[07-02-26-FP]

sec. 9-2 The Center of Mass

•1 Figure 9-36 shows a three-particle system, with masses $m_1 = 3.0$ kg, $m_2 = 4.0$ kg, and $m_3 = 8.0$ kg. What are (a) the x coordinate and (b) the y coordinate of the system's center of mass? (c) If m_3 is gradually increased, does the center of mass of the system shift toward or away from that particle, or does it remain stationary? SSM

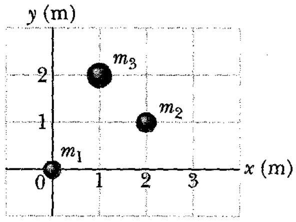

Fig. 9-36 Problem 1.

•2 A 2.00 kg particle has the xy coordinates $(-1.20$ m, 0.500 m$)$, and a 4.00 kg particle has the xy coordinates $(0.600$ m, -0.750 m$)$. Both lie on a horizontal plane. At what (a) x and (b) y coordinates must you place a 3.00 kg particle such that the center of mass of the three-particle system has the coordinates $(-0.500$ m, -0.700 m$)$?

••3 In Fig. 9-37, three uniform thin rods, each of length $L = 22$ cm, form an inverted U. The vertical rods each have a mass of 14 g; the horizontal rod has a mass of 42 g. What are (a) the x coordinate and (b) the y coordinate of the system's center of mass?

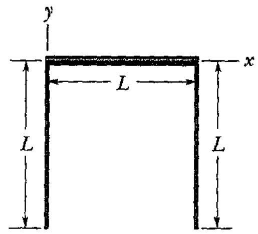
Fig. 9-37 Problem 3.

••4 What are (a) the x coordinate and (b) the y coordinate of the center of mass for the uniform plate shown in Fig. 9-38 if $L = 5.0$ cm?

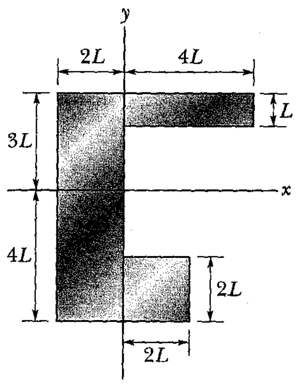
Fig. 9-38 Problem 4.

••5 In the ammonia (NH_3) molecule of Fig. 9-39, three hydrogen (H) atoms form an equilateral triangle, with the center of the triangle at distance $d = 9.40 \times 10^{-11}$ m from each hydrogen atom. The nitrogen (N) atom is at the apex of a pyramid, with the three hydrogen atoms forming the base. The nitrogen-to-hydrogen atomic mass ratio is 13.9, and the nitrogen-to-hydrogen distance is $L = 10.14 \times 10^{-11}$ m. What are the (a) x and (b) y coordinates of the molecule's center of mass? ILW

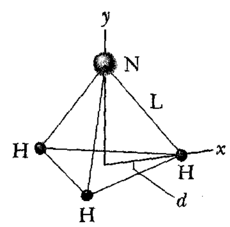
Fig. 9-39 Problem 5.

••6 Figure 9-40 shows a composite slab with dimensions $d_1 = 11.0$ cm, $d_2 = 2.80$ cm, and $d_3 = 13.0$ cm. Half the slab consists of aluminum (density $= 2.70$ g/cm^3) and half consists of iron (density $= 7.85$ g/cm^3). What are (a) the x coordinate, (b) the y coordinate, and (c) the z coordinate of the slab's center of mass?

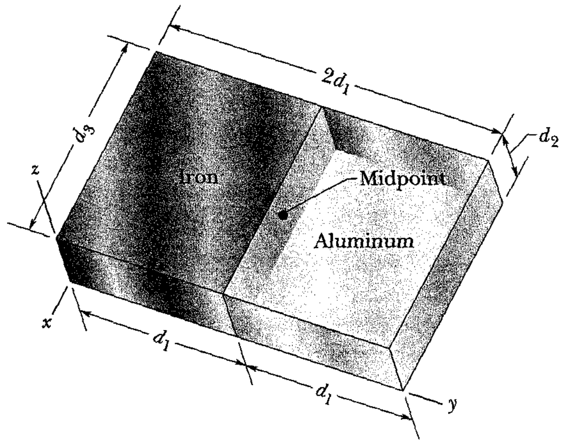

Fig. 9-40 Problem 6.

••7 Figure 9-41 shows a cubical box that has been constructed from uniform metal plate of negligible thickness. The box is open at the top and has edge length $L = 40$ cm. Find (a) the x coordinate, (b) the y coordinate, and (c) the z coordinate of the center of mass of the box.

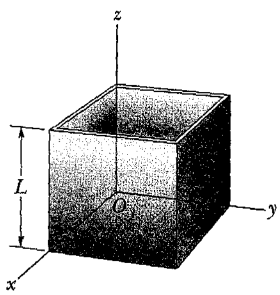
Fig. 9-41 Problem 7.

•••8 A metal soda can of uniform composition has a mass of 0.140 kg and is 12.0 cm tall (Fig. 9-42). The can is filled with 1.31 kg of soda. Then small holes are drilled in the top and bottom (with negligible loss of metal) to drain the soda. What is the height h of the center of mass of the can and contents (a) initially and (b) after the can loses all the soda? (c) What happens to h as the soda drains out? (d) If x is the height of the remaining soda at any given instant, find x when the center of mass reaches its lowest point.

Photo (waste of toner)

Fig. 9-42 Problem 8.

sec. 9-3 Newton's Second Law for a System of Particles

•9 A stone is dropped at $t = 0$. A second stone, with twice the mass of the first, is dropped from the same point at $t = 100$ ms. (a) How far below the release point is the center of mass of the two stones at $t = 300$ ms? (Neither stone has yet reached the ground.) (b) How fast is the center of mass of the two-stone system moving at that time? ILW

•10 Two skaters, one with mass 65 kg and the other with mass 40 kg, stand on an ice rink holding a pole of length 10 m and negligible mass. Starting from the ends of the pole, the skaters pull themselves along the pole until they meet. How far does the 40 kg skater move?

•11 A 1000 kg automobile is at rest at a traffic signal. At the instant the light turns green, the automobile starts to move with a constant acceleration of 4.0 m/s^2. At the same instant a 2000 kg truck, traveling at a constant speed of 8.0 m/s, overtakes and passes the automobile. (a) How far is the com of the automobile–truck system from the traffic light at t = 3.0 s? (b) What is the speed of the com then?

•12 A big olive (m = 0.50 kg) lies at the origin of an xy coordinate system, and a big Brazil nut (M = 1.5 kg) lies at the point (1.0, 2.0) m. At t = 0, a force $\vec{F}_o = (2.0\hat{i} + 3.0\hat{j})$ N begins to act on the olive, and a force $\vec{F}_n = (-3.0\hat{i} - 2.0\hat{j})$ N begins to act on the nut. In unit-vector notation, what is the displacement of the center of mass of the olive–nut system at t = 4.0 s, with respect to its position at t = 0?

••13 Figure 9-43 shows an arrangement with an air track, in which a cart is connected by a cord to a hanging block. The cart has mass m_1 = 0.600 kg, and its center is initially at xy coordinates (−0.500 m, 0 m); the block has mass m_2 = 0.400 kg, and its center is initially at xy coordinates (0, −0.100 m). The mass of the cord and pulley are negligible. The cart is released from rest, and both cart and block move until the cart hits the pulley. The friction between the cart and the air track and between the pulley and its axle is negligible. (a) In unit-vector notation, what is the acceleration of the center of mass of the cart–block system? (b) What is the velocity of the com as a function of time t? (c) Sketch the path taken by the com. (d) If the path is curved, determine whether it bulges upward to the right or downward to the left, and if it is straight, find the angle between it and the x axis.

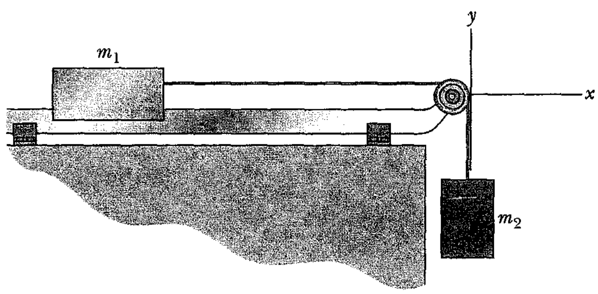

Fig. 9-43 Problem 13.

••14 In Figure 9-44, two particles are launched from the origin of the coordinate system at time t = 0. Particle 1 of mass m_1 = 5.00 g is shot directly along the x axis (on a frictionless floor), where it moves with a constant speed of 10.0 m/s. Particle 2 of mass m_2 = 3.00 g is shot with a velocity of magnitude 20.0 m/s, at an upward angle such that it always stays directly above particle 1 during its flight. (a) What is the maximum height H_{max} reached by the com of the two-particle system? In unit-vector notation, what are the (b) velocity and (c) acceleration of the com when the com reaches H_{max}?

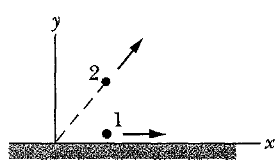

Fig. 9-44 Problem 14.

••15 A shell is shot with an initial velocity $\vec{v}_0$ of 20 m/s, at an angle of θ_0 = 60° with the horizontal. At the top of the trajectory, the shell explodes into two fragments of equal mass (Fig. 9-45). One fragment, whose speed immediately after the explosion is zero, falls vertically. How far from the gun does the other fragment land, assuming that the terrain is level and that air drag is negligible? SSM

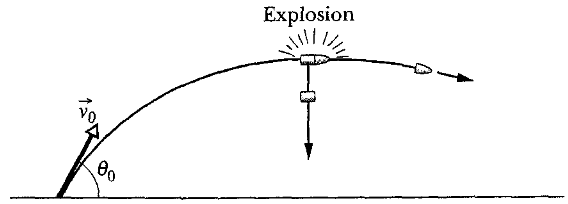

Fig. 9-45 Problem 15.

•••16 Ricardo, of mass 80 kg, and Carmelita, who is lighter, are enjoying Lake Merced at dusk in a 30 kg canoe. When the canoe is at rest in the placid water, they exchange seats, which are 3.0 m apart and symmetrically located with respect to the canoe's center. Ricardo notices that the canoe moves 40 cm horizontally relative to a pier post during the exchange and calculates Carmelita's mass. What is it?

