Note: To simplify calculations, you may use $g = 10 \text{ m/s}^2$ 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. In which of the following situations is the kinetic energy of the object decreasing?
   (A) A sphere is dropped from a building.
   (B) A satellite is moving in a circular orbit around Earth.
   (C) A baseball is heading upward after being thrown at an angle.
   (D) An elevator is moving upward at a constant velocity.

2. Two protons are held a distance $d$ apart. The electrostatic force and the gravitational force that one proton exerts on the other are $F_e$ and $F_g$, respectively. Which of the following correctly compares the magnitude and direction of these forces?
   (A) $F_e > F_g$ Opposite
   (B) $F_e > F_g$ Same
   (C) $F_e < F_g$ Opposite
   (D) $F_e < F_g$ Same

3. A 2 kg object traveling at 5 m/s on a frictionless horizontal surface collides head-on with and sticks to a 3 kg object initially at rest. Which of the following correctly identifies the change in total kinetic energy and the resulting speed of the objects after the collision?
   
<table>
<thead>
<tr>
<th>Kinetic Energy</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Increases 2 m/s</td>
<td></td>
</tr>
<tr>
<td>(B) Increases 3.2 m/s</td>
<td></td>
</tr>
<tr>
<td>(C) Decreases 2 m/s</td>
<td></td>
</tr>
<tr>
<td>(D) Decreases 3.2 m/s</td>
<td></td>
</tr>
</tbody>
</table>

4. A stone of mass $m$ is thrown upward at a 30° angle to the horizontal. At the instant the stone reaches its highest point, why is the stone neither gaining nor losing speed?
   (A) Because the acceleration of the stone at that instant is zero
   (B) Because the net force acting upon the stone at that instant has magnitude $m\ddot{g}$
   (C) Because the angle between the stone’s velocity and the net force exerted upon the stone is 90°
   (D) Because the stone follows a parabolic trajectory and the peak of the trajectory is where the parabola has zero slope
5. A small cart is rolling freely on an inclined ramp with a constant acceleration of 0.50 m/s² in the -x-direction. At time \( t = 0 \), the cart has a velocity of 2.0 m/s in the +x-direction. If the cart never leaves the ramp, which of the following statements correctly describes the motion of the cart at a time \( t > 5 \) s?

(A) The cart is traveling in the +x-direction and is slowing down.
(B) The cart is traveling in the +x-direction and is speeding up.
(C) The cart is traveling in the -x-direction and is slowing down.
(D) The cart is traveling in the -x-direction and is speeding up.

Item 6 was not scored.

7. A box of mass \( m \) is on a rough inclined plane that is at an angle \( \theta \) with the horizontal. A force of magnitude \( F \) at an angle \( \phi \) with the plane is exerted on the block, as shown above. As the block moves up the plane, there is a frictional force between the box and the plane of magnitude \( f \). What is the magnitude of the net force acting on the box?

(A) \( F \sin \phi - mg \cos \theta - f \)
(B) \( F \cos(\phi + \theta) + mg \sin \theta - f \)
(C) \( F \cos \phi - mg \sin \theta - f \)
(D) \( F \cos(\phi + \theta) - mg \sin \theta - f \)

8. An object’s velocity \( v \) as a function of time \( t \) is given in the graph above. Which of the following statements is true about the motion of the object?

(A) The object is not moving from \( t = 4 \) s to \( t = 10 \) s.
(B) The object’s initial and final positions are the same.
(C) The object is slowing down from \( t = 14 \) s to \( t = 16 \) s.
(D) The average acceleration of the object from \( t = 0 \) s to \( t = 4 \) s is different from the acceleration from \( t = 34 \) s to \( t = 36 \) s.
In the circuit shown above, the sum of the resistances of resistors $R_1$ and $R_2$ is 8 $\Omega$.

Questions 9-10 refer to the following material.

9. What is the current through the battery?
   (A) 4 A
   (B) 5 A
   (C) 8 A
   (D) 20 A

10. Resistor $R_1$ and the 2 $\Omega$ resistor are now swapped. How does the current in the right branch of the circuit change, and why?
   (A) The current does not change, because the total resistance does not change.
   (B) The current increases, because the total resistance will always decrease.
   (C) The current decreases, because the total resistance will always increase.
   (D) The change in current cannot be determined without knowing the resistances of $R_1$ and $R_2$. 
11. A block of mass 10 kg moves from position A to position B shown in the figure above. The speed of the block is 10 m/s at A and 4.0 m/s at B. The work done by friction on the block as it moves from A to B is most nearly
(A) −280 J
(B) −220 J
(C) −200 J
(D) 0 J

