Chapter 5

Momentum and Impulse
1. A car of mass \( m \), traveling at speed \( v \), stops in time \( t \) when maximum braking force is applied. Assuming the braking force is independent of mass, what time would be required to stop a car of mass \( 2m \) traveling at speed \( v \)?
   (A) \( \frac{1}{2} t \)  (B) \( t \)  (C) \( \sqrt{2} t \)  (D) \( 2t \)

2. A block of mass \( M \) is initially at rest on a frictionless floor. The block, attached to a massless spring with spring constant \( k \), is initially at its equilibrium position. An arrow with mass \( m \) and velocity \( v \) is shot into the block. The arrow sticks in the block. What is the maximum compression of the spring?
   \[
   (A) \sqrt{\frac{m}{k}} \quad (B) \sqrt{\frac{m + M}{k}} \quad (C) \sqrt{\frac{(m + M)v}{\sqrt{mk}}} \quad (D) \frac{mv}{\sqrt{(m + M)k}}
   \]

3. Two objects, \( P \) and \( Q \), have the same momentum. \( Q \) can have more kinetic energy than \( P \) if it has:
   (A) More mass than \( P \)  (B) The same mass as \( P \)  (C) More speed than \( P \)  (D) The same speed as \( P \)

4. A spring is compressed between two objects with unequal masses, \( m \) and \( M \), and held together. The objects are initially at rest on a horizontal frictionless surface. When released, which of the following is true?
   (A) The total final kinetic energy is zero.
   (B) The two objects have equal kinetic energy.
   (C) The speed of one object is equal to the speed of the other.
   (D) The total final momentum of the two objects is zero.

5. Two football players with mass 75 kg and 100 kg run directly toward each other with speeds of 6 m/s and 8 m/s respectively. If they grab each other as they collide, the combined speed of the two players just after the collision would be:
   (A) 2 m/s  (B) 3.4 m/s  (C) 4.6 m/s  (D) 7.1 m/s

6. A 5000 kg freight car moving at 4 km/hr collides and couples with an 8000 kg freight car which is initially at rest. The approximate common final speed of these two cars is
   (A) 1 km/hr  (B) 1.3 km/hr  (C) 1.5 km/hr  (D) 2.5 km/hr

7. A rubber ball is held motionless a height \( h_o \) above a hard floor and released. Assuming that the collision with the floor is elastic, which one of the following graphs best shows the relationship between the total energy \( E \) of the ball and its height \( h \) above the surface.

   \[ (A) \]  \[ (B) \]  \[ (C) \]  \[ (D) \]

8. Two carts are held together. Cart 1 is more massive than Cart 2. As they are forced apart by a compressed spring between them, which of the following will have the same magnitude for both carts.
   (A) change of velocity  (B) force  (C) speed  (D) velocity

9. A ball with a mass of 0.50 kg and a speed of 6 m/s collides perpendicularly with a wall and bounces off with a speed of 4 m/s in the opposite direction. What is the magnitude of the impulse acting on the ball?
   (A) 1 Ns  (B) 5 Ns  (C) 2 m/s  (D) 10 m/s

10. A cart with mass 2\( m \) has a velocity \( v \) before it strikes another cart of mass \( 3m \) at rest. The two carts couple and move off together with a velocity of
    (A) \( \frac{v}{5} \)  (B) \( 2\frac{v}{5} \)  (C) \( 2\frac{v}{3} \)  (D) \( 2\frac{1}{5} \) \( v \)
11. **Multiple Correct:** Consider two laboratory carts of different masses but identical kinetic energy. Which of the following statements must be correct? Select two answers.

(A) The one with the greatest mass has the greatest momentum  
(B) The same impulse was required to accelerate each cart from rest  
(C) Both can do the same amount of work as they come to a stop  
(D) The same amount of force was required to accelerate each cart from rest

12. A mass m has speed v. It then collides with a stationary object of mass 2m. If both objects stick together in a perfectly inelastic collision, what is the final speed of the newly formed object?

(A) \(\frac{v}{3}\)  
(B) \(\frac{v}{2}\)  
(C) \(\frac{2v}{3}\)  
(D) \(\frac{3v}{2}\)

13. A 50 kg skater at rest on a frictionless rink throws a 2 kg ball, giving the ball a velocity of 10 m/s. Which statement describes the skater’s subsequent motion?

(A) 0.4 m/s in the same direction as the ball’s motion.  
(B) 0.4 m/s in the opposite direction of the ball’s motion.  
(C) 2 m/s in the same direction as the ball’s motion.  
(D) 2 m/s in the opposite direction of the ball’s motion.

14. A student initially at rest on a frictionless frozen pond throws a 1 kg hammer in one direction. After the throw, the hammer moves off in one direction while the student moves off in the other direction. Which of the following correctly describes the above situation?

