End-of-Chapter Exercises

Exercises 1 – 12 are conceptual questions that are designed to see if you have understood the main concepts of the chapter.

1. Five possible free-body diagrams of one of your friends are shown in Figure 3.21. (a) Which free-body diagram applies if your friend remains at rest? Which free-body diagram applies if your friend is moving with a constant velocity directed (b) to the right? (c) to the left? (d) straight up? (e) straight down? You can use a free-body diagram more than once if you wish.

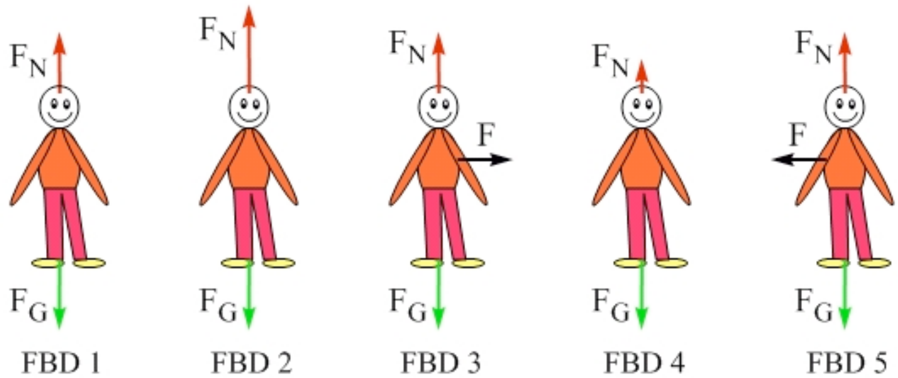


Figure 3.21. Five possible free-body diagrams of your friend, for Exercises 1 and 2. Note that the magnitude of $\vec{F}_N$ is equal to that of $\vec{F}_G$ in diagrams 1, 3, and 5.

2. Five possible free-body diagrams of one of your friends are shown in Figure 3.21. Describe a situation in which the applicable free-body diagram is (a) FBD 2 (b) FBD 3 (c) FBD 4.

3. Three possible free-body diagrams are shown in Figure 3.22 for a car moving to the right. $\vec{F}_{air}$ represents a resistive force due to air resistance, while $\vec{F}_{road}$ represents the force the road exerts on the car. Which free-body diagram is consistent with the car (a) moving at constant velocity? (b) speeding up? (c) slowing down? You can use a free-body diagram more than once if you wish. A resistive force is a force that opposes motion.

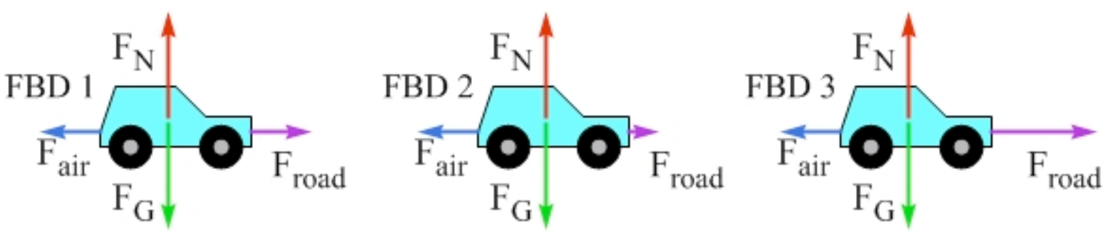


Figure 3.22: Three possible free-body diagrams for a car moving to the right. The magnitude of the force of air resistance is equal to that exerted by the road in FBD 1. For Exercises 3 and 4.

4. Consider again the three free-body diagrams shown in Figure 3.22. $\vec{F}_{air}$ represents a force that the air exerts on the car, while $\vec{F}_{road}$ represents the force the road exerts on the car. (a) Are any of the free-body diagrams consistent with the car remaining at rest? If so, which? (b) If you chose a free-body diagram in (a), describe a situation in which that free-body diagram would apply, with the car remaining at rest.

