Questions

1. We claim that momentum is conserved. Yet most moving objects eventually slow down and stop. Explain.

2. A light object and a heavy object have the same kinetic energy. Which has the greater momentum? Explain.

3. When a person jumps from a tree to the ground, what happens to the momentum of the person upon striking the ground?

4. When you release an inflated but untied balloon, why does it fly across the room?

5. Explain, on the basis of conservation of momentum, how a fish propels itself forward by swishing its tail back and forth.

6. Two children float motionlessly in a space station. The 20-kg girl pushes on the 40-kg boy and he sails away at 1.0 m/s. The girl (*a*) remains motionless; (*b*) moves in the same direction at 1.0 m/s; (*c*) moves in the opposite direction at 1.0 m/s; (*d*) moves in the opposite direction at 2.0 m/s; (*e*) none of these.

7. According to Eq. 7–4, the longer the impact time of an impulse, the smaller the force can be for the same momentum change, and hence the smaller the deformation of the object on which the force acts. On this basis, explain the value of air bags, which are intended to inflate during an automobile collision and reduce the possibility of fracture or death.

8. If a falling ball were to make a perfectly elastic collision with the floor, would it rebound to its original height? Explain.

9. A boy stands on the back of a rowboat and dives into the water. What happens to the boat as he leaves it? Explain.

10. It is said that in ancient times a rich man with a bag of gold coins was stranded on the surface of a frozen lake. Because the ice was frictionless, he could not push himself to shore and froze to death. What could he have done to save himself had he not been so miserly?

11. The speed of a tennis ball on the return of a serve can be just as fast as the serve, even though the racket isn't swung very fast. How can this be?

12. Is it possible for an object to receive a larger impulse from a small force than from a large force? Explain.

13. In a collision between two cars, which would you expect to be more damaging to the occupants: if the cars collide and remain together, or if the two cars collide and rebound backward? Explain.

14. A very elastic "superball" is dropped from a height h onto a hard steel plate (fixed to the Earth), from which it rebounds at very nearly its original speed. (*a*) Is the momentum of the ball conserved during any part of this process? (*b*) If we consider the ball and the Earth as our system, during what parts of the process is momentum conserved? (*c*) Answer part (*b*) for a piece of putty that falls and sticks to the steel plate.

15. Cars used to be built as rigid as possible to withstand collisions. Today, though, cars are designed to have "crumple zones" that collapse upon impact. What is the advantage of this new design?

16. At a hydroelectric power plant, water is directed at high speed against turbine blades on an axle that turns an electric generator. For maximum power generation, should the turbine blades be designed so that the water is brought to a dead stop, or so that the water rebounds?

17. A squash ball hits a wall at a 45° angle as shown in Fig. 7–29. What is the direction (*a*) of the change in momentum of the ball, (*b*) of the force on the wall?

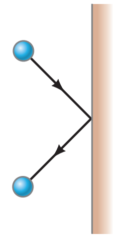

FIGURE 7–29 Question 17.

18. Why can a batter hit a pitched baseball farther than a ball he himself has tossed up in the air?

19. Describe a collision in which all kinetic energy is lost.

20. If a 20-passenger plane is not full, sometimes passengers are told they must sit in certain seats and may not move to empty seats. Why might this be?

21. Why do you tend to lean backward when carrying a heavy load in your arms?

22. Why is the CM of a 1-m length of pipe at its midpoint, whereas this is not true for your arm or leg?

23. How can a rocket change direction when it is far out in space and essentially in a vacuum?

24. Bob and Jim decide to play tug-of-war on a frictionless (icy) surface. Jim is considerably stronger than Bob, but Bob weighs 160 lb whereas Jim weighs 145 lb. Who loses by crossing over the midline first? Explain.

*25. In one type of nuclear radioactive decay, an electron and a recoil nucleus are emitted but often do not separate along the same line. Use conservation of momentum in two dimensions to explain why this implies the emission of at least one other particle (it came to be called a "neutrino").

*26. Show on a diagram how your CM shifts when you move from a lying position to a sitting position.

*27. If only an external force can change the momentum of the center of mass of an object, how can the internal force of the engine accelerate a car?

*28. A rocket following a parabolic path through the air suddenly explodes into many pieces. What can you say about the motion of this system of pieces?

MisConceptual Questions

1. A truck going 15 km/h has a head-on collision with a small car going 30 km/h. Which statement best describes the situation?
   (*a*) The truck has the greater change of momentum because it has the greater mass.
   (*b*) The car has the greater change of momentum because it has the greater speed.
   (*c*) Neither the car nor the truck changes its momentum in the collision because momentum is conserved.
   (*d*) They both have the same change in magnitude of momentum because momentum is conserved.
   (*e*) None of the above is necessarily true.

2. A small boat coasts at constant speed under a bridge. A heavy sack of sand is dropped from the bridge onto the boat. The speed of the boat
   (*a*) increases.
   (*b*) decreases.
   (*c*) does not change.
   (*d*) Without knowing the mass of the boat and the sand, we can't tell.