(A) The hammer will have the momentum with the greater magnitude  
(B) The student will have the momentum with the greater magnitude  
(C) The hammer will have the greater kinetic energy  
(D) The student will have the greater kinetic energy

15. Two toy cars with different masses originally at rest are pushed apart by a spring between them. Which TWO of the following statements would be true?

(A) both toy cars will acquire equal but opposite momenta  
(B) both toy cars will acquire equal kinetic energies  
(C) the more massive toy car will acquire the least speed  
(D) the smaller toy car will experience an acceleration of the greatest magnitude

16. A tennis ball of mass m rebounds from a racquet with the same speed v as it had initially as shown. The magnitude of the momentum change of the ball is

(A) 0  
(B) 2mv  
(C) 2mv \(\sin\theta\)  
(D) 2mv \(\cos\theta\)

17. Two bodies of masses 5 and 7 kilograms are initially at rest on a horizontal frictionless surface. A light spring is compressed between the bodies, which are held together by a thin thread. After the spring is released by burning through the thread, the 5 kilogram body has a speed of 0.2 m/s. The speed of the 7 kilogram body is (in m/s)

(A) \(\frac{1}{12}\)  
(B) \(\frac{1}{7}\)  
(C) \(\frac{1}{5}\)  
(D) \(\frac{1}{\sqrt{35}}\)

18. **Multiple Correct:** A satellite of mass M moves in a circular orbit of radius R at a constant speed v around the Earth which has mass \(M_E\). Which of the following statements must be true? Select two answers:

(A) The net force on the satellite is equal to \(Mv^2/2\) and is directed toward the center of the orbit.  
(B) The net work done on the satellite by gravity in one revolution is zero.  
(C) The angular momentum of the satellite is a constant.  
(D) The net force on the satellite is equal to \(GM_M/\sqrt{R}\)
19. Two pucks are firmly attached by a stretched spring and are initially held at rest on a frictionless surface, as shown above. The pucks are then released simultaneously. If puck I has three times the mass of puck II, which of the following quantities is the same for both pucks as the spring pulls the two pucks toward each other?
(A) Speed  (B) Magnitude of acceleration  (C) Kinetic energy  (D) Magnitude of momentum

20. Which of the following is true when an object of mass m moving on a horizontal frictionless surface hits and sticks to an object of mass M > m, which is initially at rest on the surface?
(A) The collision is elastic.
(B) The momentum of the objects that are stuck together has a smaller magnitude than the initial momentum of the less-massive object.
(C) The speed of the objects that are stuck together will be less than the initial speed of the less massive object.
(D) The direction of motion of the objects that are stuck together depends on whether the hit is a head-on collision.

21. Two objects having the same mass travel toward each other on a flat surface each with a speed of 1.0 meter per second relative to the surface. The objects collide head-on and are reported to rebound after the collision, each with a speed of 2.0 meters per second relative to the surface. Which of the following assessments of this report is most accurate?
(A) Momentum was not conserved therefore the report is false.
(B) If potential energy was released to the objects during the collision the report could be true.
(C) If the objects had different masses the report could be true.
(D) If the surface was inclined the report could be true.

22. A solid metal ball and a hollow plastic ball of the same external radius are released from rest in a large vacuum chamber. When each has fallen 1 meter, they both have the same
(A) inertia  (B) speed  (C) momentum  (D) change in potential energy

23. A railroad car of mass m is moving at speed v when it collides with a second railroad car of mass M which is at rest. The two cars lock together instantaneously and move along the track. What is the kinetic energy of the cars immediately after the collision?
(A) \( \frac{1}{2} m v^2 \)  (B) \( \frac{1}{2} (M+m)(mv/M)^2 \)  (C) \( \frac{1}{2} (M+m)(Mv/m)^2 \)  (D) \( \frac{1}{2} (M+m)(mv/(m+M))^2 \)

24. An open cart on a level surface is rolling without frictional loss through a vertical downpour of rain, as shown above. As the cart rolls, an appreciable amount of rainwater accumulates in the cart. The speed of the cart will
(A) increase because of conservation of mechanical energy
(B) decrease because of conservation of momentum
(C) decrease because of conservation of mechanical energy
(D) remain the same because the raindrops are falling perpendicular to the direction of the cart's motion
Questions 25-26

Three objects can only move along a straight, level path. The graphs below show the position $d$ of each of the objects plotted as a function of time $t$.

25. The magnitude of the momentum of the object is increasing in which of the cases?
   (A) II only           (B) III only           (C) I and II only           (D) I and III only

26. The sum of the forces on the object is zero in which of the cases?
   (A) II only           (B) III only           (C) I and II only           (D) I and III only

27. A stationary object explodes, breaking into three pieces of masses $m$, $m$, and $3m$. The two pieces of mass $m$ move off at right angles to each other with the same magnitude of momentum $mV$, as shown in the diagram above. What are the magnitude and direction of the velocity of the piece having mass $3m$?