5. In class, you see a demonstration involving a penny and a feather that are dropped simultaneously from rest inside a glass tube. The tube is held so the two objects fall vertically from one end of the tube to the other. At first, the penny easily beats the feather to the lower end of the tube, but then your professor uses a vacuum pump to remove most of the air from inside the tube. When the objects are again released from rest, which object reaches the lower end of the tube first? Why?

6. Two solid steel ball bearings are dropped from rest from the same height above the floor. Ball A is somewhat larger and heavier than ball B. Assuming air resistance can be neglected, rank the balls based on (a) the magnitude of their accelerations as they fall; (b) the magnitude of the net force acting on each ball as they fall; (c) the time it takes them to reach the ground.

7. Three identical blocks are placed in a vertical stack, one on top of the other, as shown in Figure 3.23. The stack of blocks remains at rest on the floor. (a) Which block experiences the largest net force? Explain. (b) Compare the free-body diagram of block 2, in the middle of the stack, to that of block 3, at the bottom of the stack. Comment on any differences, if there are any, between the two free-body diagrams.

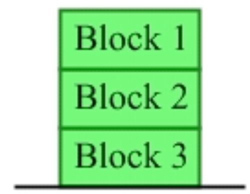


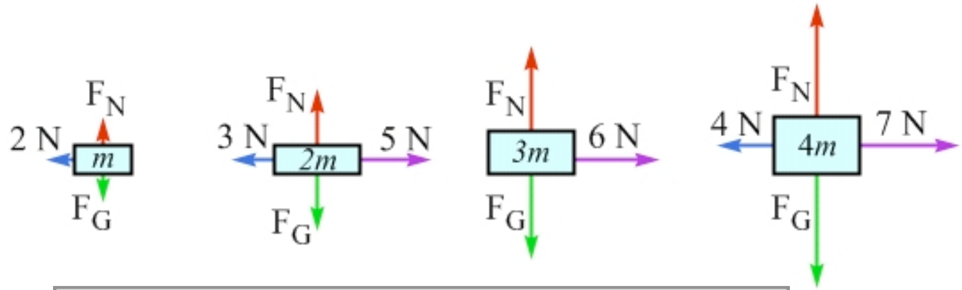
Figure 3.23: A stack of three identical blocks, for Exercise 7.

8. What situations can you think of in which one object exerts a larger-magnitude force on a second object than the second object exerts on the first object?

9. Describe a situation that matches each of the following, or state that it is impossible. (a) An object has no net force acting on it, and yet it is moving. (b) An object has a net force acting on it, but it remains at rest. (c) An object has at least one force acting on it, but it remains at rest.

10. A team of construction workers knows that the cable on a crane will break if its tension exceeds 8000 N. They then connect the cable to a load of bricks with a total weight of 7500 N. When the crane operator slowly raises the bricks off the ground, everything looks fine, and the team gives her the signal to go faster. As she increases the speed at which the bricks are being raised, however, the cable breaks, showering bricks on the ground below. Fortunately, everyone is wearing proper safety equipment, so there are no serious injuries. Using your knowledge of physics, can you come up with an explanation of the cause of the accident? Come up with two ways the accident could have been prevented.

11. Yuri, a cosmonaut on the space station, is taking a spacewalk outside of the station to fix a malfunctioning array of solar cells that provide electricity for the station. Unfortunately, he forgets to tether himself to the station, and his rocket pack also is not working, so when he finds himself drifting slowly away from the station Yuri realizes he's in a bit of trouble. Fortunately he is holding a large wrench. Based on the principles of physics we have discussed in this chapter, explain what Yuri can do to get himself back to the space station.



12. Four free-body diagrams are shown in Figure 3.24, for objects that have masses of *m*, 2*m*, 3*m*, and 4*m*, respectively. Rank these situations, from largest to smallest, based on (a) the net force being applied to the object, and (b) the acceleration of the object. Your answers should have the form 3>2=4>1.

Figure 3.24: Four free-body diagrams, for Exercise 12. On each free-body diagram, the magnitude of the normal force, $\vec{F}_N$, is equal to the magnitude of the force of gravity, $\vec{F}_G$.