3. Two identical billiard balls traveling at the same speed have a head-on collision and rebound. If the balls had twice the mass, but maintained the same size and speed, how would the rebound be different?
   (*a*) At a higher speed.
   (*b*) At slower speed.
   (*c*) No difference.

4. An astronaut is a short distance away from her space station without a tether rope. She has a large wrench. What should she do with the wrench to move toward the space station?
   (*a*) Throw it directly away from the space station.
   (*b*) Throw it directly toward the space station.
   (*c*) Throw it toward the station without letting go of it.
   (*d*) Throw it parallel to the direction of the station's orbit.
   (*e*) Throw it opposite to the direction of the station's orbit.

5. A space vehicle, in circular orbit around the Earth, collides with a small asteroid which ends up in the vehicle's storage bay. For this collision,
   (*a*) only momentum is conserved.
   (*b*) only kinetic energy is conserved.
   (*c*) both momentum and kinetic energy are conserved.
   (*d*) neither momentum nor kinetic energy is conserved.

6. A golf ball and an equal-mass bean bag are dropped from the same height and hit the ground. The bean bag stays on the ground while the golf ball rebounds. Which experiences the greater impulse from the ground?
   (*a*) The golf ball.
   (*b*) The bean bag.
   (*c*) Both the same.
   (*d*) Not enough information.

7. You are lying in bed and want to shut your bedroom door. You have a bouncy ball and a blob of clay, both with the same mass. Which one would be more effective to throw at your door to close it?
   (*a*) The bouncy ball.
   (*b*) The blob of clay.
   (*c*) Both the same.
   (*d*) Neither will work.

8. A baseball is pitched horizontally toward home plate with a velocity of 110 km/h. In which of the following scenarios does the change in momentum of the baseball have the largest magnitude?
   (*a*) The catcher catches the ball.
   (*b*) The ball is popped straight up at a speed of 110 km/h.
   (*c*) The baseball is hit straight back to the pitcher at a speed of 110 km/h.
   (*d*) Scenarios (*a*) and (*b*) have the same change in momentum.
   (*e*) Scenarios (*a*), (*b*), and (*c*) have the same change in momentum.

9. A small car and a heavy pickup truck are both out of gas. The truck has twice the mass of the car. After you push first the car and then the truck for the *same amount of time* with the same force, what can you say about the momentum and kinetic energy (KE) of the car and the truck? Ignore friction.
   (*a*) They have the same momentum and the same KE.
   (*b*) The car has more momentum and more KE than the truck.
   (*c*) The truck has more momentum and more KE than the car.
   (*d*) They have the same momentum, but the car has more kinetic energy than the truck.
   (*e*) They have the same kinetic energy, but the truck has more momentum than the car.

10. Answer the previous Question (# 9) but now assume that you push both the car and the truck for the *same distance* with the same force. [*Hint*: See also Chapter 6.]

11. A railroad tank car contains milk and rolls at a constant speed along a level track. The milk begins to leak out the bottom. The car then
    (*a*) slows down.
    (*b*) speeds up.
    (*c*) maintains a constant speed.
    (*d*) Need more information about the rate of the leak.

12. A bowling ball hangs from a 1.0-m-long cord, Fig. 7–30: (i) A 200-gram putty ball moving 5.0 m/s hits the bowling ball and sticks to it, causing the bowling ball to swing up; (ii) a 200-gram rubber ball moving 5.0 m/s hits the bowling ball and bounces straight back at nearly 5.0 m/s, causing the bowling ball to swing up. Describe what happens.
    (*a*) The bowling ball swings up by the same amount in both (i) and (ii).
    (*b*) The ball swings up farther in (i) than in (ii).
    (*c*) The ball swings up farther in (ii) than in (i).
    (*d*) Not enough information is given; we need the contact time between the rubber ball and the bowling ball.

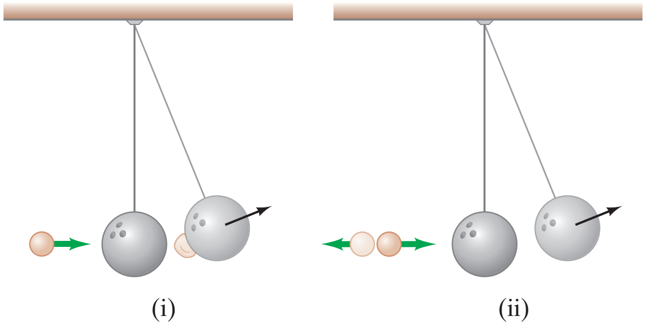

FIGURE 7–30 MisConceptual Question 12.

For assigned homework and other learning materials, go to the MasteringPhysics website.

Problems

7–1 and 7–2 Momentum and Its Conservation

1. (I) What is the magnitude of the momentum of a 28-g sparrow flying with a speed of 8.4 m/s?

2. (I) A constant friction force of 25 N acts on a 65-kg skier for 15 s on level snow. What is the skier's change in velocity?

