Questions and Problems

In a few problems, you are given more data than you actually need; in a few other problems, you are required to supply data from your general knowledge, outside sources, or informed estimate. Interpret as significant all digits in numerical values that have trailing zeros and no decimal points. For all problems, use \( g = 9.80 \text{ m/s}^2 \) for the free-fall acceleration due to gravity.

• Basic, single-concept problem  
• Intermediate-level problem, may require synthesis of concepts and multiple steps  
•• Challenging problem

SSM Solution is in Student Solutions Manual

Conceptual Questions

1. According to Newton’s second law, does the direction of the net force always equal the direction of the acceleration? SSM
2. If the sum of the forces acting on an object equals zero, does this imply that the object is at rest?
3. What are the basic SI units (kg, m, s) for force according to Newton’s second law \( \sum F_{\text{net}} = ma \)?
4. Medical, Sports Gymnastics routines are done over a padded floor to protect athletes who fall. Why is falling on padding safer than falling on concrete?
5. A definition of the inertia of an object is that it is a measure of the quantity of matter. How does this definition compare with the definition discussed in the chapter?
6. When constructing a free-body diagram, why is it a good idea to choose your coordinate system so that the motion of an object is along one of the axes?
7. A certain rope will break under any tension greater than 800 N. How can it be used to lower an object weighing 850 N over the edge of a cliff without it breaking? SSM
8. Sports A boxer claims that Newton’s third law helps him while boxing. He says that during a boxing match, the force that his jaw feels is the same as the force that his opponent’s fist feels (when the opponent is doing the punching). Therefore, his opponent will feel the same force as he feels and he will be able to fight on without any problems, no matter how many punches he receives or gives. It will always be an “even fight.” Discuss any flaws in his reasoning.
9. Astronomy We know that the Sun pulls on Earth. Does Earth also pull on the Sun? Why or why not? SSM
10. Sports How can a fisherman land a 5-lb fish using fishing line that is rated at 4 lb?
11. Tension is a very common force in day-to-day life. Identify five ordinary situations that involve the force of tension.
12. Explain why the force that a horizontal surface exerts on an object at rest on it is called the normal force.
13. A chair is mounted on a scale inside an elevator in the physics building. Describe the variation in the scale reading as the elevator begins to ascend, goes up at constant speed, stops, begins to descend, goes down at a constant speed, and stops again.
14. List all the forces acting on a bottle of water if it were sitting on your desk.
15. What is the net force on a bathroom scale when a 75-kg person stands on it? SSM
16. An object of mass \( m \) is being weighed in an elevator that is moving upward with an acceleration \( a \). What is the result if the weighing is done using (a) a spring balance and (b) a pan balance?
17. Two forces of 30 N and 70 N act on an object. What are the minimum and maximum values for the sum of these two forces?
18. You apply a 60-N force to push a box across the floor at constant speed. If you increase the applied force to 80 N, will the box speed up to some new constant speed, or will it continue to speed up until it hits the wall? Assume that the floor is horizontal and the surface is uniform. Explain your answer.
19. Astronomy Why would it be easier to lift a truck on the Moon’s surface than it is on Earth? SSM
20. Medical Why should the driver and passengers in a car wear seatbelts? Explain your answer.
21. Medical Why does the American Academy of Pediatrics recommend that all infants sit in rear-facing car seats starting with their first ride home from the hospital? Explain your answer.
22. Medical Use Newton’s third law to explain the forces involved in walking.
23. Biology Use Newton’s third law to explain how birds are able to fly forward. SSM

Multiple-Choice Questions

24. Medical A car stops suddenly during a head-on collision, causing the driver’s brain to slam into the skull. The resulting injury would most likely be to which part of the brain?
   A. frontal portion of the brain  
   B. rear portion of the brain  
   C. middle portion of the brain  
   D. left side of the brain  
   E. right side of the brain

25. Medical During the sudden impact of a car accident, a person’s neck can experience abnormal forces, resulting in an injury commonly known as whiplash. If a victim’s head and neck move in the manner shown in Figure 4-24, his car was hit from the
   A. front.  
   B. rear.  
   C. right side.  
   D. left side.  
   E. top during a rollover. SSM

Figure 4-24
26. The net force on a moving object suddenly becomes zero and remains zero. The object will
   A. stop abruptly.
   B. reduce speed gradually.
   C. continue at constant velocity.
   D. increase speed gradually.
   E. reduce speed abruptly.