Exercises 13 - 20 are designed to give you practice with free-body diagrams.

13. You are at rest, sitting down with your weight completely supported by a chair. Sketch a free-body diagram for (a) you, and (b) the chair.

14. Repeat Exercise 13, except that now you and the chair are inside an elevator that has a constant velocity directed down. Sketch a free-body diagram for (a) you, and (b) the chair. (c) Comment on what, if anything, changes on the free-body diagrams here compared to those you drew in Exercise 13.

15. Repeat Exercise 13, except that now you and the chair are inside an elevator that has a constant acceleration directed down.

16. You step off a chair and allow yourself to drop, feet first, straight down to the floor below. Sketch your free-body diagram while you are (a) dropping to the floor, not in contact with anything, (b) slowing down, after your feet initially make contact with the floor, and (c) at rest, standing on the floor. (d) What would a bathroom scale, on the floor, read if you landed on it instead of the floor while you were in the three positions in (a), (b), and (c)? Would the scale reading equal your mass, or not? (e) Are your answers in (d) consistent with the free-body diagrams you drew in (a) – (c)? Explain.

17. A ball is initially at rest in your hand. You then accelerate the ball upwards, releasing it so that it goes straight up into the air. When it comes down, you catch it and bring it to rest again. Neglect air resistance. Sketch a free-body diagram for the ball when it is (a) accelerating upward in your hand; (b) moving up after you release it; (c) at rest, just for an instant, at the top of its flight; (d) moving down before you catch it; (e) slowing down after it makes contact with your hand again. (f) What is the minimum number of unique free-body diagrams that you can draw to represent the five situations described in (a) – (e)? Explain.

18. As shown in Figure 3.25 (a), two boxes are initially at rest on a frictionless horizontal surface. The mass of the large box is five times larger than that of the small box. You then exert a horizontal force F directed right on the large box. Sketch a free-body diagram for (a) the two-box system (b) the large box (c) the small box. (d) Does the large box exert more force on the small box than the small box exerts on the large box? Explain.

Figure 3.25: Two situations involving two boxes placed side-by-side on a frictionless surface, for Exercises 18 – 20.

19. Repeat Exercise 18, except that now the position of the boxes is reversed, as shown in Figure 3.25 (b).

20. In which case above, in Exercise 18 or Exercise 19, is the force that the large box exerts on the small box larger in magnitude? Explain.

Exercises 21 – 30 are designed to give you practice with applying the general method for solving a problem that involves Newton's laws. For each exercise, start by doing the following: (a) Draw a diagram of the situation. (b) Draw one or more free-body diagram(s) showing all the forces that act on various objects or systems. (c) Choose an appropriate coordinate system for each free-body diagram. (d) Apply Newton's second law to each free-body diagram.

21. You pull on a horizontal string attached to a small block that is initially at rest on a horizontal frictionless surface. The block has an acceleration of 3.0 m/s^2 when you exert a force of 6.0 N. Parts (a) – (d) as described above. (e) What is the mass of the block?

22. Jennifer, Katie, and Leah are attempting to push Katie's car, which has run out of gas. The car has a mass of 1500 kg. Each woman exerts a force of 200 N while pushing the car forward, and, once they get the car moving, there is a net resistive force of 570 N opposing the motion. Parts (a) – (d) as described above. (e) What is the magnitude of the car's acceleration?

23. A small box with a weight of 10 N is placed on top of a larger box with a weight of 40 N. The boxes are at rest on the top of a horizontal table. Parts (a) – (d) as described above, in part (b) drawing three free-body diagrams, one for each of the boxes and one for the two-box system. What is the magnitude and direction of the force exerted on the large box by (e) the small box? (f) the table?

24. Repeat Exercise 23, except that now the system of boxes and the table are inside an elevator that has a constant acceleration down of $g/2$.