3. (I) A 7150-kg railroad car travels alone on a level frictionless track with a constant speed of 15.0 m/s. A 3350-kg load, initially at rest, is dropped onto the car. What will be the car's new speed?

4. (I) A 110-kg tackler moving at 2.5 m/s meets head-on (and holds on to) an 82-kg halfback moving at 5.0 m/s. What will be their mutual speed immediately after the collision?

5. (II) Calculate the force exerted on a rocket when the propelling gases are being expelled at a rate of 1300 kg/s with a speed of 4.5×10^4 m/s.

6. (II) A 7700-kg boxcar traveling 14 m/s strikes a second car at rest. The two stick together and move off with a speed of 5.0 m/s. What is the mass of the second car?

7. (II) A child in a boat throws a 5.30-kg package out horizontally with a speed of 10.0 m/s, Fig. 7–31. Calculate the velocity of the boat immediately after, assuming it was initially at rest. The mass of the child is 24.0 kg and the mass of the boat is 35.0 kg.

FIGURE 7–31 Problem 7.

8. (II) An atomic nucleus at rest decays radioactively into an alpha particle and a different nucleus. What will be the speed of this recoiling nucleus if the speed of the alpha particle is 2.8×10^5 m/s? Assume the recoiling nucleus has a mass 57 times greater than that of the alpha particle.

9. (II) An atomic nucleus initially moving at 320 m/s emits an alpha particle in the direction of its velocity, and the remaining nucleus slows to 280 m/s. If the alpha particle has a mass of 4.0 u and the original nucleus has a mass of 222 u, what speed does the alpha particle have when it is emitted?

10. (II) An object at rest is suddenly broken apart into two fragments by an explosion. One fragment acquires twice the kinetic energy of the other. What is the ratio of their masses?

11. (II) A 22-g bullet traveling 240 m/s penetrates a 2.0-kg block of wood and emerges going 150 m/s. If the block is stationary on a frictionless surface when hit, how fast does it move after the bullet emerges?

12. (III) A 0.145-kg baseball pitched horizontally at 27.0 m/s strikes a bat and pops straight up to a height of 31.5 m. If the contact time between bat and ball is 2.5 ms, calculate the average force between the ball and bat during contact.

13. (III) Air in a 120-km/h wind strikes head-on the face of a building 45 m wide by 75 m high and is brought to rest. If air has a mass of 1.3 kg per cubic meter, determine the average force of the wind on the building.

14. (III) A 725-kg two-stage rocket is traveling at a speed of 6.60×10^3 m/s away from Earth when a predesigned explosion separates the rocket into two sections of equal mass that then move with a speed of 2.80×10^3 m/s relative to each other along the original line of motion. (*a*) What is the speed and direction of each section (relative to Earth) after the explosion? (*b*) How much energy was supplied by the explosion? [*Hint*: What is the change in kinetic energy as a result of the explosion?]

7–3 Collisions and Impulse

15. (I) A 0.145-kg baseball pitched at 31.0 m/s is hit on a horizontal line drive straight back at the pitcher at 46.0 m/s. If the contact time between bat and ball is 5.00×10^{-3} s, calculate the force (assumed to be constant) between the ball and bat.

16. (II) A golf ball of mass 0.045 kg is hit off the tee at a speed of 38 m/s. The golf club was in contact with the ball for 3.5×10^{-3} s. Find (*a*) the impulse imparted to the golf ball, and (*b*) the average force exerted on the ball by the golf club.

17. (II) A 12-kg hammer strikes a nail at a velocity of 7.5 m/s and comes to rest in a time interval of 8.0 ms. (*a*) What is the impulse given to the nail? (*b*) What is the average force acting on the nail?

18. (II) A tennis ball of mass $m = 0.060$ kg and speed $v = 28$ m/s strikes a wall at a 45° angle and rebounds with the same speed at 45° (Fig. 7–32). What is the impulse (magnitude and direction) given to the ball?

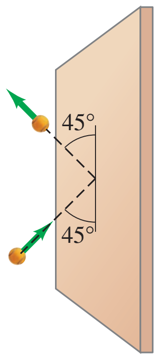

FIGURE 7–32 Problem 18.

19. (II) A 125-kg astronaut (including space suit) acquires a speed of 2.50 m/s by pushing off with her legs from a 1900-kg space capsule. (*a*) What is the change in speed of the space capsule? (*b*) If the push lasts 0.600 s, what is the average force exerted by each on the other? As the reference frame, use the position of the capsule before the push. (*c*) What is the kinetic energy of each after the push?

20. (II) Rain is falling at the rate of 2.5 cm/h and accumulates in a pan. If the raindrops hit at 8.0 m/s, estimate the force on the bottom of a 1.0-m^2 pan due to the impacting rain which we assume does not rebound. Water has a mass of 1.00×10^3 kg per m^3.

21. (II) A 95-kg fullback is running at 3.0 m/s to the east and is stopped in 0.85 s by a head-on tackle by a tackler running due west. Calculate (*a*) the original momentum of the fullback, (*b*) the impulse exerted on the fullback, (*c*) the impulse exerted on the tackler, and (*d*) the average force exerted on the tackler.