•••17 In Fig. 9-46a, a 4.5 kg dog stands on an 18 kg flatboat at distance D = 6.1 m from the shore. It walks 2.4 m along the boat toward shore and then stops. Assuming no friction between the boat and the water, find how far the dog is then from the shore. (*Hint:* See Fig. 9-46b. The dog moves leftward and the boat moves rightward, but does the *boat* + *dog* com move?) SSM WWW

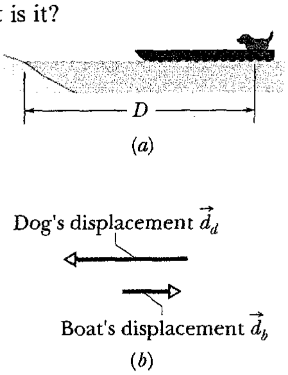

Fig. 9-46 Problem 17.

sec. 9-5 The Linear Momentum of a System of Particles

•18 A 0.70 kg ball is moving horizontally with a speed of 5.0 m/s when it strikes a vertical wall. The ball rebounds with a speed of 2.0 m/s. What is the magnitude of the change in linear momentum of the ball?

•19 A 2100 kg truck traveling north at 41 km/h turns east and accelerates to 51 km/h. (a) What is the change in the truck's kinetic energy? What are the (b) magnitude and (c) direction of the change in its momentum? ILW

••20 Figure 9-47 gives an overhead view of the path taken by a 0.165 kg cue ball as it bounces from a rail of a pool table. The ball's initial speed is 2.00 m/s, and the angle θ_1 is 30.0°. The bounce reverses the y component of the ball's velocity but does not alter the x component. What are (a) angle θ_2 and (b) the change in the ball's linear momentum in unit-vector notation? (The fact that the ball rolls is irrelevant to the problem.)

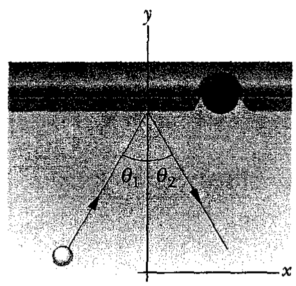

Fig. 9-47 Problem 20.

••21 At time t = 0, a ball is struck at ground level and sent over level ground. Figure 9-48 gives the magnitude p of the ball's momentum versus time t during the flight. At what initial angle is the ball launched?

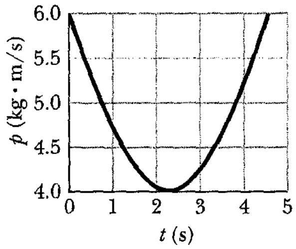

Fig. 9-48 Problem 21.

••22 A 0.30 kg softball has a velocity of 15 m/s at an angle of 35° below the horizontal just before making contact with the bat. What is the magnitude of the change in momentum of the ball while it is in contact with the bat if the ball leaves the bat with a velocity of (a) 20 m/s, vertically downward, and (b) 20 m/s, horizontally back toward the pitcher?

sec. 9-6 Collision and Impulse

•23 A force in the negative direction of an x axis is applied for 27 ms to a 0.40 kg ball initially moving at 14 m/s in the positive direction of the axis. The force varies in magnitude, and the impulse has magnitude 32.4 N · s. What are the ball's (a) speed and (b) direction of travel just after the force is applied? What are (c) the average magnitude of the force and (d) the direction of the impulse on the ball? SSM

•24 Until he was in his seventies, Henri LaMothe excited audiences by belly-flopping from a height of 12 m into 30 cm of water (Fig. 9-49). Assuming that he stops just as he reaches the bottom of the water and estimating his mass, find the magnitude of the impulse on him from the water.

Photo (waste of toner)

Fig. 9-49 Problem 24. Belly-flopping into 30 cm of water.

•25 In February 1955, a paratrooper fell 370 m from an airplane without being able to open his chute but happened to land in snow, suffering only minor injuries. Assume that his speed at impact was 56 m/s (terminal speed), that his mass (including gear) was 85 kg, and that the magnitude of the force on him from the snow was at the survivable limit of 1.2×10^5 N. What are (a) the minimum depth of snow that would have stopped him safely and (b) the magnitude of the impulse on him from the snow?

•26 A 1.2 kg ball drops vertically onto a floor, hitting with a speed of 25 m/s. It rebounds with an initial speed of 10 m/s. (a) What impulse acts on the ball during the contact? (b) If the ball is in contact with the floor for 0.020 s, what is the magnitude of the average force on the floor from the ball?

•27 It is well known that bullets and other missiles fired at Superman simply bounce off his chest. Suppose a gangster sprays Superman's chest with 3 g bullets at the rate of 100 bullets/min, and the speed of each bullet is 500 m/s. Suppose too that the bullets rebound straight back with no change in speed. What is the magnitude of the average force on Superman's chest from the stream of bullets?

••28 A 5.0 kg toy car can move along an x axis; Fig. 9-50 gives F_x of the force acting on the car, which begins at rest at time $t = 0$. In unit-vector notation, what is $\vec{p}$ at (a) $t = 4.0$ s and (b) $t = 7.0$ s, and (c) what is $\vec{v}$ at $t = 9.0$ s?

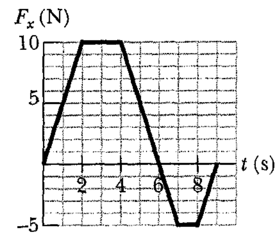

Fig. 9-50 Problem 28.

••29 Figure 9-51 shows a 0.300 kg baseball just before and just after it collides with a bat. Just before, the ball has velocity $\vec{v}_1$ of magnitude 12.0 m/s and angle $\theta_1 = 35.0°$. Just after, it is traveling directly upward with velocity $\vec{v}_2$ of magnitude 10.0 m/s. The duration of the collision is 2.00 ms. What are the (a) magnitude and (b) direction (relative to the positive direction of the x axis) of the impulse on the ball from the bat? What are the (c) magnitude and (d) direction of the average force on the ball from the bat?

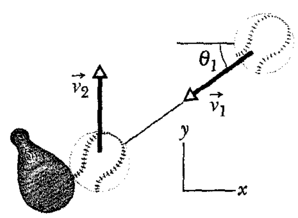

Fig. 9-51 Problem 29.

••30 Basilisk lizards can run across the top of a water surface (Fig. 9-52). With each step, a lizard first slaps its foot

Photo (waste of toner)

Fig. 9-52 Problem 30. Lizard running across water.

against the water and then pushes it down into the water rapidly enough to form an air cavity around the top of the foot. To avoid having to pull the foot back up against water drag in order to complete the step, the lizard withdraws the foot before water can flow into the air cavity. If the lizard is not to sink, the average upward impulse on the lizard during this full action of slap, downward push, and withdrawal must match the downward impulse due to the gravitational force. Suppose the mass of a basilisk lizard is 90.0 g, the mass of each foot is 3.00 g, the speed of a foot as it slaps the water is 1.50 m/s, and the time for a single step is 0.600 s. (a) What is the magnitude of the impulse on the lizard during the slap? (Assume this impulse is directly upward.) (b) During the 0.600 s duration of a step, what is the downward impulse on the lizard due to the gravitational force? (c) Which action, the slap or the push, provides the primary support for the lizard, or are they approximately equal in their support?

••31 *Two average forces.* A steady stream of 0.250 kg snowballs is shot perpendicularly into a wall at a speed of 4.00 m/s. Each ball sticks to the wall. Figure 9-53 gives the magnitude F of the force on the wall as a function of time t for two of the snowball impacts. Impacts occur with a repetition time interval Δt_r = 50.0 ms, last a duration time interval Δt_d = 10 ms, and produce isosceles triangles on the graph, with each impact reaching a force maximum F_{max} = 200 N. During each impact, what are the magnitudes of (a) the impulse and (b) the average force on the wall? (c) During a time interval of many impacts, what is the magnitude of the average force on the wall?

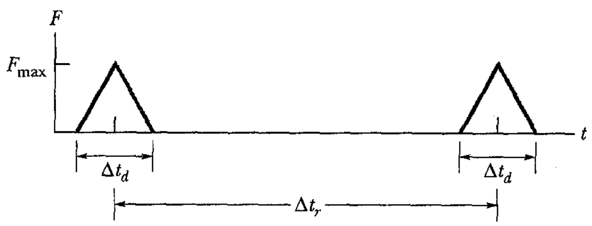

Fig. 9-53 Problem 31.

••32 Figure 9-54 shows an approximate plot of force magnitude F versus time t during the collision of a 58 g Superball with a wall. The initial velocity of the ball is 34 m/s perpendicular to the wall; it rebounds directly back with approximately the same speed, also perpendicular to the wall. What is F_{max}, the maximum magnitude of the force on the ball from the wall during the collision?

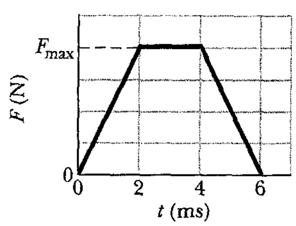

Fig. 9-54 Problem 32.

••33 In the overhead view of Fig. 9-55, a 300 g ball with a speed v of 6.0 m/s strikes a wall at an angle θ of 30° and then rebounds with the same speed and angle. It is in contact with the wall for 10 ms. In unit-vector notation, what are (a) the impulse on the ball from the wall and (b) the average force on the wall from the ball?

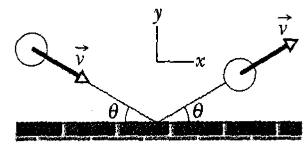

Fig. 9-55 Problem 33.

••34 A 0.25 kg puck is initially stationary on an ice surface with negligible friction. At time t = 0, a horizontal force begins to move the puck. The force is given by $\vec{F} = (12.0 - 3.00t^2)\hat{i}$, with $\vec{F}$ in newtons and t in seconds, and it acts until its magnitude is zero. (a) What is the magnitude of the impulse on the puck from the force between t = 0.500 s and t = 1.25 s? (b) What is the change in momentum of the puck between t = 0 and the instant at which F = 0?

sec. 9-7 Conservation of Linear Momentum

•35 A 91 kg man lying on a surface of negligible friction shoves a 68 g stone away from himself, giving it a speed of 4.0 m/s. What speed does the man acquire as a result? SSM

•36 A mechanical toy slides along an x axis on a frictionless surface with a velocity of $(-0.40 \text{ m/s})\hat{i}$ when two internal springs separate the toy into three parts, as given in the table. What is the velocity of part A?