25. A small box with a weight of 10 N is placed on top of a larger box with a weight of 40 N. The boxes are at rest on the top of a horizontal table. You apply an additional downward force of 10 N to the top of the small box by resting your hand on it. Parts (a) – (d) as described above, in part (c) drawing three free-body diagrams, one for each of the boxes and one for the two-box system. What is the magnitude and direction of the force exerted on the large box by (e) the small box? (f) the table?

26. A small block with a weight of 4 N is hung from a string that is tied to the ceiling of an elevator that is at rest. A large block, with a weight of 8 N, is hung from a second string that hangs down from the small block. Parts (a) – (d) as described above, in part (c) drawing three free-body diagrams, one for the each block and one for the two-block system. If the elevator is at rest, find the tension in (e) the string tied to the ceiling of the elevator; (f) the string between the blocks.

27. Return to the situation described in Exercise 26. Repeat the exercise with the elevator now having an acceleration of $g/4$ directed up.

28. Erin is playing on the floor with a wooden toy train consisting of an engine with a mass of 800 g and two passenger cars, each with a mass of 600 g. The three parts of the train are arranged in a line and are connected by horizontal strings of negligible mass. Erin accelerates the entire train forward at 4.0 m/s^2 by pulling horizontally on another string attached to the front of the engine. Neglect friction. Parts (a) – (d) as described above, in part (c) drawing four free-body diagrams, one for the engine, one for each of the passenger cars, and one for the entire train. (e) What is the tension in each of the three strings?

29. Two boxes, one with a mass two times larger than the other, are placed on a frictionless horizontal surface and tied together by a horizontal string, as shown in Figure 3.26(a). You then apply a horizontal force of 30 N to the left by pulling on another string attached to the larger box. Part (a), the diagram, is already done. Parts (b) – (d) as described above, in part (c) drawing three free-body diagrams, one for each box and one for the two-box system. (e) Find the magnitude of the tension in the string between the boxes.

Figure 3.26: Two situations involving two boxes on a horizontal surface. The boxes are connected by a string of negligible mass. For Exercises 29 and 30.

30. Repeat Exercise 29, but now you apply a horizontal force of 30 N to the right by pulling on a string attached to the smaller box, as shown in Figure 3.26(b).

Exercises 31 – 40 are designed to give you some practice connecting the force ideas from this chapter to the motion with constant acceleration ideas from Chapter 2.

31. A car with a mass of 2000 kg experiences a horizontal net force, directed east, of 4000 N for 10 seconds. What is the car's final velocity if the initial velocity of the car is (a) zero (b) 10 m/s east (c) 20 m/s west.

32. A flea, with a mass of 500 nanograms, reaches a maximum height of 50 cm after pushing on the ground for 1.3 milliseconds. What is the average force the ground exerts on the flea while the flea is in contact with the ground as it accelerates up?

33. Yolanda, having a mass of 50 kg, steps off a 2.0-meter high wall and drops down to the ground below. What is the average force exerted on Yolanda by the ground if, after first making contact with the ground, she comes to rest by bending at the knees so her upper body drops an additional distance of (a) 3 cm (b) 30 cm?

34. In a demonstration known as the vacuum bazooka, a ping-pong ball is placed inside a PVC tube, the ends of the tube are sealed with tape or foil, and most of the air is removed from the tube. The demonstrator then pierces the seal at the end of the tube where the ball is, and the in-rushing air accelerates the ball along the tube until the ball bursts through the seal at the far end and emerges from the tube at high speed. (a) If the mass of the ball is 2.5 g, the tube is approximately horizontal and has a length of 1.5 m, and the average force the air exerts on the ball is 100 N, find an upper limit for the ball's speed when it emerges from the tube. (b) In practice, the ball's speed is impressive but somewhat less than the theoretical maximum speed determined in (a). What are some factors that could reduce the ball's speed when it emerges from the tube?

35. In a tennis match, Serena Williams hits a ball that has a velocity of 20 m/s directed horizontally. If the force of her racket is applied for 0.10 s, causing the ball to completely reverse direction and acquire a velocity of 30 m/s directed horizontally, what is the average horizontal force the racket applies to the ball? A tennis ball has a mass of 57 grams.