27. Which has greater monetary value, a newton of gold on Earth or a newton of gold on the Moon?
   A. the newton of gold on Earth
   B. the newton of gold on the Moon
   C. the value is the same, regardless of location.
   D. One cannot say without checking the weight on the Moon.
   E. the newton of gold on the Moon but only when inside a spaceship

28. According to Newton’s second law of motion, when a net force acts on an object, the acceleration is
   A. zero.
   B. inversely proportional to the object’s mass.
   C. independent of mass.
   D. inversely proportional to the net force.
   E. directly proportional to the object’s mass.

29. When a net force acts on an object, the object
   A. is at rest.
   B. is in motion with a constant velocity.
   C. has zero speed.
   D. is accelerating.
   E. at rest or in motion with a constant velocity.

30. In the absence of a net force, an object cannot be
   A. at rest.
   B. in motion with a constant velocity.
   C. accelerating.
   D. moving with an acceleration of zero.
   E. experiencing opposite but equal forces.

31. In the absence of a net force, an object can be
   A. at rest.
   B. in motion with a constant velocity.
   C. accelerating.
   D. at rest or in motion with a constant velocity.
   E. It’s not possible to know without more information.

32. While an elevator traveling upward slows down to stop, the normal force on the feet of a passenger is ______ her weight. While an elevator traveling downward slows down to stop, the normal force on the feet of a passenger is ______ his weight.
   A. larger than; smaller than
   B. larger than; larger than
   C. smaller than; smaller than
   D. smaller than; larger than
   E. equal to; equal to

33. How does the magnitude of the normal force exerted by the ramp in Figure 4-25 compare to the weight of the block? The normal force is
   A. equal to the weight of the block.
   B. greater than the weight of the block.
   C. less than the weight of the block.
   D. possibly equal to or less than the weight of the block, depending on whether or not the ramp surface is smooth.
   E. possibly greater than or equal to the weight of the block, depending on whether or not the ramp surface is smooth.

Figure 4-25 Problem 33

34. Case (a) in Figure 4-26 shows block A accelerated across a frictionless table by a hanging 10-N block (1.02 kg). In case (b), the same block A is accelerated by a steady 10-N tension in the string. Treat the masses of the strings as negligible. The acceleration of block A in case (b) is
   A. greater than its acceleration in case (a).
   B. less than its acceleration in case (a).
   C. equal to its acceleration in case (a).
   D. twice its acceleration in case (a).
   E. half its acceleration in case (a).

Figure 4-26 Problem 34

Estimation/Numerical Analysis

35. Estimate the weight of five common objects using newtons (not pounds or ounces).

36. Estimate the normal force acting on an apple that rests on a flat surface. What would this estimate be if the surface were tilted at an incline of 30° with the horizontal?

37. Sports Give an estimate of the force that a major league baseball pitcher exerts on a baseball when he throws it.

38. Estimate the maximum tension in the cable that supports a typical elevator.

39. Sports Estimate the force imparted on a tennis ball as it is fired from a tennis ball machine.

40. Sports Estimate the tension in a rope that pulls you on water skis at a constant speed behind a speedboat.

41. Estimate the force that is produced with the “jaws of life” (the pneumatic tool used to rip open the jammed doors of a vehicle that is involved in an accident).
42. • Estimate the force in newtons required to flip on a light switch.
43. • Estimate the force in newtons associated with snapping your fingers.
44. • Medical During an arthroscopic surgery repair of a patient’s knee, a portion of healthy tendon is grafted in place of a damaged anterior cruciate ligament (ACL). To test the results, the surgeon applies a known force to the ligament and increases it at 1-s intervals for 10 s. Plot the data listed in the table as a function of time in a spreadsheet or on a graphing calculator and extrapolate the best-fit line to estimate the force that would correspond to a time of 15 s.