12. To determine the speed of waves on a string, some students tie a long string of unknown length between a wave generator and a wall. They vary the frequency \( f \) of the generator to get a standing wave. They count the nodes \( n \) and measure the wavelength \( \lambda \). They repeat the experiment, creating standing waves with different frequencies. Which of the following is the best relationship to graph to determine the speed of the waves on the string?
(A) \( f \) as a function of \( \lambda \)
(B) \( f \) as a function of \( 1/\lambda \)
(C) \( f \) as a function of \( n \)
(D) \( f \) as a function of \( 1/n \)

13. A ladder at rest is leaning against a wall at an angle. Which of the following forces must have the same magnitude as the frictional force exerted on the ladder by the floor?
(A) The force of gravity on the ladder
(B) The normal force exerted on the ladder by the floor
(C) The frictional force exerted on the ladder by the wall
(D) The normal force exerted on the ladder by the wall

14. Some students want to calculate the work done by friction as an object with unknown mass moves along a straight line on a rough horizontal surface. The students have a force probe, a meterstick, and a stopwatch. Which of the following will allow the students to take the measurements needed to calculate the work done by friction?
(A) Pulling the block at an unknown constant acceleration with the force probe for a measured time
(B) Pulling the block at an unknown constant speed with the force probe for a measured time
(C) Pulling the block at an unknown constant acceleration with the force probe for a measured distance
(D) Pulling the block at an unknown constant speed with the force probe for a measured distance
15. A pendulum consisting of a sphere suspended from a light string is oscillating with a small angle with respect to the vertical. The sphere is then replaced with a new sphere of the same size but greater density and is set into oscillation with the same angle. How do the period, maximum kinetic energy, and maximum acceleration of the new pendulum compare to those of the original pendulum?

<table>
<thead>
<tr>
<th>Period</th>
<th>Maximum Kinetic Energy</th>
<th>Maximum Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Larger</td>
<td>Larger</td>
<td>Smaller</td>
</tr>
<tr>
<td>(B) Smaller</td>
<td>Larger</td>
<td>Smaller</td>
</tr>
<tr>
<td>(C) The same</td>
<td>The same</td>
<td>The same</td>
</tr>
<tr>
<td>(D) The same</td>
<td>Larger</td>
<td>The same</td>
</tr>
</tbody>
</table>

16. Planet X has twice Earth’s mass and three times Earth’s radius. The magnitude of the gravitational field near Planet X’s surface is most nearly

<table>
<thead>
<tr>
<th>Option</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>2 N/kg</td>
</tr>
<tr>
<td>(B)</td>
<td>7 N/kg</td>
</tr>
<tr>
<td>(C)</td>
<td>10 N/kg</td>
</tr>
<tr>
<td>(D)</td>
<td>20 N/kg</td>
</tr>
</tbody>
</table>

17. A force $F$ is exerted on a 5 kg block to move it across a rough surface, as shown above. The magnitude of the force is initially 5 N, and the block moves at a constant velocity. While the block is moving, the force is instantaneously increased to 12 N. How much kinetic energy does the block now gain as it moves a distance of 2 m?

<table>
<thead>
<tr>
<th>Option</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>10 J</td>
</tr>
<tr>
<td>(B)</td>
<td>14 J</td>
</tr>
<tr>
<td>(C)</td>
<td>24 J</td>
</tr>
<tr>
<td>(D)</td>
<td>34 J</td>
</tr>
</tbody>
</table>
18. The figure above represents two guitar strings of different materials and lengths, which are on two guitars of different sizes. String 1 is plucked so it vibrates in the pattern shown. Very soon after string 1 is plucked, string 2, which is a short distance away, vibrates in the pattern shown. The guitars are placed in a sealed chamber and then the air is pumped out of the chamber. String 1 is again plucked and vibrates in the pattern shown. Does string 2 again vibrate in the pattern shown, and why or why not?

(A) Yes, because waves again carry some of the energy produced by string 1 to string 2
(B) Yes, because the strings share the same fundamental frequency
(C) No, because the amplitude of the vibration of string 1 becomes zero too quickly for string 2 to start vibrating
(D) No, because almost no energy associated with the vibration of string 1 reaches string 2
19. The figure above represents standing wave patterns in two identical tubes. The tubes contain the same amount of water, and the standing waves are produced by holding a vibrating tuning fork near the top of each tube. What is the relationship between the wavelengths $\lambda_X$ and $\lambda_Y$ of the standing waves?

(A) $\lambda_X = \frac{1}{7} \lambda_Y$

(B) $\lambda_X = \frac{2}{7} \lambda_Y$

(C) $\lambda_X = \frac{7}{2} \lambda_Y$

(D) $\lambda_X = 7\lambda_Y$

20. A system consists of a disk rotating on a frictionless axle and a piece of clay moving toward it, as shown in the figure above. The outside edge of the disk is moving at a linear speed $v$, and the clay is moving at speed $v/2$. The clay sticks to the outside edge of the disk. How does the angular momentum of the system after the clay sticks compare to the angular momentum of the system before the clay sticks, and what is an explanation for the comparison?