36. Consider the motion diagram shown in Figure 3.27. If the vertical marks in the diagram are 1.0 meters apart, the object has a mass of 2.0 kg, and the images of the object are shown at 1.0-second intervals, determine the net force applied to the object if the object is moving with a constant acceleration from (a) left to right (b) right to left.

Figure 3.27: Motion diagram for Exercise 36.

37. Consider the motion diagram shown in Figure 3.28. Describe the general behavior, over the 12-second interval shown in the diagram, of a net force that could be applied to the object to produce this motion diagram.

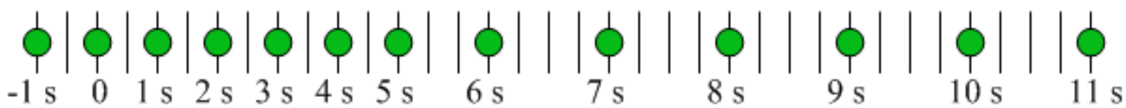


Figure 3.28: Motion diagram for Exercise 37.

38. A plot of a cat's velocity as a function of time is shown in Figure 3.29. If the cat has a mass of 5.0 kg, plot the corresponding net force vs. time graph for the cat.

39. Starting from rest, a person on a bicycle travels 200 m in 20 s, moving in a straight line on a horizontal road. Assuming that the acceleration is constant over this time interval, determine the magnitude of the horizontal force applied to the person-bicycle system in the direction of motion if there is a constant resistive force of 20 N acting horizontally opposite to the direction of motion and the person-bicycle system has a combined mass of 80 kg.

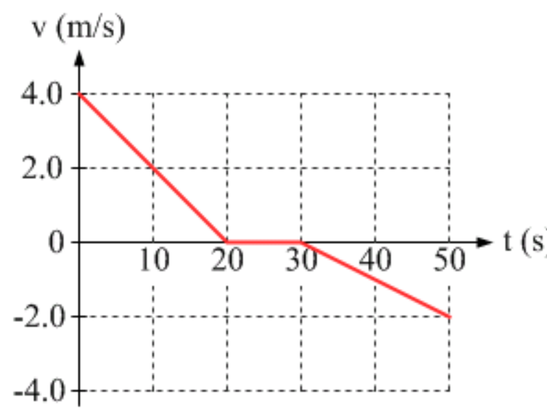


Figure 3.29: A graph of velocity versus time, for Exercise 38.

Exercises 40 – 44 involve applications of forces in one dimension.

40. A baseball pitcher can accelerate a 150-g baseball from rest to a horizontal velocity of 150 km/h over a distance of 2.0 m. What is the average horizontal force the pitcher exerts on the ball during the throwing motion?

41. You read in the paper about a planet that has been discovered orbiting a distant star. The astrophysicist quoted in the newspaper article states that the acceleration due to gravity on this planet is about 20% larger than that here on Earth. In an attempt to simulate what it would feel like to live on this newly discovered planet, you get into an elevator on the third floor of a five-story building. (a) To have an apparent weight larger than your actual weight immediately when the elevator starts to move, should you press the button for the

first floor or the fifth floor? (b) What does the acceleration of the elevator have to be for you to feel (at least briefly!) like you are living on the newly discovered planet?

42. Modern cars are designed with a number of important safety features to protect you in a crash. These include crumple zones, air bags, and seat belts. Consider how a crumple zone (a section of the car that is designed to compress, like an accordion, as does the front of the car in the photograph of a crash test shown in Figure 3.30) and a seat belt work together in a head-on collision in which you go from a speed of 120 km/h to rest. (a) If you are not wearing a seat belt then, in the crash, you generally keep moving forward until you hit something like the windshield. If you come to rest after decelerating through a distance of 4.0 cm after hitting the windshield, what is the magnitude of your average acceleration? (b) If, instead, you are wearing your seat belt, it keeps you in your seat, and you keep moving forward as the front of the car crumples like an accordion. If the compression of the crumple zone is 80 cm, what is the magnitude of your average acceleration? (c) In which case do you think you have a better chance of surviving the crash?