<table>
<thead>
<tr>
<th>Magnitude</th>
<th>Direction</th>
</tr>
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<tbody>
<tr>
<td>(A) $V/\sqrt{2}$</td>
<td></td>
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<tr>
<td>(B) $V/\sqrt{2}$</td>
<td></td>
</tr>
<tr>
<td>(C) $\sqrt{2}V/3$</td>
<td></td>
</tr>
<tr>
<td>(D) $V/\sqrt{2}$</td>
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</tbody>
</table>

28. An empty sled of mass $M$ moves without friction across a frozen pond at speed $v_o$. Two objects are dropped vertically into the sled one at a time: first an object of mass $m$ and then an object of mass $2m$. Afterward the sled moves with speed $v_f$. What would be the final speed of the sled if the objects were dropped into it in reverse order?
   (A) $v_f/3$
   (B) $v_f/2$
   (C) $v_f$
   (D) $2v_f$
29. A student obtains data on the magnitude of force applied to an object as a function of time and displays the data on the graph shown. The increase in the momentum of the object between t=0 s and t=4 s is most nearly
   (A) 40 N·s
   (B) 50 N·s
   (C) 60 N·s
   (D) 80 N·s

30. How does an air mattress protect a stunt person landing on the ground after a stunt?
   (A) It reduces the kinetic energy loss of the stunt person.
   (B) It reduces the momentum change of the stunt person.
   (C) It shortens the stopping time of the stunt person and increases the force applied during the landing.
   (D) It lengthens the stopping time of the stunt person and reduces the force applied during the landing.

31. Two objects, A and B, initially at rest, are "exploded" apart by the release of a coiled spring that was compressed between them. As they move apart, the velocity of object A is 5 m/s and the velocity of object B is −2 m/s. The ratio of the mass of object A to the mass object B, m_A/m_B is
   (A) 4/25    (B) 2/5    (C) 5/2    (D) 25/4

32. The two blocks of masses M and 2M shown above initially travel at the same speed v but in opposite directions. They collide and stick together. How much mechanical energy is lost to other forms of energy during the collision?
   (A) 1/2 M v^2
   (B) 3/4 M v^2
   (C) 4/3 M v^2
   (D) 3/2 M v^2

33. Two particles of equal mass m_o, moving with equal speeds v_o along paths inclined at 60° to the x-axis as shown, collide and stick together. Their velocity after the collision has magnitude
   \[ \frac{v_o}{4} \] (A) \[ \frac{v_o}{2} \] (B) \[ \frac{\sqrt{3}v_o}{2} \] (C) \[ \frac{2}{v_o} \] (D) \[ v_o \]
34. Two balls are on a frictionless horizontal tabletop. Ball X initially moves at 10 meters per second, as shown in Figure I above. It then collides elastically with identical ball Y which is initially at rest. After the collision, ball X moves at 6 meters per second along a path at 53° to its original direction, as shown in Figure II above. Which of the following diagrams best represents the motion of ball Y after the collision?

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

35. The graph shows the force on an object of mass M as a function of time. For the time interval 0 to 4 s, the total change in the momentum of the object is

(A) 40 kg m/s  
(B) 20 kg m/s  
(C) 0 kg m/s  
(D) –20 kg m/s

36. As shown in the top view, a disc of mass m is moving horizontally to the right with speed v on a table with negligible friction when it collides with a second disc of mass 2m. The second disc is moving horizontally to the right with speed v/2 at the moment before impact. The two discs stick together upon impact. The kinetic energy of the composite body immediately after the collision is

(A) \((1/6)mv^2\)  
(B) \((1/2)mv^2\)  
(C) \(2/3mv^2\)  
(D) \((9/8)mv^2\)

37. A 2 kg ball collides with the floor at an angle θ and rebounds at the same angle and speed as shown above. Which of the following vectors represents the impulse exerted on the ball by the floor?

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

38. An object m, on the end of a string, moves in a circle (initially of radius r) on a horizontal frictionless table as shown. As the string is pulled very slowly through a small hole in the table, which of the following is correct for an observer measuring from the hole in the table?