Part	Mass (kg)	Velocity (m/s)
A	0.50	?
B	0.60	$0.20\hat{i}$
C	0.20	$0.30\hat{i}$

•37 A space vehicle is traveling at 4300 km/h relative to Earth when the exhausted rocket motor is disengaged and sent backward with a speed of 82 km/h relative to the command module. The mass of the motor is four times the mass of the module. What is the speed of the command module relative to Earth just after the separation?

••38 Figure 9-56 shows a two-ended "rocket" that is initially stationary on a frictionless floor, with its center at the origin of an x axis. The rocket consists of a central block C (of mass M = 6.00 kg) and blocks L and R (each of mass m = 2.00 kg) on the left and right sides. Small explosions can shoot either of the side blocks away from block C and along the x axis. Here is the sequence: (1) At time t = 0, block L is shot to the left with a speed of 3.00 m/s *relative* to the velocity that the explosion gives the rest of the rocket. (2) Next, at time t = 0.80 s, block R is shot to the right with a speed of 3.00 m/s *relative* to the velocity that block C then has. At t = 2.80 s, what are (a) the velocity of block C and (b) the position of its center?

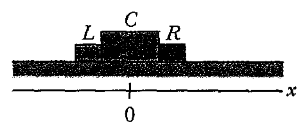

Fig. 9-56 Problem 38.

••39 A 4.0 kg mess kit sliding on a frictionless surface explodes into two 2.0 kg parts, one moving at 3.0 m/s, due north, and the other at 5.0 m/s, 30° north of east. What is the original speed of the mess kit?

••40 An object, with mass m and speed v relative to an observer, explodes into two pieces, one three times as massive as the other; the explosion takes place in deep space. The less massive piece stops relative to the observer. How much kinetic energy is added to the system during the explosion, as measured in the observer's reference frame?

••41 A vessel at rest at the origin of an xy coordinate system explodes into three pieces. Just after the explosion, one piece, of mass m, moves with velocity $(-30\text{ m/s})\hat{\text{i}}$ and a second piece, also of mass m, moves with velocity $(-30\text{ m/s})\hat{\text{j}}$. The third piece has mass $3m$. Just after the explosion, what are the (a) magnitude and (b) direction of the velocity of the third piece?

••42 In Fig. 9-57, a stationary block explodes into two pieces L and R that slide across a frictionless floor and then into regions with friction, where they stop. Piece L, with a mass of 2.0 kg, encounters a coefficient of kinetic friction $\mu_L = 0.40$ and slides to a stop in distance $d_L = 0.15$ m. Piece R encounters a coefficient of kinetic friction $\mu_R = 0.50$ and slides to a stop in distance $d_R = 0.25$ m. What was the mass of the block?

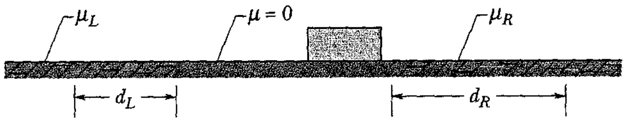

Fig. 9-57 Problem 42.

••43 A 20.0 kg body is moving through space in the positive direction of an x axis with a speed of 200 m/s when, due to an internal explosion, it breaks into three parts. One part, with a mass of 10.0 kg, moves away from the point of explosion with a speed of 100 m/s in the positive y direction. A second part, with a mass of 4.00 kg, moves in the negative x direction with a speed of 500 m/s. (a) In unit-vector notation, what is the velocity of the third part? (b) How much energy is released in the explosion? Ignore effects due to the gravitational force. SSM ILW WWW

•••44 Particle A and particle B are held together with a compressed spring between them. When they are released, the spring pushes them apart, and they then fly off in opposite directions, free of the spring. The mass of A is 2.00 times the mass of B, and the energy stored in the spring was 60 J. Assume that the spring has negligible mass and that all its stored energy is transferred to the particles. Once that transfer is complete, what are the kinetic energies of (a) particle A and (b) particle B?

sec. 9-9 Inelastic Collisions in One Dimension

•45 A 5.20 g bullet moving at 672 m/s strikes a 700 g wooden block at rest on a frictionless surface. The bullet emerges, traveling in the same direction with its speed reduced to 428 m/s. (a) What is the resulting speed of the block? (b) What is the speed of the bullet–block center of mass?

•46 A bullet of mass 10 g strikes a ballistic pendulum of mass 2.0 kg. The center of mass of the pendulum rises a vertical distance of 12 cm. Assuming that the bullet remains embedded in the pendulum, calculate the bullet's initial speed.

••47 A collision occurs between a 2.00 kg particle traveling with velocity $\vec{v}_1 = (-4.00\text{ m/s})\hat{\text{i}} + (-5.00\text{ m/s})\hat{\text{j}}$ and a 4.00 kg particle traveling with velocity $\vec{v}_2 = (6.00\text{ m/s})\hat{\text{i}} + (-2.00\text{ m/s})\hat{\text{j}}$. The collision connects the two particles. What then is their velocity in (a) unit-vector notation and as a (b) magnitude and (c) angle?

••48 In the "before" part of Fig. 9-58, car A (mass 1100 kg) is stopped at a traffic light when it is rear-ended by car B (mass 1400 kg). Both cars then slide with locked wheels until the frictional force from the slick road (with a low μ_k of 0.13) stops them, at distances $d_A = 8.2$ m and $d_B = 6.1$ m. What are the speeds of (a) car A and (b) car B at the start of the sliding, just after the collision? (c) Assuming that linear momentum is conserved during the collision, find the speed of car B just before the collision. (d) Explain why this assumption may be invalid.

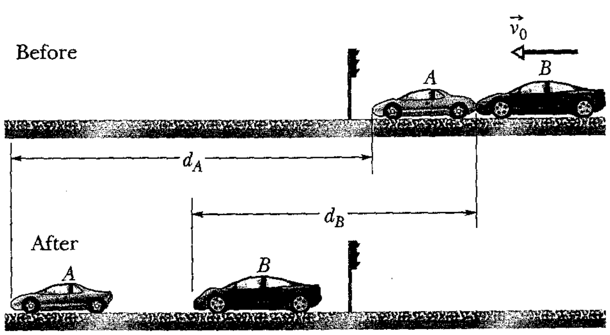

Fig. 9-58 Problem 48.

••49 In Fig. 9-59a, a 3.50 g bullet is fired horizontally at two blocks at rest on a frictionless table. The bullet passes through block 1 (mass 1.20 kg) and embeds itself in block 2 (mass 1.80 kg). The blocks end up with speeds $v_1 = 0.630$ m/s and $v_2 = 1.40$ m/s (Fig. 9-59b). Neglecting the material removed from block 1 by the bullet, find the speed of the bullet as it (a) leaves and (b) enters block 1.

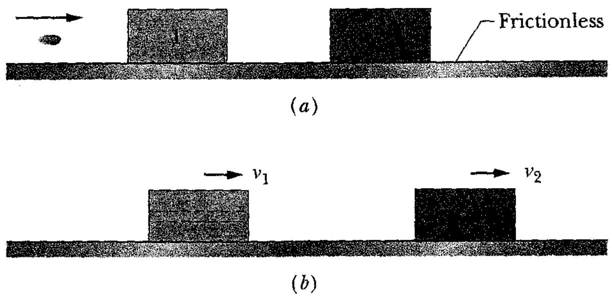

Fig. 9-59 Problem 49.

••50 In Fig. 9-60, a 10 g bullet moving directly upward at 1000 m/s strikes and passes through the center of mass of a 5.0 kg block initially at rest. The bullet emerges from the block moving directly upward at 400 m/s. To what maximum height does the block then rise above its initial position?

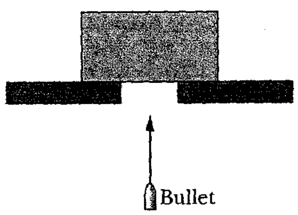

Fig. 9-60 Problem 50.

••51 A 5.0 kg block with a speed of 3.0 m/s collides with a 10 kg block that has a speed of 2.0 m/s in the same direction. After the collision, the 10 kg block is observed to be traveling in the original direction with a speed of 2.5 m/s. (a) What is the velocity of the 5.0 kg block immediately after the collision? (b) By how much does the total kinetic energy of the system of two blocks change because of the collision? (c) Suppose, instead, that the 10 kg block ends up with a speed of 4.0 m/s. What then is the change in the total kinetic energy? (d) Account for the result you obtained in (c). ILW

•••52 A completely inelastic collision occurs between two balls of wet putty that move directly toward each other along a vertical axis. Just before the collision, one ball, of mass 3.0 kg, is moving upward at 20 m/s and the other ball, of mass 2.0 kg, is moving downward at 12 m/s. How high do the combined two balls of putty rise above the collision point? (Neglect air drag.)

•••53 In Fig. 9-61, block 1 (mass 2.0 kg) is moving rightward at 10 m/s and block 2 (mass 5.0 kg) is moving rightward at 3.0 m/s. The surface is frictionless, and a spring with a spring constant of 1120 N/m is fixed to block 2. When the blocks collide, the compression of the spring is maximum at the instant the blocks have the same velocity. Find the maximum compression. ILW

Fig. 9-61 Problems 53 and 124.

•••54 In Fig. 9-62, block 2 (mass 1.0 kg) is at rest on a frictionless surface and touching the end of an unstretched spring of spring constant 200 N/m. The other end of the spring is fixed to a wall. Block 1 (mass 2.0 kg), traveling at speed v_1 = 4.0 m/s, collides with block 2, and the two blocks stick together. When the blocks momentarily stop, by what distance is the spring compressed?

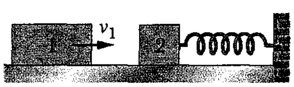

Fig. 9-62 Problem 54.

sec. 9-10 Elastic Collisions in One Dimension

•55 A cart with mass 340 g moving on a frictionless linear air track at an initial speed of 1.2 m/s undergoes an elastic collision with an initially stationary cart of unknown mass. After the collision, the first cart continues in its original direction at 0.66 m/s. (a) What is the mass of the second cart? (b) What is its speed after impact? (c) What is the speed of the two-cart center of mass? SSM

•56 In Fig. 9-63, block *A* (mass 1.6 kg) slides into block *B* (mass 2.4 kg), along a frictionless surface. The directions of three velocities before (*i*) and after (*f*) the collision are indicated; the corresponding speeds are v_{Ai} = 5.5 m/s, v_{Bi} = 2.5 m/s, and v_{Bf} = 4.9 m/s. What are the (a) speed and (b) direction (left or right) of velocity $\vec{v}_{Af}$? (c) Is the collision elastic?