22. (II) With what impulse does a 0.50-kg newspaper have to be thrown to give it a velocity of 3.0 m/s?

***23.** (III) Suppose the force acting on a tennis ball (mass 0.060 kg) points in the $+x$ direction and is given by the graph of Fig. 7–33 as a function of time. (*a*) Use graphical methods (count squares) to estimate the total impulse given the ball. (*b*) Estimate the velocity of the ball after being struck, assuming the ball is being served so it is nearly at rest initially. [*Hint*: See Section 6–2.]

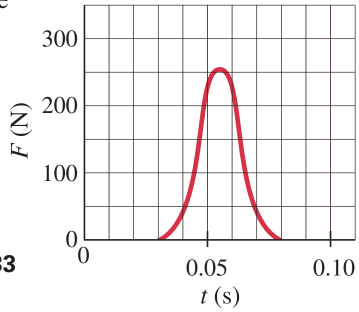

FIGURE 7–33 Problem 23.

24. (III) (*a*) Calculate the impulse experienced when a 55-kg person lands on firm ground after jumping from a height of 2.8 m. (*b*) Estimate the average force exerted on the person's feet by the ground if the landing is stiff-legged, and again (*c*) with bent legs. With stiff legs, assume the body moves 1.0 cm during impact, and when the legs are bent, about 50 cm. [*Hint*: The average net force on him, which is related to impulse, is the vector sum of gravity and the force exerted by the ground. See Fig. 7–34.] We will see in Chapter 9 that the force in (*b*) exceeds the ultimate strength of bone (Table 9–2).

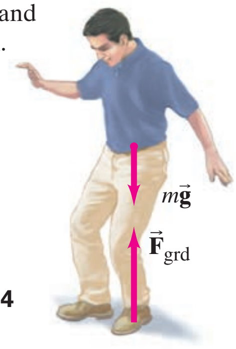

FIGURE 7–34 Problem 24.

7–4 and 7–5 Elastic Collisions

25. (II) A ball of mass 0.440 kg moving east ($+x$ direction) with a speed of 3.80 m/s collides head-on with a 0.220-kg ball at rest. If the collision is perfectly elastic, what will be the speed and direction of each ball after the collision?

26. (II) A 0.450-kg hockey puck, moving east with a speed of 5.80 m/s, has a head-on collision with a 0.900-kg puck initially at rest. Assuming a perfectly elastic collision, what will be the speed and direction of each puck after the collision?

27. (II) A 0.060-kg tennis ball, moving with a speed of 5.50 m/s, has a head-on collision with a 0.090-kg ball initially moving in the same direction at a speed of 3.00 m/s. Assuming a perfectly elastic collision, determine the speed and direction of each ball after the collision.

28. (II) Two billiard balls of equal mass undergo a perfectly elastic head-on collision. If one ball's initial speed was 2.00 m/s, and the other's was 3.60 m/s in the opposite direction, what will be their speeds and directions after the collision?

29. (II) A ball of mass m makes a head-on elastic collision with a second ball (at rest) and rebounds with a speed equal to 0.450 its original speed. What is the mass of the second ball?

30. (II) A ball of mass 0.220 kg that is moving with a speed of 5.5 m/s collides head-on and elastically with another ball initially at rest. Immediately after the collision, the incoming ball bounces backward with a speed of 3.8 m/s. Calculate (*a*) the velocity of the target ball after the collision, and (*b*) the mass of the target ball.

31. (II) Determine the fraction of kinetic energy lost by a neutron $(m_1 = 1.01\ \mathrm{u})$ when it collides head-on and elastically with a target particle at rest which is (*a*) ${}^1_1\mathrm{H}$ ($m = 1.01$ u); (*b*) ${}^2_1\mathrm{H}$ (heavy hydrogen, $m = 2.01$ u); (*c*) ${}^{12}_{6}\mathrm{C}$ ($m = 12.00$ u); (*d*) ${}^{208}_{82}\mathrm{Pb}$ (lead, $m = 208$ u).

7–6 Inelastic Collisions

32. (I) In a ballistic pendulum experiment, projectile 1 results in a maximum height h of the pendulum equal to 2.6 cm. A second projectile (of the same mass) causes the pendulum to swing twice as high, $h_2 = 5.2$ cm. The second projectile was how many times faster than the first?

33. (II) (*a*) Derive a formula for the fraction of kinetic energy lost, $\Delta\mathrm{KE}/\mathrm{KE}$, in terms of m and M for the ballistic pendulum collision of Example 7–9. (*b*) Evaluate for $m = 18.0$ g and $M = 380$ g.

34. (II) A 28-g rifle bullet traveling 190 m/s embeds itself in a 3.1-kg pendulum hanging on a 2.8-m-long string, which makes the pendulum swing upward in an arc. Determine the vertical and horizontal components of the pendulum's maximum displacement.

35. (II) An internal explosion breaks an object, initially at rest, into two pieces, one of which has 1.5 times the mass of the other. If 5500 J is released in the explosion, how much kinetic energy does each piece acquire?

