
Learning Objectives	**3.B.3.1:** The student is able to predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. **4.C.2.1:** The student is able to make predictions about the changes in the mechanical energy of a system when a component of an external force acts parallel or antiparallel to the direction of the displacement of the center of mass. **6.A.3.1:** The student is able to use graphical representation of a periodic mechanical wave to determine the amplitude of the wave.
Science Practices	**1.4:** The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively. **6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models. **7.2:** The student can *connect concepts* in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

17. Two massive, positively charged particles are initially held a fixed distance apart. When they are moved farther apart, the magnitude of their mutual gravitational force changes by a factor of n. Which of the following indicates the factor by which the magnitude of their mutual electrostatic force changes?

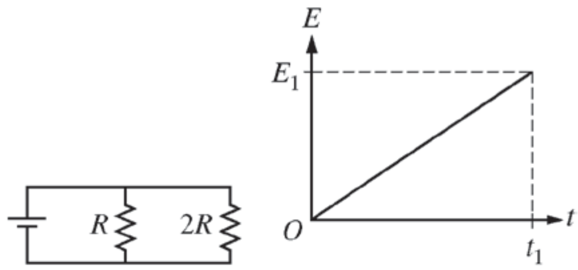
(A) $1/n^2$

(B) $1/n$

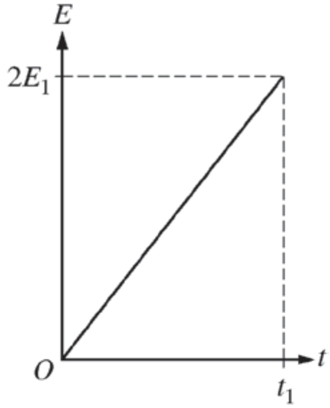
(C) n

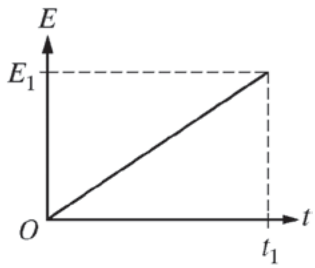
(D) n^2

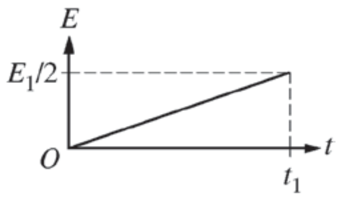
Essential Knowledge	**3.C.2:** Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.
Learning Objectives	**3.C.2.1:** The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges (interactions between collections of electric point charges are not covered in Physics 1 and instead are restricted to Physics 2). **3.C.2.2:** The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces.
Science Practices	**6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models. **7.2:** The student can *connect concepts* in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

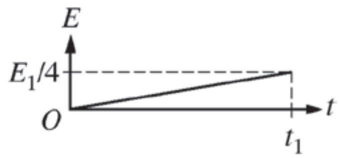


18. The circuit shown above contains two resistors of resistance R and $2R$. The graph shows the total energy E dissipated by the smaller resistance as a function of time. Which of the following shows the corresponding graph for the larger resistance?

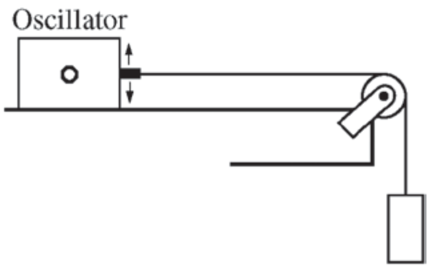
(A)


(B)


(C)


(D)


Essential Knowledge	**5.B.9:** Kirchhoff's loop rule describes conservation of energy in electrical circuits. [The application of Kirchhoff's laws to circuits is introduced in Physics 1 and further developed in Physics 2 in the context of more complex circuits, including those with capacitors.]
Learning Objectives	**5.B.9.1:** The student is able to construct or interpret a graph of the energy changes within an electrical circuit with only a single battery and resistors in series and/or in, at most, one parallel branch as an application of the conservation of energy (Kirchhoff's loop rule). **5.B.9.3:** The student is able to apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch.
Science Practices	**1.1:** The student can *create representations and models* of natural or man-made phenomena and systems in the domain. **1.4:** The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively. **6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models. **7.2:** The student can *connect concepts* in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.