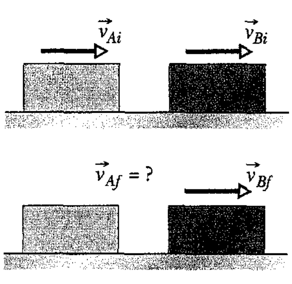

Fig. 9-63 Problem 56.

•57 Two titanium spheres approach each other head-on with the same speed and collide elastically. After the collision, one of the spheres, whose mass is 300 g, remains at rest. (a) What is the mass of the other sphere? (b) What is the speed of the two-sphere center of mass if the initial speed of each sphere is 2.00 m/s?

••58 In Fig. 9-64, particle 1 of mass m_1 = 0.30 kg slides rightward along an x axis on a frictionless floor with a speed of 2.0 m/s. When it reaches x = 0, it undergoes a one-dimensional elastic collision with stationary particle 2 of mass m_2 = 0.40 kg. When particle 2 then reaches a wall at x_w = 70 cm, it bounces from the wall with no loss of speed. At what position on the x axis does particle 2 then collide with particle 1?

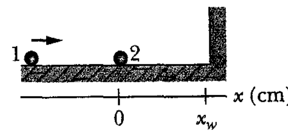

Fig. 9-64 Problem 58.

••59 A body of mass 2.0 kg makes an elastic collision with another body at rest and continues to move in the original direction but with one-fourth of its original speed. (a) What is the mass of the other body? (b) What is the speed of the two-body center of mass if the initial speed of the 2.0 kg body was 4.0 m/s? SSM

••60 A steel ball of mass 0.500 kg is fastened to a cord that is 70.0 cm long and fixed at the far end. The ball is then released when the cord is horizontal (Fig. 9-65). At the bottom of its path, the ball strikes a 2.50 kg steel block initially at rest on a frictionless surface. The collision is elastic. Find (a) the speed of the ball and (b) the speed of the block, both just after the collision.

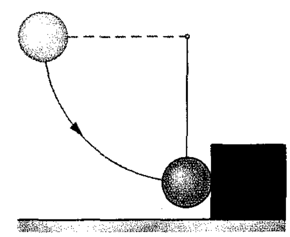

Fig. 9-65 Problem 60.

••61 Block 1 of mass m_1 slides along a frictionless floor and into a one-dimensional elastic collision with stationary block 2 of mass $m_2 = 3m_1$. Prior to the collision, the center of mass of the two-block system had a speed of 3.00 m/s. Afterward, what are the speeds of (a) the center of mass and (b) block 2?

••62 In Fig. 9-66, block 1 of mass m_1 slides from rest along a frictionless ramp from height h = 2.50 m and then collides with stationary block 2, which has mass $m_2 = 2.00m_1$. After the collision, block 2 slides into a region where the coefficient of kinetic friction μ_k is 0.500 and comes to a stop in distance d within that region. What is the value of distance d if the collision is (a) elastic and (b) completely inelastic?

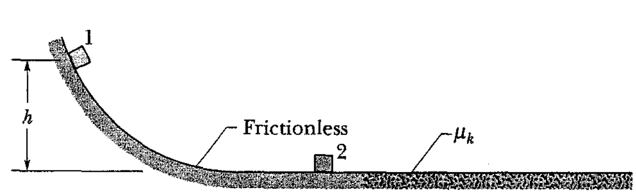

Fig. 9-66 Problem 62.

•••63 A small ball of mass m is aligned above a larger ball of mass M = 0.63 kg (with a slight separation, as with the baseball and basketball of Fig. 9-67*a*), and the two are dropped simultaneously from height h = 1.8 m. (Assume the radius of each ball is negligible relative to h.) (a) If the larger ball rebounds elastically from the floor and then the small ball rebounds elastically from the larger ball, what value of m results in the larger ball stopping when it collides with the small ball? (b) What height does the small ball then reach (Fig. 9-67b)? SSM WWW

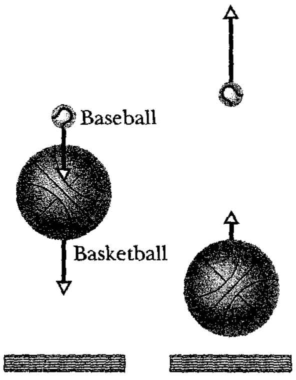

Fig. 9-67 Problem 63.

•••64 In Fig. 9-68, puck 1 of mass m_1 = 0.20 kg is sent sliding across a frictionless lab bench, to undergo a one-dimensional elastic collision with stationary puck 2. Puck 2 then slides off the bench and lands a distance d from the base of the bench. Puck 1 rebounds from the collision and slides off the opposite edge of the bench, landing a distance $2d$ from the base of the bench. What is the mass of puck 2? (*Hint:* Be careful with signs.)

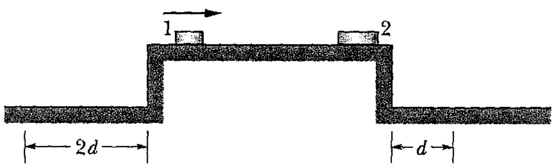

Fig. 9-68 Problem 64.

sec. 9-11 Collisions in Two Dimensions

••65 In Fig. 9-22, projectile particle 1 is an alpha particle and target particle 2 is an oxygen nucleus. The alpha particle is scattered at angle θ_1 = 64.0° and the oxygen nucleus recoils with speed 1.20×10^5 m/s and at angle θ_2 = 51.0°. In atomic mass units, the mass of the alpha particle is 4.00 u and the mass of the oxygen nucleus is 16.0 u. What are the (a) final and (b) initial speeds of the alpha particle? ILW

••66 Two 2.0 kg bodies, A and B, collide. The velocities before the collision are $\vec{v}_A = (15\hat{i} + 30\hat{j})$ m/s and $\vec{v}_B = (-10\hat{i} + 5.0\hat{j})$ m/s. After the collision, $\vec{v}'_A = (-5.0\hat{i} + 20\hat{j})$ m/s. What are (a) the final velocity of B and (b) the change in the total kinetic energy (including sign)?

••67 A projectile proton with a speed of 500 m/s collides elastically with a target proton initially at rest. The two protons then move along perpendicular paths, with the projectile path at 60° from the original direction. After the collision, what are the speeds of (a) the target proton and (b) the projectile proton?

••68 Ball B, moving in the positive direction of an x axis at speed v, collides with stationary ball A at the origin. A and B have different masses. After the collision, B moves in the negative direction of the y axis at speed $v/2$. (a) In what direction does A move? (b) Show that the speed of A cannot be determined from the given information.

•••69 After a completely inelastic collision, two objects of the same mass and same initial speed move away together at half their initial speed. Find the angle between the initial velocities of the objects. SSM

sec. 9-12 Systems with Varying Mass: A Rocket

•70 Consider a rocket that is in deep space and at rest relative to an inertial reference frame. The rocket's engine is to be fired for a certain interval. What must be the rocket's *mass ratio* (ratio of initial to final mass) over that interval if the rocket's original speed relative to the inertial frame is to be equal to (a) the exhaust speed (speed of the exhaust products relative to the rocket) and (b) 2.0 times the exhaust speed?

•71 A rocket that is in deep space and initially at rest relative to an inertial reference frame has a mass of 2.55×10^5 kg, of which 1.81×10^5 kg is fuel. The rocket engine is then fired for 250 s while fuel is consumed at the rate of 480 kg/s. The speed of the exhaust products relative to the rocket is 3.27 km/s. (a) What is the rocket's thrust? After the 250 s firing, what are (b) the mass and (c) the speed of the rocket? SSM ILW

•72 A 6090 kg space probe moving nose-first toward Jupiter at 105 m/s relative to the Sun fires its rocket engine, ejecting 80.0 kg of exhaust at a speed of 253 m/s relative to the space probe. What is the final velocity of the probe?

•73 In Fig. 9-69, two long barges are moving in the same direction in still water, one with a speed of 10 km/h and the other with a speed of 20 km/h. While they are passing each other, coal is shoveled from the slower to the faster one at a rate of 1000 kg/min. How much additional force must be provided by the driving engines of (a) the faster barge and (b) the slower barge if neither is to change speed? Assume that the shoveling is always perfectly sideways and that the frictional forces between the barges and the water do not depend on the mass of the barges. SSM

Photo (waste of toner)

Fig. 9-69 Problem 73.

Additional Problems

74 Figure 9-70 shows an overhead view of two particles sliding at constant velocity over a frictionless surface. The particles have the same mass and the same initial speed v = 4.00 m/s, and they collide where their paths intersect. An x axis is arranged to bisect the

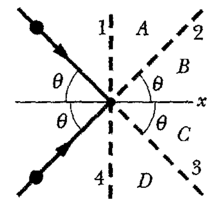

Fig. 9-70 Problem 74.

angle between their incoming paths, so that $\theta = 40.0°$. The region to the right of the collision is divided into four lettered sections by the x axis and four numbered dashed lines. In what region or along what line do the particles travel if the collision is (a) completely inelastic, (b) elastic, and (c) inelastic? What are their final speeds if the collision is (d) completely inelastic and (e) elastic?

75 *Speed amplifier.* In Fig. 9-71, block 1 of mass m_1 slides along an x axis on a frictionless floor with a speed of $v_{1i} = 4.00$ m/s. Then it undergoes a one-dimensional elastic collision with stationary block 2 of mass $m_2 = 0.500m_1$. Next, block 2 undergoes a one-dimensional elastic collision with stationary block 3 of mass $m_3 = 0.500m_2$. (a) What then is the speed of block 3? Are (b) the speed, (c) the kinetic energy, and (d) the momentum of block 3 greater than, less than, or the same as the initial values for block 1?

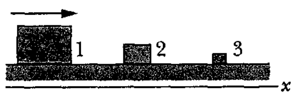

Fig. 9-71 Problem 75.

76 *Speed deamplifier.* In Fig. 9-72, block 1 of mass m_1 slides along an x axis on a frictionless floor at speed 4.00 m/s. Then it undergoes a one-dimensional elastic collision with stationary block 2 of mass $m_2 = 2.00m_1$. Next, block 2 undergoes a one-dimensional elastic collision with stationary block 3 of mass $m_3 = 2.00m_2$. (a) What then is the speed of block 3? Are (b) the speed, (c) the kinetic energy, and (d) the momentum of block 3 greater than, less than, or the same as the initial values for block 1?