(A) The angular momentum of m remains constant.  
(B) The angular momentum of m decreases.  
(C) The kinetic energy of m remains constant  
(D) The kinetic energy of m decreases
39. A boy of mass \( m \) and a girl of mass \( 2m \) are initially at rest at the center of a frozen pond. They push each other so that she slides to the left at speed \( v \) across the frictionless ice surface and he slides to the right. What is the total work done by the children?
(A) \( mv \)  (B) \( mv^2 \)  (C) \( 2mv^2 \)  (D) \( 3mv^2 \)

40. An object of mass \( M \) travels along a horizontal air track at a constant speed \( v \) and collides elastically with an object of identical mass that is initially at rest on the track. Which of the following statements is true for the two objects after the impact?
(A) The total momentum is \( Mv \) and the total kinetic energy is \( \frac{1}{2} Mv^2 \)
(B) The total momentum is \( Mv \) and the total kinetic energy is less than \( \frac{1}{2} Mv^2 \)
(C) The total momentum is less than \( Mv \) and the total kinetic energy is \( \frac{1}{2} Mv^2 \)
(D) The momentum of each object is \( \frac{1}{2} Mv \)

41. A 2 kg object initially moving with a constant velocity is subjected to a force of magnitude \( F \) in the direction of motion. A graph of \( F \) as a function of time \( t \) is shown. What is the increase, if any, in the velocity of the object during the time the force is applied?
(A) 0 m/s  (B) 3.0 m/s  (C) 4.0 m/s  (D) 6.0 m/s

42. A ball of mass \( m \) with speed \( v \) strikes a wall at an angle \( \theta \) with the normal, as shown. It then rebounds with the same speed and at the same angle. The impulse delivered by the ball to the wall is
(A) \( mv \sin \theta \)  (B) \( mv \cos \theta \)  (C) \( 2mv \sin \theta \)  (D) \( 2mv \cos \theta \)
1976B2. A bullet of mass $m$ and velocity $v_o$ is fired toward a block of mass $4m$. The block is initially at rest on a frictionless horizontal surface. The bullet penetrates the block and emerges with a velocity of $\frac{v_o}{3}$.

(a) Determine the final speed of the block.
(b) Determine the loss in kinetic energy of the bullet.
(c) Determine the gain in the kinetic energy of the block.

1978B2. A block of mass $M_1$ travels horizontally with a constant speed $v_o$ on a plateau of height $H$ until it comes to a cliff. A toboggan of mass $M_2$ is positioned on level ground below the cliff as shown above. The center of the toboggan is a distance $D$ from the base of the cliff.

(a) Determine $D$ in terms of $v_o$, $H$, and $g$ so that the block lands in the center of the toboggan.
(b) The block sticks to the toboggan which is free to slide without friction. Determine the resulting velocity of the block and toboggan.

1981B2. A massless spring is between a 1-kilogram mass and a 3-kilogram mass as shown above, but is not attached to either mass. Both masses are on a horizontal frictionless table.

In an experiment, the 1-kilogram mass is held in place and the spring is compressed by pushing on the 3-kilogram mass. The 3-kilogram mass is then released and moves off with a speed of 10 meters per second.

a. Determine the minimum work needed to compress the spring in this experiment.

In a different experiment, the spring is compressed again exactly as above, but this time both masses are released simultaneously and each mass moves off separately at unknown speeds.

b. Determine the final velocity of each mass relative to the cable after the masses are released.
A block of mass M is resting on a horizontal, frictionless table and is attached as shown above to a relaxed spring of spring constant k. A second block of mass 2M and initial speed $v_0$ collides with and sticks to the first block. Develop expressions for the following quantities in terms of M, k, and $v_0$.

a. $v$, the speed of the blocks immediately after impact
b. $x$, the maximum distance the spring is compressed
1984B2. Two objects of masses $M_1 = 1$ kilogram and $M_2 = 4$ kilograms are free to slide on a horizontal frictionless surface. The objects collide and the magnitudes and directions of the velocities of the two objects before and after the collision are shown on the diagram above. ($\sin 37^\circ = 0.6$, $\cos 37^\circ = 0.8$, $\tan 37^\circ = 0.75$)

a. Calculate the x and y components ($p_x$ and $p_y$, respectively) of the momenta of the two objects before and after the collision, and write your results in the proper places in the following table.

<table>
<thead>
<tr>
<th></th>
<th>$M_1 = 1 \text{ kg}$</th>
<th>$M_2 = 4 \text{ kg}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>$p_x \left( \frac{\text{kg} \cdot \text{m}}{\text{s}} \right)$</td>
<td>$p_y \left( \frac{\text{kg} \cdot \text{m}}{\text{s}} \right)$</td>
</tr>
<tr>
<td>After</td>
<td></td>
<td></td>
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</tbody>
</table>

b. Show, using the data that you listed in the table, that linear momentum is conserved in this collision.

c. Calculate the kinetic energy of the two-object system before and after the collision.

d. Is kinetic energy conserved in the collision?
1985B1. A 2-kilogram block initially hangs at rest at the end of two 1-meter strings of negligible mass as shown on the left diagram above. A 0.003-kilogram bullet, moving horizontally with a speed of 1000 meters per second, strikes the block and becomes embedded in it. After the collision, the bullet/block combination swings upward, but does not rotate.

a. Calculate the speed $v$ of the bullet/block combination just after the collision.

b. Calculate the ratio of the initial kinetic energy of the bullet to the kinetic energy of the bullet/block combination immediately after the collision.

c. Calculate the maximum vertical height above the initial rest position reached by the bullet/block combination.