<table>
<thead>
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<th>Time (s)</th>
<th>Force (mN)</th>
</tr>
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<tbody>
<tr>
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</tr>
<tr>
<td>1</td>
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<td>8</td>
<td>16.79</td>
</tr>
<tr>
<td>9</td>
<td>21.08</td>
</tr>
<tr>
<td>10</td>
<td>28.51</td>
</tr>
</tbody>
</table>

45. •• Use a spreadsheet or graphing calculator to plot the velocity versus height of an express elevator. The elevator starts from rest on the ground floor, experiences a constant acceleration until reaching its maximum speed of 10 m/s at the 4th floor (the distance between each floor is 3.5 m), remains at this speed until the 20th floor, and then experiences a constant acceleration until it stops at the 30th floor. Identify the point(s) on the graph when the weight of a rider as measured by a spring scale will reach its maximum value. SSM

Problems

4-2 If a net external force acts on an object, the object accelerates

46. • What is the acceleration of a 2000-kg car if the net force on the car is 4000 N?
47. • What net force is needed to accelerate a 2000-kg car at 2.00 m/s²?
48. •• Applying a constant net force to an object causes it to accelerate at 10 m/s². What will the acceleration of the object be if (a) the force is doubled, (b) the mass is halved, (c) the force is doubled and the mass is doubled, (d) the force is doubled and the mass is halved, (e) the force is halved, (f) the mass is doubled, (g) the force is halved and the mass is halved, and (h) the force is halved and the mass is doubled?
49. • Suppose that the engine of a car delivers a maximum force of 15,000 N. In the absence of any other forces, what is the maximum acceleration this engine can produce in a 1250-kg car? SSM

4-3 Mass, weight, and inertia are distinct but related concepts

50. • What is the weight on Earth of a wrestler who has a mass of 120 kg?
51. • A wrestler has a mass of 120 kg. What are (a) his mass and (b) weight on the Moon, where g is 1.62 m/s²?
52. • (a) How does your mass differ as measured in Mexico City versus Los Angeles? (b) In which city is your weight greater?

53. • A bluefin tuna has a mass of 250 kg. What is its weight? SSM
54. •• Astronomy An astronaut has a mass of 80.0 kg. How much would the astronaut weigh on Mars where surface gravity is 38.0% of that on Earth?
55. • What is the net force on an apple that weighs 3.5 N when you hold it at rest in your hand?

4-4 Making a free-body diagram is essential in solving any problem involving forces

56. • Draw a free-body diagram for a heavy crate being lowered by a steel cable straight down at a constant speed.
57. • Draw a free-body diagram for a box being pushed horizontally by a person across a smooth floor at a steadily increasing speed. Ignore the friction between the box and the smooth floor. SSM
58. • Draw a free-body diagram for a bicycle rolling down a hill. Ignore the friction between the bicycle wheels and the hill, but consider any air resistance.
59. •• A tugboat uses its winch to pull up a sinking sailboat with an upward force of 4500 N. The mass of the boat is 200 kg and the water acts on the sailboat with a drag force of 2000 N. Draw a free-body diagram for the sailboat and describe the motion of the sailboat.

4-6 All problems involving forces can be solved using the same series of steps

60. •• Two forces are applied to a block of mass \( M = 14.0 \text{ kg} \) that sits on a horizontal, frictionless table. One force \( F_1 \) has a magnitude of 10.0 N and is directed at an angle \( \theta_1 \) equal to 37.0° from the x direction as labeled in Figure 4-27. As a result of the forces, the block experiences an acceleration \( a \) equal to 0.500 m/s² in the x direction only. (a) What are the x and y components of the second force? (b) Draw the second force in its correct position and to scale on the picture.

Figure 4-27 Problem 60

61. •• Three rugby players are pulling horizontally on ropes attached to a box, which remains stationary. Player 1 exerts a force \( F_1 \) equal to 100 N at an angle \( \theta_1 \) equal to 60.0° with respect to the +x direction (Figure 4-28). Player 2 exerts a force \( F_2 \) equal to 200 N at an angle \( \theta_2 \) equal to 37.0° with respect to the +x direction. The view in the figure is from above. Ignore friction and note that gravity plays no role in this problem! (a) Determine the force \( F_3 \) exerted by Player 3. State your answer by giving the components of \( F_3 \) in the directions perpendicular to and parallel to the positive x direction. (b) Redraw the
diagram and add the force \( \vec{F}_3 \) as carefully as you can. (c) Player 3's rope breaks, and Player 2 adjusts by pulling with a force of magnitude \( F_3 \) equal to 150 N at the same angle as before. In which direction is the acceleration of the box relative to the +x direction shown? (d) In part (c), the acceleration is measured to be \( 10.0 \text{ m/s}^2 \). What is the mass of the box? SSM