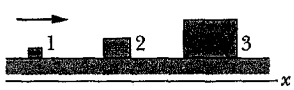

Fig. 9-72 Problem 76.

77 *"Relative" is an important word.* In Fig. 9-73, block L of mass $m_L = 1.00$ kg and block R of mass $m_R = 0.500$ kg are held in place with a compressed spring between them. When the blocks are released, the spring sends them sliding across a frictionless floor. (The spring has negligible mass and falls to the floor after the blocks leave it.) (a) If the spring gives block L a release speed of 1.20 m/s *relative* to the floor, how far does block R travel in the next 0.800 s? (b) If, instead, the spring gives block L a release speed of 1.20 m/s *relative* to the velocity that the spring gives block R, how far does block R travel in the next 0.800 s?

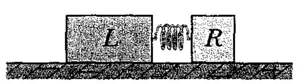

Fig. 9-73 Problem 77.

78 A rocket of mass M moves along an x axis at the constant speed $v_i = 40$ m/s. A small explosion separates the rocket into a rear section (of mass m_1) and a front section; both sections move along the x axis. The relative speed between the rear and front sections is 20 m/s. What are (a) the minimum possible value of final speed v_f of the front section and (b) for what limiting value of m_1 does it occur? (c) What is the maximum possible value of v_f and (d) for what limiting value of m_1 does it occur?

79 A railroad car moves under a grain elevator at a constant speed of 3.20 m/s. Grain drops into the car at the rate of 540 kg/min. What is the magnitude of the force needed to keep the car moving at constant speed if friction is negligible?

80 A man (weighing 915 N) stands on a long railroad flatcar (weighing 2415 N) as it rolls at 18.2 m/s in the positive direction of an x axis, with negligible friction. Then the man runs along the flatcar in the negative x direction at 4.00 m/s relative to the flatcar. What is the resulting increase in the speed of the flatcar?

81 In Fig. 9-74, two identical containers of sugar are connected by a cord that passes over a frictionless pulley. The cord and pulley have negligible mass, each container and its sugar together have a mass of 500 g, the centers of the containers are separated by 50 mm, and the containers are held fixed at the same height. What is the horizontal distance between the center of container 1 and the center of mass of the two-container system (a) initially and (b) after 20 g of sugar is transferred from container 1 to container 2? After the transfer and after the containers are released, (c) in what direction and (d) at what acceleration magnitude does the center of mass move?

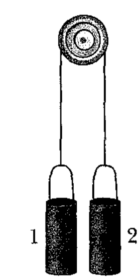

Fig. 9-74 Problem 81.

82 Figure 9-75 shows a uniform square plate of edge length $6d = 6.0$ m from which a square piece of edge length $2d$ has been removed. What are (a) the x coordinate and (b) the y coordinate of the center of mass of the remaining piece?

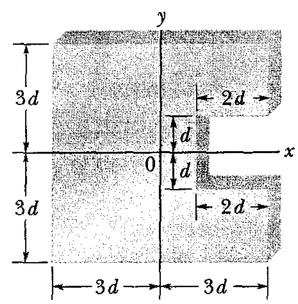

Fig. 9-75 Problem 82.

83 A 2.65 kg stationary package explodes into three parts that then slide across a frictionless floor. The package had been at the origin of a coordinate system. Part 1 has mass $m_1 = 0.500$ kg and velocity $(10.0\hat{i} + 12.0\hat{j})$ m/s. Part 2 has mass $m_2 = 0.750$ kg and a speed of 14.0 m/s, and travels at an angle 110° (counterclockwise from the positive direction of the x axis). (a) What is the speed of part 3? (b) In what direction does it travel?

84 Particle 1 with mass 3.0 kg and velocity $(5.0 \text{ m/s})\hat{i}$ undergoes a one-dimensional elastic collision with particle 2 with mass 2.0 kg and velocity $(-6.0 \text{ m/s})\hat{i}$. After the collision, what are the velocities of (a) particle 1 and (b) particle 2?

85 The last stage of a rocket, which is traveling at a speed of 7600 m/s, consists of two parts that are clamped together: a rocket case with a mass of 290.0 kg and a payload capsule with a mass of 150.0 kg. When the clamp is released, a compressed spring causes the two parts to separate with a relative speed of 910.0 m/s. What are the speeds of (a) the rocket case and (b) the payload after they have separated? Assume that all velocities are along the same line. Find the total kinetic energy of the two parts (c) before and (d) after they separate. (e) Account for the difference.

86 Particle 1 of mass 200 g and speed 3.00 m/s undergoes a one-dimensional collision with stationary particle 2 of mass

400 g. What is the magnitude of the impulse on particle 1 if the collision is (a) elastic and (b) completely inelastic?

87 An object is tracked by a radar station and found to have a position vector given by $\vec{r} = (3500 - 160t)\hat{i} + 2700\hat{j} + 300\hat{k}$, with $\vec{r}$ in meters and t in seconds. The radar station's x axis points east, its y axis north, and its z axis vertically up. If the object is a 250 kg meteorological missile, what are (a) its linear momentum, (b) its direction of motion, and (c) the net force on it?

88 In the two-sphere arrangement of Sample Problem 9-10, assume that sphere 1 has a mass of 50 g and an initial height of $h_1 = 9.0$ cm, and that sphere 2 has a mass of 85 g. After sphere 1 is released and collides elastically with sphere 2, what height is reached by (a) sphere 1 and (b) sphere 2? After the next (elastic) collision, what height is reached by (c) sphere 1 and (d) sphere 2? (*Hint:* Do not use rounded-off values.)

89 In Fig. 9-76, an 80 kg man is on a ladder hanging from a balloon that has a total mass of 320 kg (including the basket passenger). The balloon is initially stationary relative to the ground. If the man on the ladder begins to climb at 2.5 m/s relative to the ladder, (a) in what direction and (b) at what speed does the balloon move? (c) If the man then stops climbing, what is the speed of the balloon?

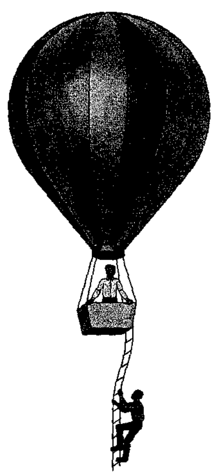

Fig. 9-76 Problem 89.

90 A 0.15 kg ball hits a wall with a velocity of $(5.00\text{ m/s})\hat{i} + (6.50\text{ m/s})\hat{j} + (4.00\text{ m/s})\hat{k}$. It rebounds from the wall with a velocity of $(2.00\text{ m/s})\hat{i} + (3.50\text{ m/s})\hat{j} + (-3.20\text{ m/s})\hat{k}$. What are (a) the change in the ball's momentum, (b) the impulse on the ball, and (c) the impulse on the wall?

91 At a certain instant, four particles have the xy coordinates and velocities given in the following table. At that instant, what are the (a) x and (b) y coordinates of their center of mass and (c) the velocity of their center of mass?

Particle	Mass (kg)	Position (m)	Velocity (m/s)
1	2.0	0, 3.0	$-9.0\hat{j}$
2	4.0	3.0, 0	$6.0\hat{i}$
3	3.0	0, −2.0	$6.0\hat{j}$
4	12	−1.0, 0	$-2.0\hat{i}$

92 A 0.550 kg ball falls directly down onto concrete, hitting it with a speed of 12.0 m/s and rebounding directly upward with a speed of 3.00 m/s. Extend a y axis upward. In unit-vector notation, what are (a) the change in the ball's momentum, (b) the impulse on the ball, and (c) the impulse on the concrete?

93 A body is traveling at 2.0 m/s along the positive direction of an x axis; no net force acts on the body. An internal explosion separates the body into two parts, each of 4.0 kg, and increases the total kinetic energy by 16 J. The forward part continues to move in the original direction of motion. What are the speeds of (a) the rear part and (b) the forward part?

94 Block 1, with mass m_1 and speed 4.0 m/s, slides along an x axis on a frictionless floor and then undergoes a one-dimensional elastic collision with stationary block 2, with mass $m_2 = 0.40m_1$. The two blocks then slide into a region where the coefficient of kinetic friction is 0.50; there they stop. How far into that region do (a) block 1 and (b) block 2 slide?

95 At time $t = 0$, force $\vec{F}_1 = (-4.00\hat{i} + 5.00\hat{j})$ N acts on an initially stationary particle of mass 2.00×10^{-3} kg and force $\vec{F}_2 = (2.00\hat{i} - 4.00\hat{j})$ N acts on an initially stationary particle of mass 4.00×10^{-3} kg. From time $t = 0$ to $t = 2.00$ ms, what are the (a) magnitude and (b) angle (relative to the positive direction of the x axis) of the displacement of the center of mass of the two-particle system? (c) What is the kinetic energy of the center of mass at $t = 2.00$ ms?

96 An atomic nucleus at rest at the origin of an xy coordinate system transforms into three particles. Particle 1, mass 16.7×10^{-27} kg, moves away from the origin at velocity $(6.00 \times 10^6\text{ m/s})\hat{i}$; particle 2, mass 8.35×10^{-27} kg, moves away at velocity $(-8.00 \times 10^6\text{ m/s})\hat{j}$. (a) In unit-vector notation, what is the linear momentum of the third particle, mass 11.7×10^{-27} kg? (b) How much kinetic energy appears in this transformation?

97 Figure 9-77 shows two 22.7 kg ice sleds that are placed a short distance apart, one directly behind the other. A 3.63 kg cat initially standing on one sled jumps to the other one and then back to the first. Both jumps are made at a speed of 3.05 m/s relative to the ice. What are the final speeds of (a) the first sled and (b) the other sled?

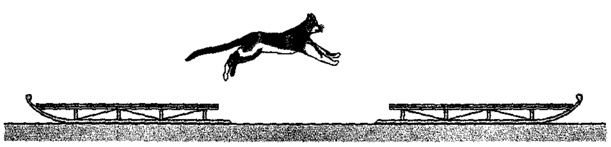

Fig. 9-77 Problem 97.

98 In the ballistic pendulum of Sample Problem 9-8, assume the bullet's mass m is 8.00 g, the block's mass M is 7.00 kg, and the vertical distance h the block rises is 5.00 cm. (a) When the bullet is fired into the block, what fraction of the bullet's initial kinetic energy remains as mechanical energy of the bullet–block pendulum after the collision? (b) If we increase the initial speed of the bullet, does that fraction increase, decrease, or remain the same? Why?