1990B1. A bullet of mass $m$ is moving horizontally with speed $v_o$ when it hits a block of mass $100m$ that is at rest on a horizontal frictionless table, as shown above. The surface of the table is a height $h$ above the floor. After the impact, the bullet and the block slide off the table and hit the floor a distance $x$ from the edge of the table. Derive expressions for the following quantities in terms of $m$, $h$, $v_o$, and appropriate constants:

a. the speed of the block as it leaves the table

b. the change in kinetic energy of the bullet-block system during impact

c. the distance $x$

Suppose that the bullet passes through the block instead of remaining in it.

d. State whether the time required for the block to reach the floor from the edge of the table would now be greater, less, or the same. Justify your answer.

e. State whether the distance $x$ for the block would now be greater, less, or the same. Justify your answer.
**1992B2.** A 30-kilogram child moving at 4.0 meters per second jumps onto a 50-kilogram sled that is initially at rest on a long, frictionless, horizontal sheet of ice.

a. Determine the speed of the child-sled system after the child jumps onto the sled.
b. Determine the kinetic energy of the child-sled system after the child jumps onto the sled.

After coasting at constant speed for a short time, the child jumps off the sled in such a way that she is at rest with respect to the ice.

c. Determine the speed of the sled after the child jumps off it.
d. Determine the kinetic energy of the child-sled system when the child is at rest on the ice.
e. Compare the kinetic energies that were determined in parts (b) and (d). If the energy is greater in (d) than it is in (b), where did the increase come from? If the energy is less in (d) than it is in (b), where did the energy go?

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**1994B2.** A track consists of a frictionless arc XY, which is a quarter-circle of radius R, and a rough horizontal section YZ. Block A of mass M is released from rest at point X, slides down the curved section of the track, and collides instantaneously and inelastically with identical block B at point Y. The two blocks move together to the right, sliding past point P, which is a distance L from point Y. The coefficient of kinetic friction between the blocks and the horizontal part of the track is $\mu$. Express your answers in terms of M, L, $\mu$, R, and g.

a. Determine the speed of block A just before it hits block B.
b. Determine the speed of the combined blocks immediately after the collision.
c. Assuming that no energy is transferred to the track or to the air surrounding the blocks. Determine the amount of internal energy transferred in the collision
d. Determine the additional thermal energy that is generated as the blocks move from Y to P
1995B1. As shown above, a 0.20-kilogram mass is sliding on a horizontal, frictionless air track with a speed of 3.0 meters per second when it instantaneously hits and sticks to a 1.3-kilogram mass initially at rest on the track. The 1.3-kilogram mass is connected to one end of a massless spring, which has a spring constant of 100 newtons per meter. The other end of the spring is fixed.

a. Determine the following for the 0.20-kilogram mass immediately before the impact.
   i. Its linear momentum
   ii. Its kinetic energy

b. Determine the following for the combined masses immediately after the impact.
   i. The linear momentum
   ii. The kinetic energy

After the collision, the two masses compress the spring as shown.

c. Determine the maximum compression distance of the spring.

1996B1. Two identical objects A and B of mass M move on a one-dimensional, horizontal air track. Object B initially moves to the right with speed $v_0$. Object A initially moves to the right with speed $3v_0$, so that it collides with object B. Friction is negligible. Express your answers to the following in terms of M and $v_0$.

a. Determine the total momentum of the system of the two objects.

b. A student predicts that the collision will be totally inelastic (the objects stick together on collision). Assuming this is true, determine the following for the two objects immediately after the collision.
   i. The speed
   ii. The direction of motion (left or right)

When the experiment is performed, the student is surprised to observe that the objects separate after the collision and that object B subsequently moves to the right with a speed $2.5v_0$.

c. Determine the following for object A immediately after the collision.
   i. The speed
   ii. The direction of motion (left or right)

d. Determine the kinetic energy dissipated in the actual experiment.
A 0.20 kg object moves along a straight line. The net force acting on the object varies with the object's displacement as shown in the graph above. The object starts from rest at displacement \( x = 0 \) and time \( t = 0 \) and is displaced a distance of 20 m. Determine each of the following.

a. The acceleration of the particle when its displacement \( x \) is 6 m.
b. The time taken for the object to be displaced the first 12 m.
c. The amount of work done by the net force in displacing the object the first 12 m.
d. The speed of the object at displacement \( x = 12 \) m.
e. The final speed of the object at displacement \( x = 20 \) m.
f. The change in the momentum of the object as it is displaced from \( x = 12 \) m to \( x = 20 \) m.
An incident ball A of mass 0.10 kg is sliding at 1.4 m/s on the horizontal tabletop of negligible friction as shown above. It makes a head-on collision with a target ball B of mass 0.50 kg at rest at the edge of the table. As a result of the collision, the incident ball rebounds, sliding backwards at 0.70 m/s immediately after the collision.

a. Calculate the speed of the 0.50 kg target ball immediately after the collision.