36. (II) A 980-kg sports car collides into the rear end of a 2300-kg SUV stopped at a red light. The bumpers lock, the brakes are locked, and the two cars skid forward 2.6 m before stopping. The police officer, estimating the coefficient of kinetic friction between tires and road to be 0.80, calculates the speed of the sports car at impact. What was that speed?

37. (II) You drop a 14-g ball from a height of 1.5 m and it only bounces back to a height of 0.85 m. What was the total impulse on the ball when it hit the floor? (Ignore air resistance.)

38. Croquet ball A moving at 4.3 m/s makes a head on collision with ball B of equal mass and initially at rest. Immediately after the collision ball B moves forward at 3.0 m/s. What fraction of the initial kinetic energy is lost in the collision?

39. (II) A 144-g baseball moving 28.0 m/s strikes a stationary 5.25-kg brick resting on small rollers so it moves without significant friction. After hitting the brick, the baseball bounces straight back, and the brick moves forward at 1.10 m/s. (*a*) What is the baseball's speed after the collision? (*b*) Find the total kinetic energy before and after the collision.

40. (III) A pendulum consists of a mass M hanging at the bottom end of a massless rod of length ℓ, which has a frictionless pivot at its top end. A mass m, moving as shown in Fig. 7–35 with velocity v, impacts M and becomes embedded. What is the smallest value of v sufficient to cause the pendulum (with embedded mass m) to swing clear over the top of its arc?

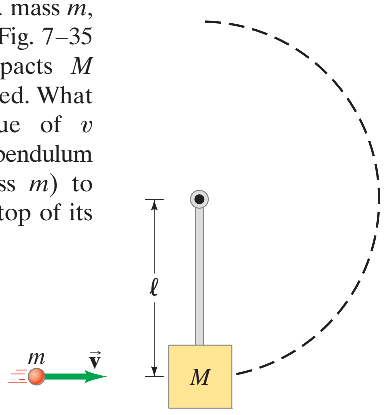

FIGURE 7–35 Problem 40.

*7–7 Collisions in Two Dimensions

***41.** (II) Billiard ball A of mass $m_A = 0.120\,\text{kg}$ moving with speed $v_A = 2.80\,\text{m/s}$ strikes ball B, initially at rest, of mass $m_B = 0.140\,\text{kg}$. As a result of the collision, ball A is deflected off at an angle of 30.0° with a speed $v'_A = 2.10\,\text{m/s}$. (*a*) Taking the x axis to be the original direction of motion of ball A, write down the equations expressing the conservation of momentum for the components in the x and y directions separately. (*b*) Solve these equations for the speed, v'_B, and angle, θ'_B, of ball B after the collision. Do not assume the collision is elastic.

***42.** (II) A radioactive nucleus at rest decays into a second nucleus, an electron, and a neutrino. The electron and neutrino are emitted at right angles and have momenta of $9.6 \times 10^{-23}\,\text{kg}\cdot\text{m/s}$ and $6.2 \times 10^{-23}\,\text{kg}\cdot\text{m/s}$, respectively. Determine the magnitude and the direction of the momentum of the second (recoiling) nucleus.

***43.** (III) Billiard balls A and B, of equal mass, move at right angles and meet at the origin of an xy coordinate system as shown in Fig. 7–36. Initially ball A is moving along the y axis at $+2.0\,\text{m/s}$, and ball B is moving to the right along the x axis with speed $+3.7\,\text{m/s}$. After the collision (assumed elastic), ball B is moving along the positive y axis (Fig. 7–36) with velocity v'_B. What is the final direction of ball A, and what are the speeds of the two balls?

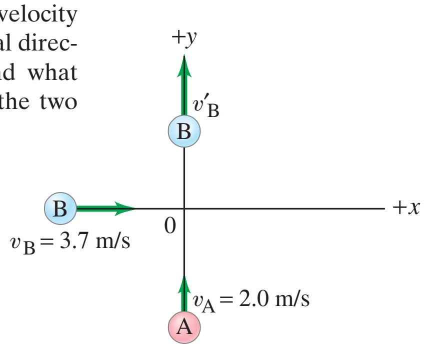

FIGURE 7–36 Problem 43. (Ball A after the collision is not shown.)

***44.** (III) An atomic nucleus of mass m traveling with speed v collides elastically with a target particle of mass $2m$ (initially at rest) and is scattered at 90°. (*a*) At what angle does the target particle move after the collision? (*b*) What are the final speeds of the two particles? (*c*) What fraction of the initial kinetic energy is transferred to the target particle?

7–8 Center of Mass (CM)

45. (I) The distance between a carbon atom $(m = 12\,\text{u})$ and an oxygen atom $(m = 16\,\text{u})$ in the CO molecule is $1.13 \times 10^{-10}\,\text{m}$. How far from the carbon atom is the center of mass of the molecule?

46. (I) Find the center of mass of the three-mass system shown in Fig. 7–37 relative to the 1.00-kg mass.