99 A pellet gun fires ten 2.0 g pellets per second with a speed of 500 m/s. The pellets are stopped by a rigid wall. What are (a) the magnitude of the momentum of each pellet, (b) the kinetic energy of each pellet, and (c) the magnitude of the average force on the wall from the stream of pellets? (d) If each pellet is in contact with the wall for 0.60 ms, what is the magnitude of the average force on the wall from each pellet during contact? (e) Why is this average force so different from the average force calculated in (c)?

100 A spacecraft is separated into two parts by detonating the explosive bolts that hold them together. The masses of the parts are 1200 kg and 1800 kg; the magnitude of the impulse on each part from the bolts is 300 N · s. With what relative speed do the two parts separate because of the detonation?

101 A 1400 kg car moving at 5.3 m/s is initially traveling north along the positive direction of a y axis. After completing a 90° right-hand turn in 4.6 s, the inattentive operator drives into a tree, which stops the car in 350 ms. In unit-vector notation, what is the impulse on the car (a) due to the turn and (b) due to the collision? What is the magnitude of the average force that acts on the car (c) during the turn and (d) during the collision? (e) What is the direction of the average force during the turn?

102 A carbon monoxide molecule lies along an x axis, with the carbon atom at $x = 0$ and the oxygen atom at $x = 1.131 \times 10^{-10}$ m. At what value of x is the molecule's center of mass located?

103 A ball having a mass of 150 g strikes a wall with a speed of 5.2 m/s and rebounds with only 50% of its initial kinetic energy. (a) What is the speed of the ball immediately after rebounding? (b) What is the magnitude of the impulse on the wall from the ball? (c) If the ball is in contact with the wall for 7.6 ms, what is the magnitude of the average force on the ball from the wall during this time interval?

104 An old Chrysler with mass 2400 kg is moving along a straight stretch of road at 80 km/h. It is followed by a Ford with mass 1600 kg moving at 60 km/h. How fast is the center of mass of the two cars moving?

105 A soccer player kicks a soccer ball of mass 0.45 kg that is initially at rest. The player's foot is in contact with the ball for 3.0×10^{-3} s, and the force of the kick is given by

$$F(t) = [(6.0 \times 10^6)t - (2.0 \times 10^9)t^2]\ \text{N}$$

for $0 \leq t \leq 3.0 \times 10^{-3}$ s, where t is in seconds. Find the magnitudes of (a) the impulse on the ball due to the kick, (b) the average force on the ball from the player's foot during the period of contact, (c) the maximum force on the ball from the player's foot during the period of contact, and (d) the ball's velocity immediately after it loses contact with the player's foot.

106 Two blocks of masses 1.0 kg and 3.0 kg are connected by a spring and rest on a frictionless surface. They are given velocities toward each other such that the 1.0 kg block travels initially at 1.7 m/s toward the center of mass, which remains at rest. What is the initial speed of the other block?

107 A railroad freight car of mass 3.18×10^4 kg collides with a stationary caboose car. They couple together, and 27.0% of the initial kinetic energy is transferred to thermal energy, sound, vibrations, and so on. Find the mass of the caboose.

108 A 75 kg man is riding on a 39 kg cart traveling at a speed of 2.3 m/s. He jumps off with zero horizontal speed relative to the ground. What is the resulting change in the cart's speed, including sign?

109 In Fig. 9-78, a ball of mass $m = 60$ g is shot with speed $v_i = 22$ m/s into the barrel of a spring gun of mass $M = 240$ g initially at rest on a frictionless surface. The ball sticks in the barrel at the point of maximum compression of the spring. Assume that the increase in thermal energy due to friction between the ball and the barrel is negligible. (a) What is the speed of the spring gun after the ball stops in the barrel? (b) What fraction of the initial kinetic energy of the ball is stored in the spring?

Fig. 9-78 Problem 109.

110 A certain radioactive (parent) nucleus transforms to a different (daughter) nucleus by emitting an electron and a neutrino. The parent nucleus was at rest at the origin of an xy coordinate system. The electron moves away from the origin with linear momentum $(-1.2 \times 10^{-22}\ \text{kg} \cdot \text{m/s})\hat{\text{i}}$; the neutrino moves away from the origin with linear momentum $(-6.4 \times 10^{-23}\ \text{kg} \cdot \text{m/s})\hat{\text{j}}$. What are the (a) magnitude and (b) direction of the linear momentum of the daughter nucleus? (c) If the daughter nucleus has a mass of 5.8×10^{-26} kg, what is its kinetic energy? ILW

111 An electron undergoes a one-dimensional elastic collision with an initially stationary hydrogen atom. What percentage of the electron's initial kinetic energy is transferred to kinetic energy of the hydrogen atom? (The mass of the hydrogen atom is 1840 times the mass of the electron.)

112 A rocket is moving away from the solar system at a speed of 6.0×10^3 m/s. It fires its engine, which ejects exhaust with a speed of 3.0×10^3 m/s relative to the rocket. The mass of the rocket at this time is 4.0×10^4 kg, and its acceleration is 2.0 m/s². (a) What is the thrust of the engine? (b) At what rate, in kilograms per second, is exhaust ejected during the firing?

113 In Fig. 9-79, block 1 of mass $m_1 = 6.6$ kg is at rest on a long frictionless table that is up against a wall. Block 2 of mass m_2 is placed between block 1 and the wall and sent sliding to the left, toward block 1, with constant speed v_{2i}. Find the value of m_2 for which both blocks move with the same velocity after block 2 has collided once with block 1 and once with the wall. Assume all collisions are elastic (the collision with the wall does not change the speed of block 2).

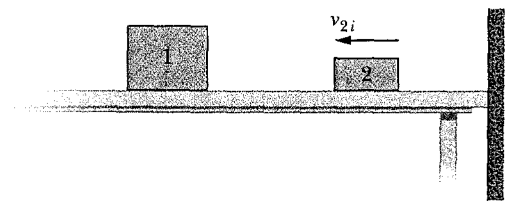

Fig. 9-79 Problem 113.

114 During a lunar mission, it is necessary to increase the speed of a spacecraft by 2.2 m/s when it is moving at 400 m/s relative to the Moon. The speed of the exhaust products from the rocket engine is 1000 m/s relative to the spacecraft. What fraction of the initial mass of the spacecraft must be burned and ejected to accomplish the speed increase?

115 In a railroad accident, a boxcar weighing 200 kN and traveling at 3.00 m/s on horizontal track slams into a stationary caboose weighing 400 kN. The collision connects the caboose to the boxcar. How much energy is transferred from kinetic energy to other forms of energy in the collision?

116 The script for an action movie calls for a small race car (of mass 1500 kg and length 3.0 m) to accelerate along a flat-top boat (of mass 4000 kg and length 14 m), from one end of the boat to the other, where the car will then jump the gap between the boat and a somewhat lower dock. You are the technical advisor for the movie. The boat will initially touch the dock, as in Fig. 9-80; the boat can slide through the water without significant resistance; both the car and the boat can be approximated as uniform in their mass distribution. Determine what the width of the gap will be just as the car is about to make the jump.

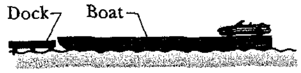

Fig. 9-80 Problem 116.

117 A 2.00 kg "particle" traveling with velocity $\vec{v} = (4.0 \text{ m/s})\hat{\text{i}}$ collides with a 4.00 kg "particle" traveling with velocity $\vec{v} = (2.0 \text{ m/s})\hat{\text{j}}$. The collision connects the two particles. What then is their velocity in (a) unit-vector notation and as (b) a magnitude and (c) an angle?

118 An electron (mass $m_1 = 9.11 \times 10^{-31}$ kg) and a proton (mass $m_2 = 1.67 \times 10^{-27}$ kg) attract each other via an electrical force. Suppose that an electron and a proton are released from rest with an initial separation $d = 3.0 \times 10^{-6}$ m. When their separation has decreased to 1.0×10^{-6} m, what is the ratio of (a) the electron's linear momentum magnitude to the proton's linear momentum magnitude, (b) the electron's speed to the proton's speed, and (c) the electron's kinetic energy to the proton's kinetic energy? (d) As the separation continues to decrease, do the answers to (a) through (c) increase, decrease, or remain the same?

119 A 140 g ball with speed 7.8 m/s strikes a wall perpendicularly and rebounds in the opposite direction with the same speed. The collision lasts 3.80 ms. What are the magnitudes of the (a) impulse and (b) average force on the wall from the ball?

120 Two identical coins are initially held at height $h = 11.0$ m. Coin 1 is dropped at time $t = 0$ and then lands on a muddy field where it sticks. Coin 2 is dropped at $t = 0.500$ s and then lands on the field. What is the acceleration $\vec{a}_{com}$ of the center of mass (com) of the two-coin system (a) between $t = 0$ and $t = 0.500$ s, (b) between $t = 0.500$ s and time t_1 when coin 1 hits and sticks, and (c) between t_1 and time t_2 when coin 2 hits and sticks? What is the speed of the center of mass when t is (d) 0.250 s, (e) 0.750 s, and (f) 1.75 s?

121 A 3.0 kg object moving at 8.0 m/s in the positive direction of an x axis has a one-dimensional elastic collision with an object of mass M, initially at rest. After the collision the object of mass M has a velocity of 6.0 m/s in the positive direction of the axis. What is mass M?

122 A 500.0 kg module is attached to a 400.0 kg shuttle craft, which moves at 1000 m/s relative to the stationary main spaceship. Then a small explosion sends the module backward with speed 100.0 m/s relative to the new speed of the shuttle craft. As measured by someone on the main spaceship, by what fraction did the kinetic energy of the module and shuttle craft increase because of the explosion?

123 A 6.00 kg model rocket is traveling horizontally and due south with a speed of 20.0 m/s when it explodes into two pieces. The velocity of one piece, with a mass of 2.00 kg, is

$$\vec{v}_1 = (-12.0 \text{ m/s})\hat{\text{i}} + (30.0 \text{ m/s})\hat{\text{j}} - (15.0 \text{ m/s})\hat{\text{k}},$$

with $\hat{\text{i}}$ pointing due east, $\hat{\text{j}}$ pointing due north, and $\hat{\text{k}}$ pointing vertically upward. (a) What is the linear momentum of the other piece, in unit-vector notation? (b) What is the kinetic energy of the other piece? (c) How much kinetic energy is produced by the explosion?