The tabletop is 1.20 m above a level, horizontal floor. The target ball is projected horizontally and initially strikes the floor at a horizontal displacement \( d \) from the point of collision.

b. Calculate the horizontal displacement

In another experiment on the same table, the target ball B is replaced by target ball C of mass 0.10 kg. The incident ball A again slides at 1.4 m/s, as shown below left, but this time makes a glancing collision with the target ball C that is at rest at the edge of the table. The target ball C strikes the floor at point P, which is at a horizontal displacement of 0.15 m from the point of the collision, and at a horizontal angle of 30° from the +x-axis, as shown below right.

c. Calculate the speed \( v \) of the target ball C immediately after the collision.

d. Calculate the y-component of incident ball A’s momentum immediately after the collision.
2002B1. A model rocket of mass 0.250 kg is launched vertically with an engine that is ignited at time t = 0, as shown above. The engine provides an impulse of 20.0 N•s by firing for 2.0 s. Upon reaching its maximum height, the rocket deploys a parachute, and then descends vertically to the ground.

(a) On the figures below, draw and label a free-body diagram for the rocket during each of the following intervals.

- Engine ignites.
- Engine shut down.
- Maximum height; parachute deploys.
- Rocket descends.

(b) Determine the magnitude of the average acceleration of the rocket during the 2 s firing of the engine.

(c) What maximum height will the rocket reach?

(d) At what time after t = 0 will the maximum height be reached?
A 2.0 kg frictionless cart is moving at a constant speed of 3.0 m/s to the right on a horizontal surface, as shown above, when it collides with a second cart of undetermined mass \( m \) that is initially at rest. The force \( F \) of the collision as a function of time \( t \) is shown in the graph below, where \( t = 0 \) is the instant of initial contact. As a result of the collision, the second cart acquires a speed of 1.6 m/s to the right. Assume that friction is negligible before, during, and after the collision.

(a) Calculate the magnitude and direction of the velocity of the 2.0 kg cart after the collision.

(b) Calculate the mass \( m \) of the second cart.

After the collision, the second cart eventually experiences a ramp, which it traverses with no frictional losses. The graph below shows the speed \( v \) of the second cart as a function of time \( t \) for the next 5.0 s, where \( t = 0 \) is now the instant at which the carts separate.

(c) Calculate the acceleration of the cart at \( t = 3.0 \) s.

(d) Calculate the distance traveled by the second cart during the 5.0 s interval after the collision (0 s < \( t < 5.0 \) s).

(e) State whether the ramp goes up or down and calculate the maximum elevation (above or below the initial height) reached by the second cart on the ramp during the 5.0 s interval after the collision (0 s < \( t < 5.0 \) s).
2006B2B

A small block of mass $M$ is released from rest at the top of the curved frictionless ramp shown above. The block slides down the ramp and is moving with a speed $3.5v_0$ when it collides with a larger block of mass $1.5M$ at rest at the bottom of the incline. The larger block moves to the right at a speed $2v_0$ immediately after the collision. Express your answers to the following questions in terms of the given quantities and fundamental constants.

(a) Determine the height $h$ of the ramp from which the small block was released.
(b) Determine the speed of the small block after the collision.
(c) The larger block slides a distance $D$ before coming to rest. Determine the value of the coefficient of kinetic friction $\mu$ between the larger block and the surface on which it slides.
(d) Indicate whether the collision between the two blocks is elastic or inelastic. Justify your answer.

2008B1B

A 70 kg woman and her 35 kg son are standing at rest on an ice rink, as shown above. They push against each other for a time of 0.60 s, causing them to glide apart. The speed of the woman immediately after they separate is 0.55 m/s. Assume that during the push, friction is negligible compared with the forces the people exert on each other.

(a) Calculate the initial speed of the son after the push.
(b) Calculate the magnitude of the average force exerted on the son by the mother during the push.
(c) How do the magnitude and direction of the average force exerted on the mother by the son during the push compare with those of the average force exerted on the son by the mother? Justify your answer.
(d) After the initial push, the friction that the ice exerts cannot be considered negligible, and the mother comes to rest after moving a distance of 7.0 m across the ice. If their coefficients of friction are the same, how far does the son move after the push?
Several students are riding in bumper cars at an amusement park. The combined mass of car A and its occupants is 250 kg. The combined mass of car B and its occupants is 200 kg. Car A is 15 m away from car B and moving to the right at 2.0 m/s, as shown, when the driver decides to bump into car B, which is at rest.