Figure 4-28 Problem 61

62. *** Three forces act on a 2.00-kg object at angles \( \theta_1 = 40.0^\circ \), \( \theta_2 = 60.0^\circ \), and \( \theta_3 = 20.0^\circ \) as shown in Figure 4-29. Find the magnitude of \( F_2 \) and \( F_1 \) if the magnitude of \( F_1 \) is 1.00 N and the acceleration of the object is \( 1.50 \text{ m/s}^2 \) toward the +x direction.

Figure 4-29 Problem 62

63. *** Box A weighs 80 N and rests on a table (Figure 4-30). A rope that connects boxes A and B drapes over a pulley so that box B hangs above the table, as shown in the figure. The pulley and rope are massless, and the pulley is frictionless. What force does the table exert on box A if box B weighs (a) 35 N; (b) 70 N; (c) 90 N?

Figure 4-30 Problem 63

64. ** Two forces act on an object of mass \( M = 3.00 \text{ kg} \) as shown in Figure 4-31. Because of these forces, the object experiences an acceleration of \( a = 7.00 \text{ m/s}^2 \) in the x direction. If \( \theta_1 = 30.0^\circ \), (a) calculate the magnitude of \( F_2 \) and (b) make a careful drawing to show its direction, given that \( F_1 = 20.0 \text{ N} \).

Figure 4-31 Problem 64

65. ** A 100-kg streetlight is supported equally by two ropes as shown in Figure 4-32. One rope pulls up and to the right, 40° above the horizontal; the other rope pulls up and to the left, 40° above the horizontal. What is the tension in each rope? SSM

Figure 4-32 Problem 65

66. ** A 200-N sign is supported by two ropes as shown in Figure 4-33. If \( \theta_L = 45.0^\circ \) and \( \theta_R = 30.0^\circ \), what is the tension in each rope?

Figure 4-33 Problem 66

67. ** The distance between two telephone poles is 50 m. When a 0.500-kg bird lands on the telephone wire midway between the poles, the wire sags 0.15 m. How much tension does the bird produce in the wire? Ignore the weight of the wire.

68. ** A locomotive pulls 10 identical freight cars with an acceleration of \( 2 \text{ m/s}^2 \). How does the force between the third and fourth cars compare to the force between the seventh and eighth cars?

69. ** A locomotive pulls 10 identical freight cars. The force between the locomotive and the first car is 100,000 N, and the acceleration of the train is \( 2 \text{ m/s}^2 \). There is no friction to consider. Find the force between the ninth and tenth cars. SSM

70. ** A block that has a mass of 0.0100 kg and a block that has a mass of 2.00 kg are attached to the ends of a rope. A student holds the 2.00-kg block and lets the 0.0100-kg block hang below it; then he lets go. What is the tension in the rope while the blocks are falling, before either hits the ground? Air resistance can be neglected.

71. ** While parachuting, a 66.0-kg person experiences a downward acceleration of \( 2.50 \text{ m/s}^2 \). What is the downward force on the parachute from the person?
72. A bicycle and 50.0-kg rider accelerate at 1.00 m/s² up an incline of 10.0° above the horizontal. What is the magnitude of the force that the bicycle exerts on the rider?

73. A car uniformly accelerates from 0 to 28.0 m/s. A 60.0-kg passenger experiences a horizontal force of 400 N. How much time does it take for the car to reach 28.0 m/s? SSM

74. A car accelerates from 0 to 100 km/h in 4.50 s. What force does a 65.0-kg passenger experience during this acceleration?

75. Adam and Ben pull hand over hand on opposite ends of a rope while standing on a frictionless frozen pond. Adam’s mass is 75.0 kg and Ben’s mass is 50.0 kg. If Adam’s acceleration is 1.00 m/s² to the east, what are the magnitude and direction of Ben’s acceleration?