124 In Fig. 9-61, block 1 (mass 6.0 kg) is moving rightward at 8.0 m/s and block 2 (mass 4.0 kg) is moving rightward at 2.0 m/s. The surface is frictionless, and a spring with a spring constant of 8000 N/m is fixed to block 2. Eventually block 1 overtakes block 2. At the instant block 1 is moving rightward at 6.4 m/s, what are (a) the speed of block 2 and (b) the elastic potential energy of the spring?

125 A rocket sled with a mass of 2900 kg moves at 250 m/s on a set of rails. At a certain point, a scoop on the sled dips into a trough of water located between the tracks and scoops water into an empty tank on the sled. By applying the principle of conservation of linear momentum, determine the speed of the sled after 920 kg of water has been scooped up. Ignore any retarding force on the scoop.

126 In Fig. 9-81, a 3.2 kg box of running shoes slides on a horizontal frictionless table and collides with a 2.0 kg box of ballet slippers initially at rest on the edge of the table, at height $h = 0.40$ m. The speed of the 3.2 kg box is 3.0 m/s just before the collision. If the two boxes stick together because of packing tape on their sides, what is their kinetic energy just before they strike the floor?

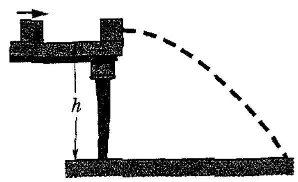

Fig. 9-81 Problem 126.

127 A 2140 kg railroad flatcar, which can move with negligible friction, is motionless next to a platform. A 242 kg sumo wrestler runs at 5.3 m/s along the platform (parallel to the track) and then jumps onto the flatcar. What is the speed of the flatcar if he then (a) stands on it, (b) runs at 5.3 m/s relative to it in his original direction, and (c) turns and runs at 5.3 m/s relative to the flatcar opposite his original direction?

128 A remote-controlled toy car of mass 2.0 kg starts from rest at the origin at $t = 0$ and moves in the positive direction of an x axis. The net force on the car as a function of time is given by Fig. 9-82. (a) What is the time rate of change of the momentum of the car at $t = 3.0$ s? (b) What is the momentum of the car at $t = 3.0$ s?

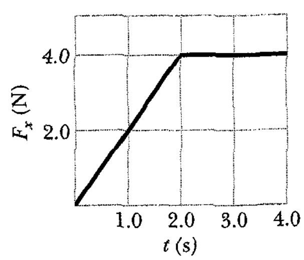

Fig. 9-82 Problem 128.

129 *Tyrannosaurus rex* may have known from experience not to run particularly fast because of the danger of tripping, in which case its short forearms would have been no help in cushioning the fall. Suppose a *T. Rex* of mass m trips while walking, toppling over, with its center of mass falling freely a distance of 1.5 m. Then its center of mass descends an additional 0.30 m due to compression of its body and the ground.

(a) In multiples of the dinosaur's weight, what is the approximate magnitude of the average vertical force on the dinosaur during its collision with the ground (during the descent of 0.30 m)? Now assume that the dinosaur is running at a speed of 19 m/s (fast) when it trips, falls to the ground, and then slides to a stop with a coefficient of kinetic friction of 0.6. Assume also that the average vertical force during the collision and sliding is that in (a). What, approximately, are (b) the magnitude of the average total force on the dinosaur from the ground (again in multiples of its weight) and (c) the sliding distance? The force magnitudes of (a) and (b) strongly suggest that the collision would injure the torso of the dinosaur. The head, which would fall farther, would suffer even greater injury.

130 The three balls in the overhead view of Fig. 9-83 are identical. Balls 2 and 3 touch each other and are aligned perpendicular to the path of ball 1. The velocity of ball 1 has magnitude $v_0 = 10$ m/s and is directed at the contact point of balls 1 and 2. After the collision, what are the (a) speed and (b) direction of the velocity of ball 2, the (c) speed and (d) direction of the velocity of ball 3, and the (e) speed and (f) direction of the velocity of ball 1? (*Hint:* With friction absent, each impulse is directed along the line connecting the centers of the colliding balls, normal to the colliding surfaces.)

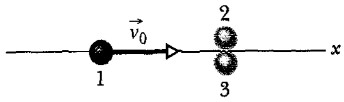

Fig. 9-83 Problem 130.

131 In the arrangement of Fig. 9-22, billiard ball 1 moving at a speed of 2.2 m/s undergoes a glancing collision with identical billiard ball 2 that is at rest. After the collision, ball 2 moves at speed 1.1 m/s, at an angle of $\theta_2 = 60°$. What are (a) the magnitude and (b) the direction of the velocity of ball 1 after the collision? (c) Do the given data suggest the collision is elastic or inelastic?

132 In a game of pool, the cue ball strikes another ball of the same mass and initially at rest. After the collision, the cue ball moves at 3.50 m/s along a line making an angle of 22.0° with the cue ball's original direction of motion, and the second ball has a speed of 2.00 m/s. Find (a) the angle between the direction of motion of the second ball and the original direction of motion of the cue ball and (b) the original speed of the cue ball. (c) Is kinetic energy (of the centers of mass, don't consider the rotation) conserved?

133 (a) How far is the center of mass of the Earth–Moon system from the center of Earth? (Appendix C gives the masses of Earth and the Moon and the distance between the two.) (b) What percentage of Earth's radius is that distance?

134 In Fig. 9-84, block 1 slides along an x axis on a frictionless floor with a speed of 0.75 m/s. When it reaches stationary block 2, the two blocks undergo an elastic collision. The following table gives the mass and length of the (uniform) blocks and also the locations of their centers at time $t = 0$. Where is the center of mass of the two-block system located (a) at $t = 0$, (b) when the two blocks first touch, and (c) at $t = 4.0$ s?

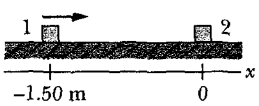

Fig. 9-84 Problem 134.

Block	Mass (kg)	Length (cm)	Center at $t = 0$
1	0.25	5.0	$x = -1.50$ m
2	0.50	6.0	$x = 0$

135 A 6100 kg rocket is set for vertical firing from the ground. If the exhaust speed is 1200 m/s, how much gas must be ejected each second if the thrust (a) is to equal the magnitude of the gravitational force on the rocket and (b) is to give the rocket an initial upward acceleration of 21 m/s^2?

136 A 3000 kg block falls vertically through 6.0 m and then collides with a 500 kg pile, driving it 3.0 cm into bedrock. Assuming that the block–pile collision is completely inelastic, find the magnitude of the average force on the pile from the bedrock during the 3.0 cm descent.

137 A railroad freight car weighing 280 kN and traveling at 1.52 m/s overtakes one weighing 210 kN and traveling at 0.914 m/s in the same direction. If the cars couple together, find (a) the speed of the cars after the collision and (b) the loss of kinetic energy during the collision. If instead, as is very unlikely, the collision is elastic, find the after-collision speed of (c) the lighter car and (d) the heavier car.

138 Two particles P and Q are released from rest 1.0 m apart. P has a mass of 0.10 kg, and Q a mass of 0.30 kg. P and Q attract each other with a constant force of 1.0×10^{-2} N. No external forces act on the system. (a) What is the speed of the center of mass of P and Q when the separation is 0.50 m? (b) At what distance from P's original position do the particles collide?

139 A 60 kg man is ice-skating due north with a velocity of 6.0 m/s when he collides with a 38 kg child. The man and child stay together and have a velocity of 3.0 m/s at an angle of 35° north of due east immediately after the collision. What are (a) the magnitude and (b) the direction of the child's velocity just before the collision?

140 A 0.20 kg hockey puck is sliding on a frictionless ice surface with a velocity of 10 m/s toward the east just before making contact with a hockey stick. What change in momentum (magnitude and direction) does the puck undergo while in contact with the stick if just afterward the velocity of the puck is (a) 20 m/s toward the east, (b) 5.0 m/s toward the east, and (c) 10 m/s toward the west?

On-Line Simulation Problems

The website http://www.wiley.com/college/halliday has simulation problems about this chapter.

(c) 1.3 m; (d) 9.1 m; (e) 2.2 J; (f) 4.0 m; (g) $(4 - x)e^{-x/4}$; (h) 4.0 m **41.** (a) 5.6×10^2 J; (b) 5.6×10^2 J **43.** (a) 30.1 J; (b) 30.1 J; (c) 0.225 **45.** (a) −2.9 kJ; (b) 3.9×10^2 J; (c) 2.1×10^2 N **47.** 20 ft · lb **49.** 75 J **51.** (a) 67 J; (b) 67 J; (c) 46 cm **53.** (a) 0.292 m; (b) 14.2 J **53.** (a) 1.5×10^2 J; (b) 5.5 m/s **57.** (a) −0.90 J; (b) 0.46 J; (c) 1.0 m/s **59.** 20 cm **61.** 3.5 m/s **63.** (a) 39.6 cm; (b) 3.64 cm **65.** (a) 10 m; (b) 49 N; (c) 4.1 m; (d) 1.2×10^2 N **67.** 4.33 m/s **69.** (a) 4.9 m/s; (b) 4.5 N; (c) 71°; (d) same **71.** (a) 4.8 N; (b) $+x$ direction; (c) 1.5 m; (d) 13.5 m; (e) 3.5 m/s **73.** (a) 5.5 m/s; (b) 5.4 m; (c) same **75.** 69 hp **77.** (a) 13 m/s; (b) 11 m/s; (c) no, 9.3 m **79.** (a) 109 J; (b) 60.3 J; (c) 68.2 J; (d) 41.0 J **81.** (a) 0.950 m/s; (b) 11.0 m **83.** (a) 24 kJ; (b) 4.7×10^2 N **85.** (a) 2.1×10^6 kg; (b) $(100 + 1.5t)^{0.5}$ m/s; (c) $(1.5 \times 10^6)/(100 + 1.5t)^{0.5}$ N; (d) 6.7 km **87.** (a) 6.75 J; (b) −6.75 J; (c)–(d) 6.75 J; (e) −6.75 J; (f) 0.459 m **89.** 3.7 J **91.** 5.4 kJ **93.** (a) 2.2 kJ; (b) 7.7×10^2 J **95.** (a) 2.7 J; (b) 1.8 J; (c) 0.39 m **97.** 80 mJ **99.** (a) 7.0 J; (b) 22 J **101.** (a) 94 J; (b) 94 J; (c) 7.7 m/s **103.** 5.5×10^6 N **105.** 25 J **107.** 24 W **109.** (a) 2.35×10^3 J; (b) 352 J **111.** −12 J **113.** (a) 8.8 m/s; (b) 2.6 kJ; (c) 1.6 kW **115.** (a) 3.7 J; (b) 4.3 J; (c) 4.3 J **117.** (a) 3.0 mm; (b) 1.1 J; (d) yes; (e) ≈ 40 J; (f) no **119.** (a) 6.0 kJ; (b) 6.0×10^2 W; (c) 3.0×10^2 W; (d) 9.0×10^2 W **121.** 3.1×10^{11} W **123.** (a) 0.75 J; (b) −1.0 J; (c) 0.25 J; (d) 1.0 J; (e) −2.0 J; (f) 1.0 J; (g) 0.75 J; (h) −3.0 J; (i) 2.3 J (j) 0 J; (k) −4.0 J; (l) 4.0 J **125.** 880 MW **127.** (a) 1.2 J; (b) 11 m/s; (c) no; (d) no **129.** (a) $v_0 = (2gL)^{0.5}$; (b) $5mg$; (c) $-mgL$; (d) $-2mgL$ **131.** (a) 2.7×10^9 J; (b) 2.7×10^9 W; (c) \$$2.4 \times 10^8$ **133.** (a) turning point on left, none on right, molecule breaks apart; (b) turning points on both left and right, molecule does not break apart; (c) -1.1×10^{-19} J; (d) 2.1×10^{-19} J; (e) ≈ 1×10^{-9} N on each, directed toward the other; (f) $r < 0.2$ nm; (g) $r > 0.2$ nm; (h) $r = 0.2$ nm **135.** (a) $U(x) = -Gm_1m_2/x$; (b) $Gm_1m_2d/x_1(x_1 + d)$