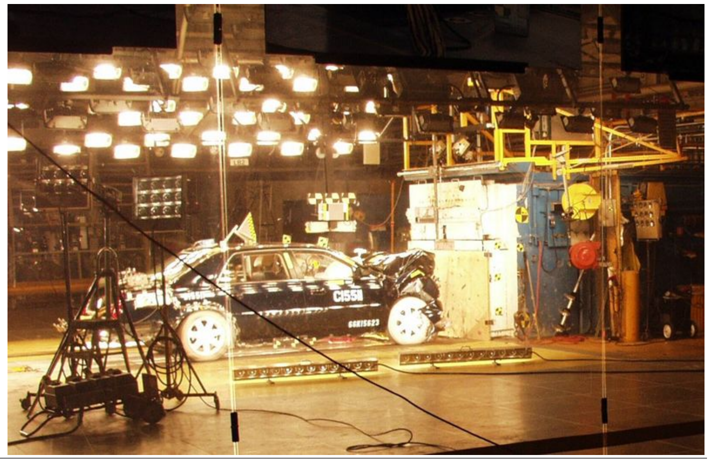


Figure 3.30: In this crash-test photo, the crumple zone at the front of the vehicle has compressed like an accordion, leaving the car's passenger cabin intact. For Exercise 42. Photo credit: Douglas Waite, via Wikimedia Commons.

43. A "solar sailboat" is a space probe that is propelled by sunlight reflecting off a shiny sail with a large area. Let's say the probe and sail have a combined mass of 1000 kg and that the net force exerted on the system is 4.0 N directed away from the Sun. (a) What is the acceleration of the probe/sail system? If the system is released from rest, how fast will it be traveling after (b) 1 day? (c) 1 week? The net force will actually decrease in magnitude as the probe gets farther from the Sun, but let's not worry about that.

44. NASA's Goddard Space Center is named after Robert Goddard of Worcester, Massachusetts, who was a pioneer in the field of rocketry. After Goddard published a paper in 1919 about rockets, the New York Times, in 1920, published an editorial lambasting Goddard, and stating that everybody knows that rockets won't travel in the vacuum of space, where there is nothing to push against. (The paper retracted the statement in 1969, after the launch of Apollo 11.) How does a rocket work? How would you respond to the issue raised by the Times?

Figure 3.31: In 1964, Robert Goddard was honored by the United States Postal Service, via this image on an 8-cent stamp, for his contributions to rocketry. For Exercise 44. Photo credit: Wikimedia Commons.

General Problems and Conceptual Questions.

45. Three children are pushing a very large ball, which has a mass of 10 kg, around a field. If each child exerts a force of 12 N, determine the maximum and minimum possible values of the ball's acceleration. Assume the ball is in contact with the ground, and the normal force from the ground acting on the ball exactly balances the force of gravity acting on the ball.

46. A box with a weight of 25 N remains at rest when it is placed on a ramp that is inclined at 30˚ with respect to the horizontal. What is the magnitude and direction of the contact force exerted on the box by the ramp?

47. You exert a horizontal force of 10 N on a box with a weight of 25 N, but it remains at rest on a horizontal tabletop. What is the magnitude of the contact force exerted on the box by the table?

48. In the following situations, which object exerts a larger-magnitude force on the other? (a) The head of a golf club strikes a golf ball. In other words, does the club exert more force on the ball than the ball exerts on the club, is the opposite true, or is there another answer? (b) While stretching, you push on a wall. (c) A large truck and a small car have a head-on collision on the freeway. (d) The Earth orbits the Sun.

49. Three blocks are tied in a vertical line by three strings, and the top string is tied to the ceiling of an elevator that is initially at rest (see Figure 3.32). If the tension in string 3 is T what is the tension in (a) string 2? (b) string 1 (in terms of T)?

50. Return to the situation described in Exercise 49. Use $g = 10$ m/s^2. What is the magnitude of the tension in the second string if the elevator is (a) at rest? (b) moving at a constant velocity of 2.0 m/s up? (c) accelerating up at 2.0 m/s^2? (d) accelerating down at 2.0 m/s^2?