76. Two blocks of masses \( M_1 \) and \( M_2 \) are connected by a massless string that passes over a massless pulley (Figure 4-34). \( M_2 \), which has a mass of 20.0 kg, rests on a long ramp of angle \( \theta = 30.0° \). Friction can be ignored in this problem. (a) What is the value of \( M_1 \) for which the two blocks are in equilibrium (no acceleration)? (b) If the actual mass of \( M_1 \) is 5.00 kg and the system is allowed to move, what is the magnitude of the acceleration of the two blocks? (c) In part (b) does \( M_2 \) move up or down the ramp? (d) In part (b), how far does \( M_2 \) move in 2.00 s?

77. In Figure 4-35, the block on the left incline is 6.00 kg. If \( \theta_1 = 60.0° \) and \( \theta_2 = 25° \), find the mass of the block on the right incline so that the system is in equilibrium (no acceleration). All surfaces are frictionless. SSM

78. A child on a sled starts from rest at the top of a 20.0° slope. Assuming that there are no forces resisting the sled’s motion, how long will the child take to reach the bottom of the slope, 210 m from the top?

79. A car is proceeding at a speed of 14.0 m/s when it collides with a stationary car in front. During the collision, the first car moves a distance of 0.300 m as it comes to a stop. The driver is wearing her seat belt, so she remains in her seat during the collision. If the driver’s mass is 52.0 kg, how much force does the belt exert on her during the collision? Neglect any friction between the driver and the seat.

80. Your friend’s car runs out of fuel, and you volunteer to push it to the nearest gas station. You carefully drive your car so that the bumpers of the two cars are in contact and then slowly accelerate to a speed of 2.00 m/s over the course of 1.00 min. If the mass of your friend’s car is 1200 kg, what is the contact force between the two bumpers?

81. A 30.0-kg golden retriever stands on a scale in an elevator. Calculate the reading on the scale when the elevator (a) accelerates at 3.50 m/s² downward, (b) when the elevator cruises down at a steady speed, and (c) when the elevator accelerates at 4.00 m/s² upward. SSM

82. A person weighs 588 N. If she stands on a scale while riding on the Inclinator (the lift at the Luxor Hotel in Las Vegas), what will be the reading on the scale? Assume the Inclinator moves at a constant acceleration of 1.25 m/s², in a direction 39.0° above the horizontal, and that the rider stands vertically in the elevator car.

83. A rider in an elevator weighs 700 N. If this person stands on a scale in an elevator, describe the variation in the scale readings as the elevator initially starts from rest, accelerates upward at 3.00 m/s², cruises upward at 4.00 m/s, slows to a stop at 2.00 m/s², then free-falls all the way to the bottom of the elevator shaft before striking springs that bring the car to a safe stop.

84. A fuzzy die that has a weight of 1.80 N hangs from the ceiling of a car by a massless string. The car travels on a horizontal road and has an acceleration of 2.70 m/s² to the left. The string makes an angle \( \theta \) with respect to the vertical, shown in Figure 4-36. What is the angle \( \theta \)?

85. Biology On average, froghopper insects have a mass of 12.3 mg and jump to a height of 428 mm. The takeoff velocity is achieved as the little critter flexes its legs over a distance of approximately 2.00 mm. Assume a vertical jump with constant acceleration. (a) How long does the jump last (the jump itself, not the time in the air), and what is the froghopper’s acceleration during that time? (b) Make a free-body diagram of the froghopper during its leap (but before it leaves the ground). (c) What force did the ground exert on the froghopper during the jump? Express your answer in millinewtons and as a multiple of the insect’s weight. SSM

86. Medical A car traveling at 28.0 m/s hits a bridge abutment. A passenger in the car, who has a mass of 45.0 kg, moves forward a distance of 55.0 cm while being brought to rest by an inflated air bag. Assuming that the force that stops the
passenger is constant, what is the magnitude of force acting on the passenger?

87. Two mountain climbers are working their way up a glacier when one falls into a crevasse (Figure 4-37). The icy slope, which makes an angle of $\theta = 45.0^\circ$ with the horizontal, can be considered frictionless. Sue's weight is pulling Paul up the 45.0° slope. If Sue's mass is 66.0 kg and she falls 2.00 m in 10.0 s starting from rest, calculate (a) the tension in the rope joining them and (b) Paul's mass.

88. Medical During a front-end car collision, the acceleration limit for the chest is 60 g as the car comes to rest. If a car was initially traveling at 48.0 km/h, (a) how much time does it take for the car to come to rest, assuming a constant acceleration equal to the threshold acceleration for damage to the chest? (b) Draw a free-body diagram of a person during the crash. (c) What force in newtons does the air bag exert on the chest of a 72.0-kg person? The trunk of the body comprises about 43.0% of body weight. (d) Why doesn’t this force injure the person?