chapter 9

CP 1. (a) origin; (b) fourth quadrant; (c) on y axis below origin; (d) origin; (e) third quadrant; (f) origin **2.** (a)–(c) at the center of mass, still at the origin (their forces are internal to the system and cannot move the center of mass) **3.** (Consider slopes and Eq. 9-23.) (a) 1, 3, and then 2 and 4 tie (zero force); (b) 3 **4.** (a) unchanged; (b) unchanged (see Eq. 9-32); (c) decrease (see Eq. 9-35) **5.** (a) zero; (b) positive (initial p_y down y; final p_y up y); (c) positive direction of y **6.** (No net external force; $\vec{P}$ conserved.) (a) 0; (b) no; (c) $-x$ **7.** (a) 500 km/h; (b) 2600 km/h; (c) 1600 km/h **8.** (a) yes; (b) no (because of net force along y) **9.** (a) 10 kg · m/s; (b) 14 kg · m/s; (c) 6 kg · m/s **10.** (a) 4 kg · m/s; (b) 8 kg · m/s; (c) 3 J **11.** (a) 2 kg · m/s (conserve momentum along x); (b) 3 kg · m/s (conserve momentum along y) **Q 1.** (a) ac, cd, bc; (b) bc; (c) bd, ad **3.** d, c, a, b (zero) **5.** all tie **7.** a, c, e, f: the sum of the momenta after explosion does not equal the momentum before explosion. **9.** (a) positive; (b) positive; (c) 2 and 3 **11.** (a) forward; (b) stationary; (c) backward **P 1.** (a) 1.1 m; (b) 1.3 m; (c) toward **3.** (a) 11 cm; (b) −4.4 cm **5.** (a) 0; (b) 3.13×10^{-11} m **7.** (a) 20 cm; (b) 20 cm; (c) 16 cm **9.** (a) 28 cm; (b) 2.3 m/s **11.** (a) 22 m; (b) 9.3 m/s **13.** (a) $(2.35\hat{i} - 1.57\hat{j})$ m/s²; (b) $(2.35\hat{i} - 1.57\hat{j})t$ m/s, with t in seconds; (d) straight, at downward angle 34° **15.** 53 m **17.** 4.2 m **19.** (a) 7.5×10^4 J; (b) 3.8×10^4 kg · m/s; (c) 39° south of due east **21.** 48° **23.** (a) 67 m/s; (b) $-x$; (c) 1.2 kN; (d) $-x$ **25.** (a) 1.1 m; (b) 4.8×10^3 kg · m/s **27.** 5 N **29.** (a) 5.86 kg · m/s; (b) 59.8°; (c) 2.93 kN; (d) 59.8° **31.** (a) 1.00 N · s; (b) 100 N; (c) 20 N **33.** (a) (1.8 N · s)$\hat{j}$; (b) (−180 N)$\hat{j}$ **35.** 3.0 mm/s **37.** 4.4×10^3 km/h **39.** 3.5 m/s **41.** (a) 14 m/s; (b) −45° **43.** (a) $(1.00\hat{i} - 0.167\hat{j})$ km/s; (b) 3.23 MJ **45.** (a) 1.81 m/s; (b) 4.96 m/s **47.** (a) (2.67 m/s)$\hat{i}$ + (−3.00 m/s)$\hat{j}$; (b) 4.01 m/s; (c) 48.4° **49.** (a) 721 m/s; (b) 937 m/s **51.** (a) +2.0 m/s; (b) −1.3 J; (c) +40 J; (d) system got energy from some source, such as a small explosion **53.** 25 cm **55.** (a) 99 g; (b) 1.9 m/s; (c) 0.93 m/s **57.** (a) 100 g; (b) 1.0 m/s **59.** (a) 1.2 kg; (b) 2.5 m/s **61.** (a) 3.00 m/s; (b) 6.00 m/s **63.** (a) 0.21 kg; (b) 7.2 m **65.** (a) 4.15×10^5 m/s; (b) 4.84×10^5 m/s **67.** (a) 433 m/s; (b) 250 m/s **69.** 120° **71.** (a) 1.57×10^6 N; (b) 1.35×10^5 kg; (c) 2.08 km/s **73.** (a) 46 N; (b) none **75.** (a) 7.11 m/s; (b) greater; (c) less; (d) less **77.** (a) 1.92 m; (b) 0.640 m **79.** 28.8 N **81.** (a) 25 mm; (b) 26 mm; (c) down; (d) 1.6×10^{-2} m/s² **83.** (a) 11.4 m/s; (b) 95.1° **85.** (a) 7290 m/s; (b) 8200 m/s; (c) 1.271×10^{10} J; (d) 1.275×10^{10} J **87.** (a) $(-4.0 \times 10^4$ kg · m/s$)\hat{i}$; (b) due west; (c) 0 **89.** (a) down; (b) 0.50 m/s; (c) 0 **91.** (a) 0; (b) 0; (c) 0 **93.** (a) 0; (b) 4.0 m/s **95.** (a) 0.745 mm; (b) 153°; (c) 1.67 mJ **97.** (a) 0.841 m/s; (b) 0.975 m/s **99.** (a) 1.0 kg · m/s; (b) 2.5×10^2 J; (c) 10 N; (d) 1.7 kN; (e) answer for (c) includes time between pellet collisions **101.** (a) $(7.4 \times 10^3$ N · s$)\hat{i}$ − $(7.4 \times 10^3$ N · s$)\hat{j}$; (b) $(-7.4 \times 10^3$ N · s$)\hat{i}$; (c) 2.3×10^3 N; (d) 2.1×10^4 N; (e) −45° **103.** (a) 3.7 m/s; (b) 1.3 N · s; (c) 1.8×10^2 N **105.** (a) 9.0 kg · m/s; (b) 3.0 kN; (c) 4.5 kN; (d) 20 m/s **107.** 1.18×10^4 kg **109.** (a) 4.4 m/s; (b) 0.80 **111.** 0.22% **113.** 2.2 kg **115.** 61.2 kJ **117.** (a) (1.3 m/s)$\hat{i}$ + (1.3 m/s)$\hat{j}$; (b) 1.9 m/s; (c) 45° **119.** (a) 2.18 kg · m/s; (b) 575 N **121.** 5.0 kg **123.** (a) (24.0 kg · m/s)$\hat{i}$ − (180 kg · m/s)$\hat{j}$ + (30.0 kg · m/s)$\hat{k}$; (b) 4.23 kJ; (c) 4.30 kJ **125.** 190 m/s **127.** (a) 0.54 m/s; (b) 0; (c) 1.1 m/s **129.** (a) $5mg$; (b) $7mg$; (c) 5 m **131.** (a) 1.9 m/s; (b) −30°; (c) elastic **133.** (a) 4.6×10^3 km; (b) 73% **135.** (a) 50 kg/s; (b) 1.6×10^2 kg/s **137.** (a) 1.26 m/s; (b) 2.25 kJ; (c) 1.61 m/s; (d) 1.00 m/s **139.** (a) 8.1 m/s; (b) 38° south of due east

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CP 1. (b) and (c) **2.** (a) and (d) ($\alpha = d^2\theta/dt^2$ must be a constant) **3.** (a) yes; (b) no; (c) yes; (d) yes **4.** all tie **5.** 1, 2, 4, 3 (see Eq. 10-36) **6.** (see Eq. 10-40) 1 and 3 tie, 4, then 2 and 5 tie (zero) **7.** (a) downward in the figure ($\tau_{net} = 0$); (b) less (consider moment arms) **Q 1.** (a) positive; (b) zero; (c) negative; (d) negative **3.** (a) 1: counterclockwise (positive); 2: counterclockwise (positive); 3: at $\theta = 0$; (b) 1: before; 2: at $t = 0$; 3: after; (c) 1: positive; 2: negative; 3: positive **5.** larger **7.** $\vec{F}_5$, $\vec{F}_4$, $\vec{F}_2$, $\vec{F}_1$, $\vec{F}_3$ (zero) **9.** (a) 1 and 2 tie, then 3; (b) 1 and 3 tie, then 2; (c) 2, 1, 3 **P 1.** (a) 0.105 rad/s; (b) 1.75×10^{-3} rad/s; (c) 1.45×10^{-4} rad/s **3.** (a) 12:00; (b) 12:00; (c) 3:00; (d) 6:00; (e) 9:00; (f) 12:00; (g) 2:24; (h) 4:48; (i) 7:12; (j) 9:36; (k) 12:00 **5.** 11 rad/s **7.** (a) 4.0 m/s; (b) no **9.** (a) 9.0×10^3 rev/min²; (b) 4.2×10^2 rev **11.** (a) 2.0 rad/s²; (b) 5.0 rad/s; (c) 10 rad/s; (d) 75 rad **13.** 8.0 s