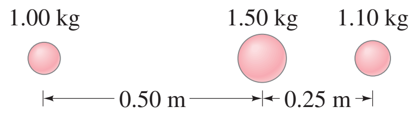

FIGURE 7–37 Problem 46.

47. (II) The CM of an empty 1250-kg car is 2.40 m behind the front of the car. How far from the front of the car will the CM be when two people sit in the front seat 2.80 m from the front of the car, and three people sit in the back seat 3.90 m from the front? Assume that each person has a mass of 65.0 kg.

48. (II) Three cubes, of side ℓ_0, $2\ell_0$, and $3\ell_0$, are placed next to one another (in contact) with their centers along a straight line as shown in Fig. 7–38. What is the position, along this line, of the CM of this system? Assume the cubes are made of the same uniform material.

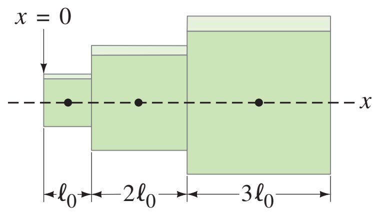

FIGURE 7–38 Problem 48.

49. (II) A (lightweight) pallet has a load of ten identical cases of tomato paste (see Fig. 7–39), each of which is a cube of length ℓ. Find the center of gravity in the horizontal plane, so that the crane operator can pick up the load without tipping it.

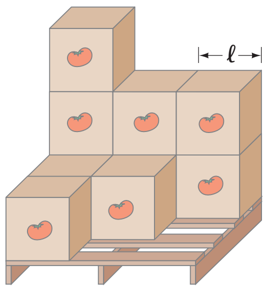

FIGURE 7–39 Problem 49.

50. (III) Determine the CM of the uniform thin L-shaped construction brace shown in Fig. 7–40.

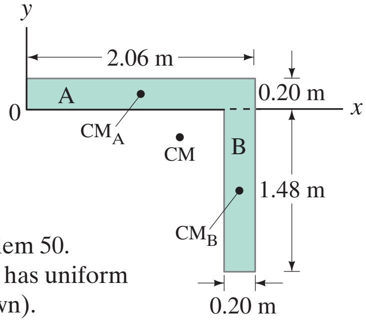

FIGURE 7–40 Problem 50. This L-shaped object has uniform thickness d (not shown).

*7–9 CM for the Human Body

*51. (I) Assume that your proportions are the same as those in Table 7–1, and calculate the mass of one of your legs.

*52. (I) Determine the CM of an outstretched arm using Table 7–1.

*53. (II) Use Table 7–1 to calculate the position of the CM of an arm bent at a right angle. Assume that the person is 155 cm tall.

*54. (II) When a high jumper is in a position such that his arms and lower legs are hanging vertically, and his thighs, trunk, and head are horizontal just above the bar, estimate how far below the torso's median line the CM will be. Will this CM be outside the body? Use Table 7–1.

*55. (III) Repeat Problem 54 assuming the body bends at the hip joint by about 15°. Estimate, using Fig. 7–27 as a model.

*7–10 CM and Translational Motion

*56. (II) The masses of the Earth and Moon are 5.98×10^{24} kg and 7.35×10^{22} kg, respectively, and their centers are separated by 3.84×10^{8} m. (*a*) Where is the CM of the Earth–Moon system located? (*b*) What can you say about the motion of the Earth–Moon system about the Sun, and of the Earth and Moon separately about the Sun?

*57. (II) A 52-kg woman and a 72-kg man stand 10.0 m apart on nearly frictionless ice. (*a*) How far from the woman is their CM? (*b*) If each holds one end of a rope, and the man pulls on the rope so that he moves 2.5 m, how far from the woman will he be now? (*c*) How far will the man have moved when he collides with the woman?

*58. (II) Suppose that in Example 7–14 (Fig. 7–28), $m_{\mathrm{II}} = 3m_{\mathrm{I}}$. (*a*) Where then would m_{II} land? (*b*) What if $m_{\mathrm{I}} = 3m_{\mathrm{II}}$?

*59. (II) Two people, one of mass 85 kg and the other of mass 55 kg, sit in a rowboat of mass 58 kg. With the boat initially at rest, the two people, who have been sitting at opposite ends of the boat, 3.0 m apart from each other, now exchange seats. How far and in what direction will the boat move?

*60. (III) A huge balloon and its gondola, of mass M, are in the air and stationary with respect to the ground. A passenger, of mass m, then climbs out and slides down a rope with speed v, measured with respect to the balloon. With what speed and direction (relative to Earth) does the balloon then move? What happens if the passenger stops?

General Problems

61. Two astronauts, one of mass 55 kg and the other 85 kg, are initially at rest together in outer space. They then push each other apart. How far apart are they when the lighter astronaut has moved 12 m?

62. Two asteroids strike head-on: before the collision, asteroid A $(m_A = 7.5 \times 10^{12}\ \mathrm{kg})$ has velocity 3.3 km/s and asteroid B $(m_B = 1.45 \times 10^{13}\ \mathrm{kg})$ has velocity 1.4 km/s in the opposite direction. If the asteroids stick together, what is the velocity (magnitude and direction) of the new asteroid after the collision?