(a) Car A accelerates at 1.5 m/s$^2$ to a speed of 5.0 m/s and then continues at constant velocity until it strikes car B. Calculate the total time for car A to travel the 15 m.

(b) After the collision, car B moves to the right at a speed of 4.8 m/s.
   i. Calculate the speed of car A after the collision.
   ii. Indicate the direction of motion of car A after the collision.
      ____ To the left  ____ To the right  ____ None; car A is at rest.

(c) Is this an elastic collision?
   ____ Yes  ____ No
   Justify your answer.

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A swing seat of mass $M$ is connected to a fixed point $P$ by a massless cord of length $L$. A child also of mass $M$ sits on the seat and begins to swing with zero velocity at a position at which the cord makes a 60° angle with the vertical as shown in Figure I. The swing continues down until the cord is exactly vertical at which time the child jumps off in a horizontal direction. The swing continues in the same direction until its cord makes a 45° angle with the vertical as shown in Figure II: at that point it begins to swing in the reverse direction.

a) Determine the speed of the child and seat just at the lowest position prior to the child’s dismount from the seat
b) Determine the speed if the seat immediately after the child dismounts

c) Determine the speed of the child immediately after he dismounts from the swing?
C1991M1. A small block of mass 2m initially rests on a track at the bottom of the circular, vertical loop-the-loop shown above, which has a radius r. The surface contact between the block and the loop is frictionless. A bullet of mass m strikes the block horizontally with initial speed $v_0$ and remains embedded in the block as the block and bullet circle the loop.

Determine each of the following in terms of m, $v_0$, r, and g.

a. The speed of the block and bullet immediately after impact
b. The kinetic energy of the block and bullet when they reach point P on the loop
c. The speed $v_{min}$ of the block at the top of the loop to remain in contact with track at all times
d. The new required entry speed $v_{o'}$ of the block and bullet at the bottom of the loop such that the conditions in part c apply.
e. The new initial speed of the bullet to produce the speed from part d above.
A ball of mass \(9m\) is dropped from rest from a height \(H = 5.0\) meters above the ground, as shown above on the left. It undergoes a perfectly elastic collision with the ground and rebounds. At the instant that the ball rebounds, a small blob of clay of mass \(m\) is released from rest from the original height \(H\), directly above the ball, as shown above on the right. The clay blob, which is descending, collides with the ball 0.5 seconds later, which is ascending. Assume that \(g = 10\) m/s\(^2\), that air resistance is negligible, and that the collision process takes negligible time.

a. Determine the speed of the ball immediately before it hits the ground.

b. Determine the rebound speed of the ball immediately after it collides with the ground, justify your answer.

c. Determine the height above the ground at which the clay-ball collision takes place.

d. Determine the speeds of the ball and the clay blob immediately before the collision.

e. If the ball and the clay blob stick together on impact, what is the magnitude and direction of their velocity immediately after the collision?
C1993M1. A massless spring with force constant $k = 400$ newtons per meter is fastened at its left end to a vertical wall, as shown in Figure 1. Initially, block C (mass $m_C = 4.0$ kilograms) and block D (mass $m_D = 2.0$ kilograms) rest on a horizontal surface with block C in contact with the spring (but not compressing it) and with block D in contact with block C. Block C is then moved to the left, compressing the spring a distance of 0.50 meter, and held in place while block D remains at rest as shown in Figure 11. (Use $g = 10 \text{ m/s}^2$.)

a. Determine the elastic energy stored in the compressed spring.

Block C is then released and accelerates to the right, toward block D. The surface is rough and the coefficient of friction between each block and the surface is $\mu = 0.4$. The two blocks collide instantaneously, stick together, and move to the right. Remember that the spring is not attached to block C. Determine each of the following.

b. The speed $v_C$ of block C just before it collides with block D

c. The speed $v_f$ of blocks C and D just after they collide

d. The horizontal distance the blocks move before coming to rest

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C1994M1. A 2-kilogram block is attached to an ideal spring (for which $k = 200 \text{ N/m}$) and initially at rest on a horizontal frictionless surface, as shown in the diagram above.

In an initial experiment, a 100-gram (0.1 kg) ball of clay is thrown at the 2-kilogram block. The clay is moving horizontally with speed $v$ when it hits and sticks to the block. The spring is attached to a wall as shown. As a result, the spring compresses a maximum distance of 0.4 meters.

a. Calculate the energy stored in the spring at maximum compression.

b. Calculate the speed of the clay ball and 2-kilogram block immediately after the clay sticks to the block but before the spring compresses significantly.

c. Calculate the initial speed $v$ of the clay.
C1995M1. A 5-kilogram ball initially rests at the edge of a 2-meter-long, 1.2-meter-high frictionless table, as shown above. A hard plastic cube of mass 0.5 kilogram slides across the table at a speed of 26 meters per second and strikes the ball, causing the ball to leave the table in the direction in which the cube was moving. The figure below shows a graph of the force exerted on the ball by the cube as a function of time.