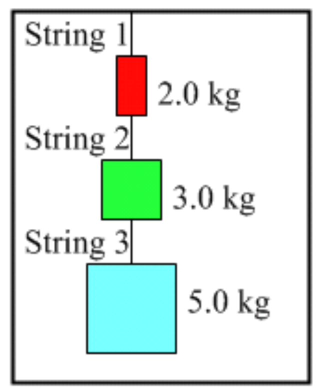


Figure 3.32: Three blocks connected by strings and tied to the ceiling of an elevator, for Exercises 49 and 50.

51. Three blocks are placed side-by-side on a horizontal frictionless surface and subjected to a horizontal force F, as shown in case 1 of Figure 3.33, which causes the blocks to accelerate to the right. The blocks are then re-arranged, as in case 2, and subjected again to the same horizontal force F. (a) In which case does the 2.0 kg block experience a larger net force? (b) In terms of F, calculate the magnitude of the net force on the 2.0 kg block in (i) Case 1 (ii) Case 2. (c) In which case does the 5.0 kg block exert more force on the 2.0 kg block? (d) In terms of F, calculate the magnitude of the force exerted by the 5.0 kg block on the 2.0 kg block in (i) Case 1 (ii) Case 2.

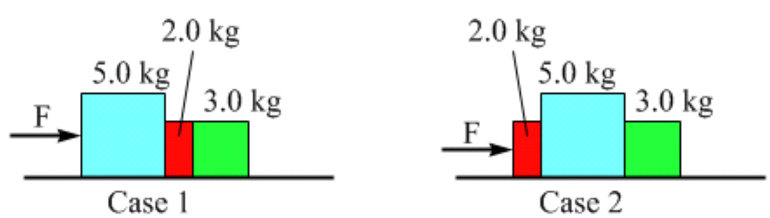


Figure 3.33: Two situations involving three blocks being pushed from the left by a horizontal force F, for Exercise 51.

52. As shown in Figure 3.34, a mobile made from ten 1.0 N balls is tied to the ceiling. Assume the other parts of the mobile (the strings and rods) have negligible mass. What is the tension in the string (a) above the green ball? (b) above the red rod? (c) tying the mobile to the ceiling?

53. Repeat Exercise 52, but this time let's say that the mobile is tied to the ceiling of an elevator, and that the elevator is accelerating down at $g/2$.

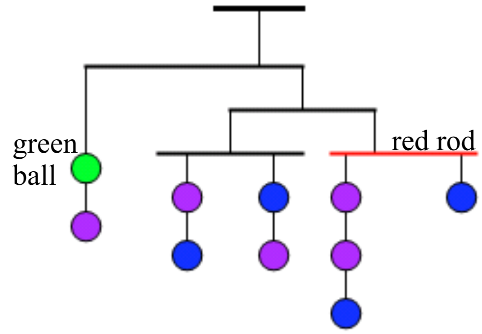


Figure 3.34: A mobile made from 10 balls and some light strings and rods, for Exercises 52 and 53.

54. You give a book a small push with your hand so that, after you remove your hand, the book slides for some distance across a table before coming to rest. (a) Sketch a motion diagram for the book as it is sliding, showing the book's position at regular time intervals after you remove your hand. (b) You should see a trend in your motion diagram. Does the distance between successive images of the book on the motion diagram change as time goes by? If so, how? (c) Sketch a free-body diagram for the book, showing all forces acting on the book as it is sliding, and after the period in which your hand was pushing the book. (d) What applies each of the forces on your free-body diagram? (e) Is there a net force acting on the book as it is sliding? If so, in what direction is it? (f) Is the book's motion consistent with this net force?

55. In Exploration 3.2B, we drew a free-body diagram for a ball falling straight down toward the floor. (a) Now, consider the free-body diagram for a ball you toss straight up in the air. While it is in flight (after it leaves your hand) does the free-body diagram differ from that in Exploration 3.2B? If so, in what way(s)? (b) Consider the free-body diagram for a ball you toss across the room to your friend. While the ball is in flight, does the free-body diagram differ from that in Exploration 3.2B? If so, in what way(s)?