(A) It is the same because there is no external torque acting on the system.

(B) It is greater because the rotating mass increases, which increases the rotational inertia.

(C) It is less because the speed of the disk decreases when the clay sticks to it.

(D) It is less because the angular momentum of the clay opposes that of the disk.
21. A disk of known radius and rotational inertia can rotate without friction in a horizontal plane around its fixed central axis. The disk has a cord of negligible mass wrapped around its edge. The disk is initially at rest, and the cord can be pulled to make the disk rotate. Which of the following procedures would best determine the relationship between applied torque and the resulting change in angular momentum of the disk?

(A) Pulling on the cord, exerting a force of 15 N for 2 s and then 25 N for 3 s, and measuring the final angular velocity of the disk

(B) For five different time intervals, pulling on the cord, exerting a force of 15 N, and then measuring the angle through which the disk rotates in each case

(C) For five different time intervals, pulling on the cord, exerting a force of 15 N, and then measuring the final angular velocity of the disk

(D) For five forces of different magnitude, pulling on the cord for 5 s, and then measuring the final angular velocity of the disk

22. When object X with charge +2 μC is 1 m from object Y with charge −3 μC, the magnitude of the force between them is F. Object Y is removed, and object Z with charge −2 μC is placed 2 m from object X. What is the magnitude of the force between objects X and Z?

(A) F/2

(B) F/3

(C) F/4

(D) F/6

23. Each of the figures above shows a tractor attached to an object. The tractor exerts the same constant force F on each object in every case. Which of the following is a true statement about an object and the relative magnitude of the force exerted by the object on the tractor?

(A) The magnitude of the force exerted by the truck on the tractor is greatest, because the resulting motion is in the direction opposite the tractor’s pull.

(B) The magnitude of the force exerted by the boulder on the tractor is least, because no motion results.

(C) The magnitude of the force exerted by the wagon on the tractor is least, because the resulting motion is in the direction of the tractor’s pull.

(D) The magnitude of the force exerted by each object on the tractor is equal, because the tractor exerts an equal force on each object.
24. A planet is in an elliptical orbit around a star, as shown above. Which of the following best represents the mechanical energy \( E_{\text{planet}} \) of just the planet and the mechanical energy \( E_{\text{star-planet}} \) of the star-planet system as functions of time for one complete orbit?

(A) \[
\begin{align*}
E_{\text{planet}} & \quad O \\
\text{Time} & \quad O
\end{align*}
\]

(B) \[
\begin{align*}
E_{\text{planet}} & \quad O \\
\text{Time} & \quad O
\end{align*}
\]

(C) \[
\begin{align*}
E_{\text{planet}} & \quad O \\
\text{Time} & \quad O
\end{align*}
\]

(D) \[
\begin{align*}
E_{\text{planet}} & \quad O \\
\text{Time} & \quad O
\end{align*}
\]
25. A cart of known mass moves with known speed along a level, frictionless track, as shown in the figure above. The cart hits a force sensor and rebounds. The force sensor measures the force exerted on the cart as a function of time and as a function of the position of the cart. The results will be graphed on the axes shown. Which of the two graphs can be used to determine the cart’s speed after it rebounds?

(A) Only graph 1; graph 2 will have no information useful for finding the speed.
(B) Only graph 2; graph 1 will have no information useful for finding the speed.
(C) Either graph 1 or graph 2 can be used.
(D) Neither graph alone is sufficient; both graph 1 and graph 2 are needed.

26. The figure above represents the orbits of two planets of equal mass that orbit their star in the counterclockwise direction as a double-planet system. From the point of view of an observer on either planet, the planets appear to orbit each other while also orbiting the star. The dots on the orbits represent the position of the planets at time \( t_0 \), and \( X \) is the position of their center of mass at that time. Which of the following arrows best represents the acceleration of the center of mass of the double-planet system when it is at point \( X \)?

(A) 

(B) 

(C) 

(D)
27. Two identical blocks are connected to the opposite ends of a compressed spring. The blocks initially slide together on a frictionless surface with velocity $v$ to the right. The spring is then released by remote control. At some later instant, the left block is moving at $v/2$ to the left, and the other block is moving to the right. What is the speed of the center of mass of the system at that instant?

(A) $5v/2$
(B) $3v/2$
(C) $v$
(D) $v/2$

28. A person holds a book at rest a few feet above a table. The person then lowers the book at a slow constant speed and places it on the table. Which of the following accurately describes the change in the total mechanical energy of the Earth-book system?