63. A ball is dropped from a height of 1.60 m and rebounds to a height of 1.20 m. Approximately how many rebounds will the ball make before losing 90% of its energy?

64. A 4800-kg open railroad car coasts at a constant speed of 7.60 m/s on a level track. Snow begins to fall vertically and fills the car at a rate of 3.80 kg/min. Ignoring friction with the tracks, what is the car's speed after 60.0 min? (See Section 7–2.)

65. Two bumper cars in an amusement park ride collide elastically as one approaches the other directly from the rear (Fig. 7–41). Car A has a mass of 435 kg and car B 495 kg, owing to differences in passenger mass. If car A approaches at 4.50 m/s and car B is moving at 3.70 m/s, calculate (*a*) their velocities after the collision, and (*b*) the change in momentum of each.

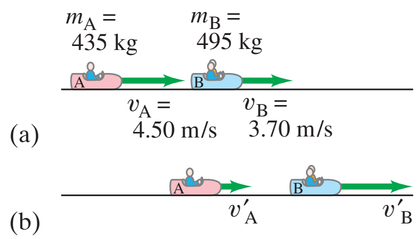

FIGURE 7–41 Problem 65: (a) before collision, (b) after collision.

66. A gun fires a bullet vertically into a 1.40-kg block of wood at rest on a thin horizontal sheet, Fig. 7–42. If the bullet has a mass of 25.0 g and a speed of 230 m/s, how high will the block rise into the air after the bullet becomes embedded in it?

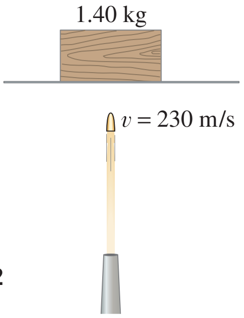

FIGURE 7–42 Problem 66.

67. You have been hired as an expert witness in a court case involving an automobile accident. The accident involved car A of mass 1500 kg which crashed into stationary car B of mass 1100 kg. The driver of car A applied his brakes 15 m before he skidded and crashed into car B. After the collision, car A slid 18 m while car B slid 30 m. The coefficient of kinetic friction between the locked wheels and the road was measured to be 0.60. Show that the driver of car A was exceeding the 55-mi/h (90-km/h) speed limit before applying the brakes.

68. A meteor whose mass was about 1.5×10^8 kg struck the Earth $\left(m_E = 6.0 \times 10^{24}\,\text{kg}\right)$ with a speed of about 25 km/s and came to rest in the Earth. (*a*) What was the Earth's recoil speed (relative to Earth at rest before the collision)? (*b*) What fraction of the meteor's kinetic energy was transformed to kinetic energy of the Earth? (*c*) By how much did the Earth's kinetic energy change as a result of this collision?

69. A 28-g bullet strikes and becomes embedded in a 1.35-kg block of wood placed on a horizontal surface just in front of the gun. If the coefficient of kinetic friction between the block and the surface is 0.28, and the impact drives the block a distance of 8.5 m before it comes to rest, what was the muzzle speed of the bullet?

70. You are the design engineer in charge of the crashworthiness of new automobile models. Cars are tested by smashing them into fixed, massive barriers at 45 km/h. A new model of mass 1500 kg takes 0.15 s from the time of impact until it is brought to rest. (*a*) Calculate the average force exerted on the car by the barrier. (*b*) Calculate the average deceleration of the car in *g*'s.

71. Two balls, of masses $m_A = 45$ g and $m_B = 65$ g, are suspended as shown in Fig. 7–43. The lighter ball is pulled away to a 66° angle with the vertical and released. (*a*) What is the velocity of the lighter ball before impact? (*b*) What is the velocity of each ball after the elastic collision? (*c*) What will be the maximum height of each ball after the elastic collision?

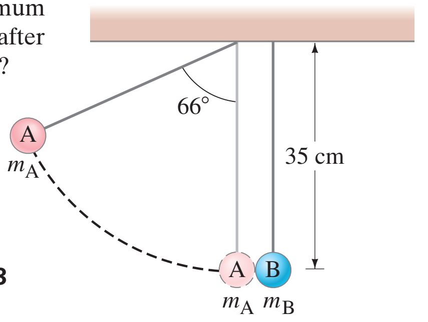

FIGURE 7–43 Problem 71.

72. The space shuttle launches an 850-kg satellite by ejecting it from the cargo bay. The ejection mechanism is activated and is in contact with the satellite for 4.8 s to give it a velocity of 0.30 m/s in the *x* direction relative to the shuttle. The mass of the shuttle is 92,000 kg. (*a*) Determine the component of velocity v_f of the shuttle in the minus *x* direction resulting from the ejection. (*b*) Find the average force that the shuttle exerts on the satellite during the ejection.