56. You overhear two of your classmates discussing the issue of the force experienced by a ball that is tossed straight up into the air. Comment on each of their statements.

   Sarah: Once the ball leaves my hand, the only force acting on it is gravity, so the ball's acceleration changes at a steady rate.

   Tasha: But, after it leaves your hand, the ball is moving up, and gravity acts down. The ball must have the force of your throw acting on it as it moves up.

   Sarah: So what makes the ball slow down?

   Tasha: As time goes by, the force of your throw decreases, and gravity takes over.

57. A hockey puck of mass m is sliding across some ice at a constant speed of 8 m/s. It then experiences a head-on collision with a hockey stick of mass $5m$ that is lying on the ice. The puck is in contact with the stick for 0.10 s. After the collision, the puck is traveling at a constant speed of 2 m/s in the direction opposite what it was going originally. (a) Find the magnitude of the average force exerted on the puck by the stick during the collision. (b) Find the velocity of the stick after the collision. You can assume no friction acts on either object.

58. Consider the following situations involving a car of mass *m* and a truck of mass 5*m*. In each situation, state which force has a larger magnitude, the force the truck exerts on the car or the force the car exerts on the truck. (a) The truck collides with the car, which is parked by the side of the road. (b) The car collides with the truck, which is parked by the side of the road. (c) The vehicles have identical speeds and are going in opposite directions when they have a head-on collision. (d) The vehicles are going in opposite directions when they collide, with the car's speed being five times larger than the truck's speed.

59. Two boxes are side-by-side on a frictionless horizontal surface as shown in Figure 3.35. In Case 1, a horizontal force *F* directed right is applied to the box of mass *M*. In Case 2, the horizontal force *F* is instead directed left and applied to the box of mass *m*. Find an expression for the magnitude of F_{Mm}, the force the box of mass *M* exerts on the box of mass *m*, in (a) Case 1 (b) Case 2. Express your answers in terms of variables given in the problem. (c) If F_{Mm} is four times larger in case 2 than it is in case 1, find the ratio of the masses of the boxes.

60. Consider again the situation shown in Figure 3.35 and described in Exercise 59, but now let's say that $M = 2m$. In which case is the magnitude of the (a) acceleration of the two-box system larger? (b) acceleration of the box of mass *m* larger? (c) force that the box of mass *M* exerts on the box of mass *m* larger? (d) force that the box of mass *m* exerts on the box of mass *M* larger?

Figure 3.35: Two cases involving two boxes on a frictionless surface, with an applied force, for Exercises 59 and 60.

61. You get on an elevator on the fifth floor of a building, stand on a regular bathroom scale, and then push a button in the elevator. The elevator doors close, and the elevator moves from the fifth floor to a different floor, where it stops and the doors open again. At this point, you get off the scale and exit the elevator. A graph of the scale reading as a function of time is shown in Figure 3.36. Use $g = 10$ m/s^2. Based on this graph, (a) qualitatively describe the motion of the elevator; (b) determine the magnitude of the peak acceleration of the elevator; (c) determine how far, and in what direction, the elevator moved.

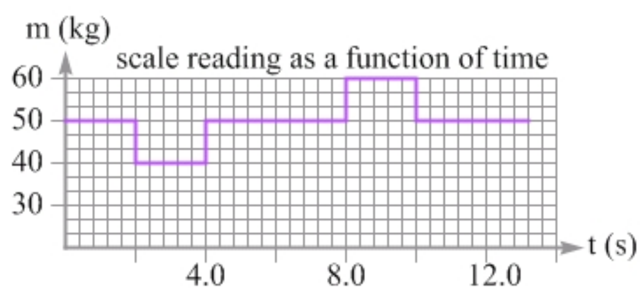


Figure 3.36: A graph of a scale reading as a function of time while you are standing on it in an elevator, for Exercise 61.