19. A student connects one end of a string with negligible mass to an oscillator. The other end of the string is passed over a pulley and attached to a suspended weight, as shown above. The student finds that a standing wave with one antinode is formed on the string when the frequency of the oscillator is f_0. The student then moves the oscillator to shorten the horizontal segment of string to half its original length. At what frequency will a standing wave with one antinode now be formed on the string?

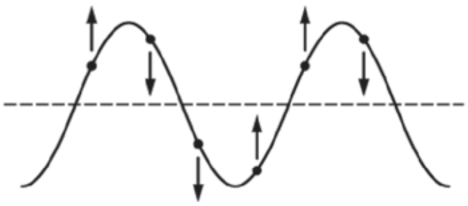
(A) $f_0/2$

(B) f_0

(C) $2f_0$

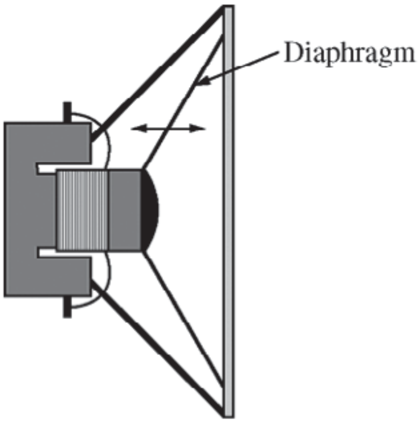
(D) There is no frequency at which a standing wave will be formed.

Essential Knowledge	**6.D.4:** The possible wavelengths of a standing wave are determined by the size of the region to which it is confined.
Learning Objectives	**6.D.4.2:** The student is able to calculate wavelengths and frequencies (if given wave speed) of standing waves based on boundary conditions and length of region within which the wave is confined, and calculate numerical values of wavelengths and frequencies. Examples should include musical instruments.
Science Practices	**2.2:** The student can *apply mathematical routines* to quantities that describe natural phenomena.



20. The figure above shows a portion of a periodic wave on a string at a particular moment in time. The vertical arrows indicate the direction of the velocity of some points on the string. Is the wave moving to the right or to the left?
    (A) To the right
    (B) To the left
    (C) Neither direction; the wave is a standing wave, so it is not moving.
    (D) Either direction; the figure is consistent with wave motion to the right or to the left.

Essential Knowledge	**6.A.1:** Waves can propagate via different oscillation modes such as transverse and longitudinal.
Learning Objectives	**6.A.1.2:** The student is able to describe representations of transverse and longitudinal waves.
Science Practices	**1.2:** The student can *describe representations and models* of natural or man-made phenomena and systems in the domain.



21. A radio speaker produces sound when a membrane called a diaphragm vibrates, as shown above. A person turns up the volume on the radio. Which of the following aspects of the motion of a point on the diaphragm must increase?
    (A) The maximum displacement only
    (B) The average speed only
    (C) Both the maximum displacement and the average speed
    (D) Neither the maximum displacement nor the average speed

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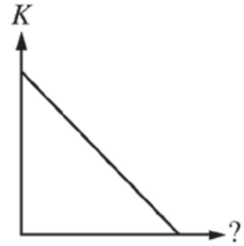
Essential Knowledge	**3.A.1:** An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. **6.A.2:** For propagation, mechanical waves require a medium, while electromagnetic waves do not require a physical medium. Examples should include light traveling through a vacuum and sound not traveling through a vacuum.
Learning Objectives	**3.A.1.1:** The student is able to express the motion of an object using narrative, mathematical, and graphical representations. **6.A.2.1:** The student is able to describe sound in terms of transfer of energy and momentum in a medium and relate the concepts to everyday examples.
Science Practices	**1.5:** The student can *reexpress key elements of natural phenomena across multiple representations* in the domain. **6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models. **7.2:** The student can *connect concepts* in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

Directions: For each of questions 22–25 below, two of the suggested answers will be correct. Select the two answers that are best in each case, and then fill in both of the corresponding circles on the answer sheet.