(A) The total mechanical energy is unchanged, because there is no change in the book’s kinetic energy as it is lowered to the table.
(B) The total mechanical energy is unchanged, because no work is done on the Earth-book system while the book is lowered.
(C) The total mechanical energy decreases, because the person does positive work on the book by exerting a force that opposes the gravitational force.
(D) The total mechanical energy decreases, because the person does negative work on the book by exerting a force on the book in the direction opposite to its displacement.
Questions 29-30 refer to the following material.

A system consists of two spheres, of mass \( m \) and \( 2m \), connected by a rod of negligible mass, as shown above. The system is held at its center of mass with the rod horizontal and released from rest near Earth’s surface at time \( t = 0 \).

29. The graph above shows the rate of change of linear momentum of the sphere of mass \( m \) as a function of time. What is the linear momentum of the two-sphere system at time \( t = 3.0 \) s?

(A) 5 kg\(\cdot\)m/s
(B) 15 kg\(\cdot\)m/s
(C) 45 kg\(\cdot\)m/s
(D) 60 kg\(\cdot\)m/s

30. Which of the following best explains why the system does not rotate around its center of mass as it falls?

(A) The Earth exerts the same gravitational force on both spheres, causing them to accelerate at the same rate.
(B) The Earth exerts the same gravitational force on both spheres, generating torques that cancel out.
(C) The Earth exerts a larger gravitational force on the sphere of mass \( 2m \), but that sphere is closer to the center of mass and the torques cancel out.
(D) The Earth exerts a larger gravitational force on the sphere of mass \( 2m \), but that sphere has more inertia and the torques cancel out.
31. A person is running on a track. Which of the following forces propels the runner forward?

(A) The normal force exerted by the ground on the person
(B) The normal force exerted by the person on the ground
(C) The force of friction exerted by the ground on the person
(D) The force of friction exerted by the person on the ground

32. In a one-dimensional perfectly elastic collision, an object of mass $m$ is traveling with speed $v_0$ in the $+x$-direction when it strikes an object with mass $3m$ that is at rest. What are the objects’ velocities following the collision?

<table>
<thead>
<tr>
<th>Object of Mass $m$</th>
<th>Object of Mass $3m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Zero</td>
<td>$v_0/3$, $+x$-direction</td>
</tr>
<tr>
<td>(B) $v_0/4$, $+x$-direction</td>
<td>$v_0/2$, $+x$-direction</td>
</tr>
<tr>
<td>(C) $v_0/2$, $+x$-direction</td>
<td>$v_0/2$, $+x$-direction</td>
</tr>
<tr>
<td>(D) $v_0/2$, $-x$-direction</td>
<td>$v_0/2$, $+x$-direction</td>
</tr>
</tbody>
</table>
33. A student conducts an experiment to determine the relationship between applied torque and change in angular velocity. The student uses the apparatus shown in the figure above, consisting of two disks that are glued together and mounted on a horizontal axle. Blocks of varying mass are hung from a string wound around the smaller disk. The blocks are released from rest, exerting different torques on the disks, and are allowed to fall a fixed distance. For each block, the time of fall \( t \) and the final angular velocity \( \omega_f \) of the disks are measured. There is considerable friction between the disks and the axle. Which of the following best represents a plot that can be obtained from the student’s data?

(A) 

(B) 

(C) 

(D)
34. An athlete with mass $m$ running at speed $v$ grabs a light rope that hangs from a ceiling of height $H$ and swings to a maximum height of $h_1$. In another room with a lower ceiling of height $H/2$, a second athlete with mass $2m$ running at the same speed $v$ grabs a light rope hanging from the ceiling and swings to a maximum height of $h_2$. How does the maximum height reached by the two athletes compare, and why?

(A) The first athlete reaches a greater height, because this athlete swings on a longer rope.

(B) The second athlete reaches a greater height, because this athlete has a greater mass.

(C) The two athletes reach the same height, because the effect of the rope length offsets the effect of the athletes’ masses.

(D) The two athletes reach the same height, because the athletes run with the same speed.
Two identical spaceships are traveling in deep space, far from any planets or stars. The ships travel in the same direction, with the slower one directly behind the faster one. The ships are connected by a cable attached to a spool, so that the part of the cable outside the ships can be made longer or shorter as needed. The cable is used to bring the ships to the same speed for a transfer of cargo. The graph above shows the speed of the two ships during a 10 s interval.

35. Does at least one of the ships have its engine turned on during the time interval shown, and what evidence indicates so?
(A) Yes, because Ship 2 is speeding up.
(B) Yes, because the momentum of the two-rocket system increases.
(C) Yes, because an engine is needed to keep the system moving.
(D) No, because the cable alone could be responsible for making Ship 1 slow down and Ship 2 speed up.

36. Which of the following graphs best represents the net force $F_{net}$ exerted on the two-ship system?
(A) $F_{net}$ (N)
(B) $F_{net}$ (N)
(C) $F_{net}$ (N)
(D) $F_{net}$ (N)