73. Astronomers estimate that a 2.0-km-diameter asteroid collides with the Earth once every million years. The collision could pose a threat to life on Earth. (*a*) Assume a spherical asteroid has a mass of 3200 kg for each cubic meter of volume and moves toward the Earth at 15 km/s. How much destructive energy could be released when it embeds itself in the Earth? (*b*) For comparison, a nuclear bomb could release about 4.0×10^{16} J. How many such bombs would have to explode simultaneously to release the destructive energy of the asteroid collision with the Earth?

74. An astronaut of mass 210 kg including his suit and jet pack wants to acquire a velocity of 2.0 m/s to move back toward his space shuttle. Assuming the jet pack can eject gas with a velocity of 35 m/s, what mass of gas will need to be ejected?

75. A massless spring with spring constant k is placed between a block of mass m and a block of mass $3m$. Initially the blocks are at rest on a frictionless surface and they are held together so that the spring between them is compressed by an amount D from its equilibrium length. The blocks are then released and the spring pushes them off in opposite directions. Find the speeds of the two blocks when they detach from the spring.

76. A golf ball rolls off the top of a flight of concrete steps of total vertical height 4.00 m. The ball hits four times on the way down, each time striking the horizontal part of a different step 1.00 m lower. If all collisions are perfectly elastic, what is the bounce height on the fourth bounce when the ball reaches the bottom of the stairs?

77. Two blocks of mass m_A and m_B, resting on a frictionless table, are connected by a stretched spring and then released (Fig. 7–44). (*a*) Is there a net external force on the system before release? (*b*) Determine the ratio of their speeds, v_A/v_B. (*c*) What is the ratio of their kinetic energies? (*d*) Describe the motion of the CM of this system. Ignore mass of spring.

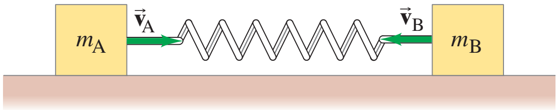

FIGURE 7–44 Problem 77.

Search and Learn

1. Consider the Examples in this Chapter involving $\Sigma\vec{F}_{ext} = \Delta\vec{p}/\Delta t$. Provide some general guidelines as to when it is best to solve the problem using $\Sigma\vec{F}_{ext} = 0$ so $\Sigma\vec{p}_i = \Sigma\vec{p}_f$, and when to use the principle of impulse instead so that $\Sigma\vec{F}_{ext}\,\Delta t = \Delta\vec{p}$.

2. A 6.0-kg object moving in the $+x$ direction at 6.5 m/s collides head-on with an 8.0-kg object moving in the $-x$ direction at 4.0 m/s. Determine the final velocity of each object if: (*a*) the objects stick together; (*b*) the collision is elastic; (*c*) the 6.0-kg object is at rest after the collision; (*d*) the 8.0-kg object is at rest after the collision; (*e*) the 6.0-kg object has a velocity of 4.0 m/s in the $-x$ direction after the collision. Finally, (*f*) are the results in (*c*), (*d*), and (*e*) "reasonable"? Explain.

3. Take the general case of an object of mass m_A and velocity v_A elastically striking a stationary $(v_B = 0)$ object of mass m_B head-on. (*a*) Show that the final velocities v'_A and v'_B are given by

$$v'_A = \left(\frac{m_A - m_B}{m_A + m_B}\right)v_A, \qquad v'_B = \left(\frac{2m_A}{m_A + m_B}\right)v_A.$$

(*b*) What happens in the extreme case when m_A is much smaller than m_B? Cite a common example of this. (*c*) What happens in the extreme case when m_A is much larger than m_B? Cite a common example of this. (*d*) What happens in the case when $m_A = m_B$? Cite a common example.

4. **The gravitational slingshot effect.** Figure 7–45 shows the planet Saturn moving in the negative x direction at its orbital speed (with respect to the Sun) of 9.6 km/s. The mass of Saturn is 5.69×10^{26} kg. A spacecraft with mass 825 kg approaches Saturn. When far from Saturn, it moves in the $+x$ direction at 10.4 km/s. The gravitational attraction of Saturn (a conservative force) acting on the spacecraft causes it to swing around the planet (orbit shown as dashed line) and head off in the opposite direction. Estimate the final speed of the spacecraft after it is far enough away to be considered free of Saturn's gravitational pull.

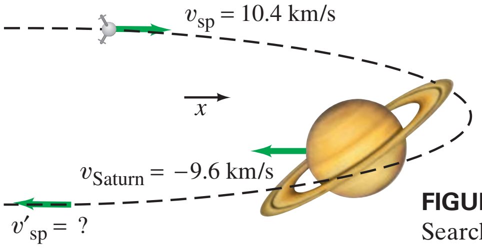

FIGURE 7–45 Search and Learn 4.

ANSWERS TO EXERCISES

A: Yes, if the sports car's speed is three times greater.
B: Larger (Δp is greater).
C: (*a*) 6.0 m/s; (*b*) almost zero; (*c*) almost 24.0 m/s.
D: 0.50 m/s.
E: (*b*); (*d*).
F: The curve would be wider and less high.
G: $x_{CM} = -2.0$ m; yes.
H: The boat moves in the opposite direction.