22. A block is given a short push and then slides with constant friction across a horizontal floor. The graph above shows the kinetic energy of the block after the push ends as a function of an unidentified quantity. The quantity could be which of the following? Select two answers.
    (A) Time elapsed since the push
    (B) Distance traveled by the block
    (C) Speed of the block
    (D) Magnitude of the net work done on the block

Essential Knowledge	**3.A.1:** An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. **3.E.1:** The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the time interval that the force is exerted.

Learning Objectives	**3.A.1.1:** The student is able to express the motion of an object using narrative, mathematical, and graphical representations. **3.E.1.1:** The student is able to make predictions about the changes in kinetic energy of an object based on considerations of the direction of the net force on the object as the object moves.
Science Practices	**1.5:** The student can *reexpress key elements of natural phenomena across multiple representations* in the domain. **2.2:** The student can *apply mathematical routines* to quantities that describe natural phenomena. **6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models. **7.2:** The student can *connect concepts* in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

23. A musician stands outside in a field and plucks a string on an acoustic guitar. Standing waves will most likely occur in which of the following media? Select two answers.
    (A) The guitar string
    (B) The air inside the guitar
    (C) The air surrounding the guitar
    (D) The ground beneath the musician

Essential Knowledge	**6.D.3:** Standing waves are the result of the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. Examples should include waves on a fixed length of string, and sound waves in both closed and open tubes.
Learning Objectives	**6.D.3.2:** The student is able to predict properties of standing waves that result from the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. **6.D.3.4:** The student is able to describe representations and models of situations in which standing waves result from the addition of incident and reflected waves confined to a region.
Science Practices	**1.2:** The student can *describe representations and models* of natural or man-made phenomena and systems in the domain. **6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models.

24. A 0.2 kg rock is dropped into a lake from a few meters above the surface of the water. The rock reaches terminal velocity in the lake after 5 s in the water. During the final 3 s of its descent to the lake bottom, the rock moves at a constant speed of 4 m/s. Which of the following can be determined from the information given? Select two answers.
    (A) The speed of the rock as it enters the lake
    (B) The distance the rock travels in the first 5 s of its descent in the water
    (C) The acceleration of the rock 2 s before it reaches the lake bottom
    (D) The change in potential energy of the rock-Earth-water system during the final 3 s of the rock's descent

Essential Knowledge	**3.A.1:** An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. **4.C.1:** The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy.
Learning Objectives	**3.A.1.1:** The student is able to express the motion of an object using narrative, mathematical, and graphical representations. **4.C.1.2:** The student is able to predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system.
Science Practices	**1.5:** The student can *reexpress key elements of natural phenomena across multiple representations* in the domain. **6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models.

25. In an experiment, three microscopic latex spheres are sprayed into a chamber and become charged with $+3e$, $+5e$, and $-3e$, respectively. Later, all three spheres collide simultaneously and then separate. Which of the following are possible values for the final charges on the spheres? Select two answers.

	$\underline{X}$	$\underline{Y}$	$\underline{Z}$
(A)	$+4e$	$-4e$	$+5e$
(B)	$-4e$	$+4.5e$	$+4.5e$
(C)	$+5e$	$-8e$	$+7e$
(D)	$+6e$	$+6e$	$-7e$

Essential Knowledge	**1.B.1:** Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system. **1.B.3:** The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.
Learning Objectives	**1.B.1.2:** The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. **1.B.3.1:** The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated.
Science Practices	**6.4:** The student can *make claims and predictions about natural phenomena* based on scientific theories and models. **7.2:** The student can *connect concepts* in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

Answers to Multiple-Choice Questions

1. A	14. A
2. B	15. B
3. D	16. C
4. C	17. C
5. B	18. C
6. C	19. C
7. D	20. B
8. A	21. C
9. B	22. B, D
10. D	23. A, B
11. A	24. C, D
12. B	25. A, D
13. D	