Note: Figure not drawn to scale.

C1995M1. A 5-kilogram ball initially rests at the edge of a 2-meter-long, 1.2-meter-high frictionless table, as shown above. A hard plastic cube of mass 0.5 kilogram slides across the table at a speed of 26 meters per second and strikes the ball, causing the ball to leave the table in the direction in which the cube was moving. The figure below shows a graph of the force exerted on the ball by the cube as a function of time.

a. Determine the total impulse given to the ball.
b. Determine the horizontal velocity of the ball immediately after the collision.
c. Determine the following for the cube immediately after the collision.
   i. Its speed
   ii. Its direction of travel (right or left), if moving
d. Determine the kinetic energy dissipated in the collision.
e. Determine the distance between the two points of impact of the objects with the floor.
Two gliders move freely on an air track with negligible friction, as shown above. Glider A has a mass of 0.90 kg and glider B has a mass of 0.60 kg. Initially, glider A moves toward glider B, which is at rest. A spring of negligible mass is attached to the right side of glider A. Strobe photography is used to record successive positions of glider A at 0.10 s intervals over a total time of 2.00 s, during which time it collides with glider B.

The following diagram represents the data for the motion of glider A. Positions of glider A at the end of each 0.10 s interval are indicated by the symbol ΄ against a metric ruler. The total elapsed time t after each 0.50 s is also indicated.

a. Determine the average speed of glider A for the following time intervals.
   i. 0.0 s to 0.30 s  
   ii. 0.90 s to 1.10 s  
   iii. 1.70 s to 1.90 s

b. On the axes below, sketch a graph, consistent with the data above, of the speed of glider A as a function of time t for the 2.00 s interval.
c.  
   i. Use the data to calculate the speed of glider B immediately after it separates from the spring.
   ii. On the axes below, sketch a graph of the speed of glider B as a function of time $t$.

\[ v(\text{m/s}) \]

\[ 1.50 \]
\[ 1.00 \]
\[ 0.50 \]
\[ 0 \]  \hspace{1cm} 0.50  \hspace{1cm} 1.00  \hspace{1cm} 1.50  \hspace{1cm} 2.00 \]
\[ t (\text{s}) \]

A graph of the total kinetic energy $K$ for the two-glider system over the 2.00 s interval has the following shape. $K_0$ is the total kinetic energy of the system at time $t = 0$.

\[ K(\text{J}) \]

\[ K_0 \]
\[ 0 \]  \hspace{1cm} 0.50  \hspace{1cm} 1.00  \hspace{1cm} 1.50  \hspace{1cm} 2.00 \]
\[ t (\text{s}) \]

d.  
   i. Is the collision elastic? Justify your answer.
   
   ii. Briefly explain why there is a minimum in the kinetic energy curve at $t = 1.00$ s.
C1999M1. In a laboratory experiment, you wish to determine the initial speed of a dart just after it leaves a dart gun. The dart, of mass $m$, is fired with the gun very close to a wooden block of mass $M_0$ which hangs from a cord of length $l$ and negligible mass, as shown. Assume the size of the block is negligible compared to $l$, and the dart is moving horizontally when it hits the left side of the block at its center and becomes embedded in it. The block swings up to a maximum angle from the vertical. Express your answers to the following in terms of $m$, $M_0$, $l$, $\theta_{\text{max}}$, and $g$.

a. Determine the speed $v_o$ of the dart immediately before it strikes the block.

b. The dart and block subsequently swing as a pendulum. Determine the tension in the cord when it returns to the lowest point of the swing.

c. At your lab table you have only the following additional equipment.

<table>
<thead>
<tr>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meter stick</td>
</tr>
<tr>
<td>Stopwatch</td>
</tr>
<tr>
<td>Set of known masses</td>
</tr>
<tr>
<td>Protractor</td>
</tr>
<tr>
<td>5 m of string</td>
</tr>
<tr>
<td>Five more blocks of mass $M_0$</td>
</tr>
<tr>
<td>Spring</td>
</tr>
</tbody>
</table>

Without destroying or disassembling any of this equipment, design another practical method for determining the speed of the dart just after it leaves the gun. Indicate the measurements you would take, and how the speed could be determined from these measurements.

2001M1. A motion sensor and a force sensor record the motion of a cart along a track, as shown above. The cart is given a push so that it moves toward the force sensor and then collides with it. The two sensors record the values shown in the following graphs.

a. Determine the cart's average acceleration between $t = 0.33$ s and $t = 0.37$ s.

b. Determine the magnitude of the change in the cart's momentum during the collision.

c. Determine the mass of the cart.

d. Determine the energy lost in the collision between the force sensor and the cart.