89. A window washer sits in a bosun's chair that dangles from a massless rope that runs over a massless, frictionless pulley and back down to the man's hand. The combined mass of man, chair, and bucket is 95.0 kg. With how much force must he pull downward to raise himself (a) slowly at constant speed and (b) with an upward acceleration 1.50 m/s²?

90. A 200-kg block is hoisted up by two massless pulleys as shown in Figure 4-38. If a force of 1500 N is applied to the massless rope, what is the acceleration of the suspended mass?

91. Two blocks connected by a light string are being pulled across a frictionless horizontal tabletop by a hanging 10.0-N weight (block C) (Figure 4-39). Block A has a mass of 2.00 kg. The mass of block B is only 1.00 kg. The blocks gain speed as they move toward the right, and the strings remain taut at all times. Assuming the pulley is massless and frictionless, what are the values of the tensions $T_1$ and $T_2$?

92. Three boxes are lined up so that they are touching each other as shown in Figure 4-40. Box A has a mass of 20.0 kg, box B has a mass of 30.0 kg, and box C has a mass of 50.0 kg. If an external force (F) pushes on box A toward the right, and the force that box B exerts on box C is 200 N, what is the acceleration of the boxes and the magnitude of the external force F?

93. A 2.00-kg object A is connected with a massless string across a massless, frictionless pulley to a 3.00-kg object B (Figure 4-41). The smaller object rests on an inclined plane which is tilted at an angle of $\theta = 40.0^\circ$ as shown. What are the acceleration of the system and the tension in the string?

94. A 1.00-kg object A is connected with a string to a 2.00-kg object B, which is connected with a second string over a massless, frictionless pulley to a 4.00-kg object C (Figure 4-42). The 2.00-kg object is connected with a second string over a massless, frictionless pulley to a 4.00-kg object as shown. Calculate the acceleration of the system and the tension in both strings. Assume the strings have negligible mass and do not stretch, and assume the level tabletop is frictionless.
95. A 1.00-kg object A is connected with a string to a 2.00-kg object B, which is connected with a second string over a massless, frictionless pulley to a 4.00-kg object C (Figure 4-43). The first two objects are placed onto a frictionless inclined plane that makes an angle $\theta = 30.0^\circ$ as shown. Calculate the acceleration of the masses and the tensions in both strings.

![Figure 4-43](Problem 95)

96. A compound Atwood’s machine is constructed as shown in Figure 4-44. If block A has a mass of 2.00 kg, block B has a mass of 1.00 kg, and block C has a mass of 5.00 kg, calculate the acceleration of block A when the system is released from rest.

![Figure 4-44](Problem 96)

97. Medical, Astronomy The space shuttle takes off vertically from rest with an acceleration of 29.0 m/s$^2$. What force is exerted on a 75.0-kg astronaut during takeoff? Express your answer in newtons and also as a multiple of the astronaut’s weight on Earth.

98. Sports An athlete drops from rest from a platform 10.0 m above the surface of a 5.00-m-deep pool. Assuming that the athlete enters the water vertically and moves through the water with constant acceleration, what is the minimum average force the water must exert on a 62.0-kg diver to prevent her from hitting the bottom of the pool? Express your answer in newtons and also as a multiple of the diver’s weight.

99. A person pulls three crates over a smooth horizontal floor as shown in Figure 4-45. The crates are connected to each other by identical horizontal strings A and B, each of which can support a maximum tension of 45.0 N before breaking. (a) What is the largest pulling force that can be exerted without breaking either of the strings? (b) What are the tensions in A and B just before one of the strings breaks?

![Figure 4-45](Problem 99)

100. A 275-g hard rubber ball falls from a height of 2.20 m. After each bounce, it rebounds to 75.0% of its previous height. High-speed photos reveal that the ball is in contact with the floor for 18.4 ms during each bounce. (a) Draw a free-body diagram of the ball before it hits the floor, (b) while it is in contact with the floor, and (c) after it has bounced and is rising. (d) What average force (magnitude and direction) does the floor exert on the ball during the first bounce?