EXERCISES AND PROBLEMS

Exercises

Section 7.2 Analyzing Interacting Objects

Exercises 1 through 6 describe a situation. For each:

a. Draw an interaction diagram, following the steps of Tactics Box 7.1.
b. Identify the "system" on your interaction diagram.
c. Draw a free-body diagram for each object in the system. Use dashed lines to connect the members of an action/reaction pair.

1. | A weightlifter stands up from a squatting position while holding a heavy barbell across his shoulders.
2. | A soccer ball and a bowling ball have a head-on collision. Rolling friction is negligible.
3. | A mountain climber is using a rope to pull a bag of supplies up a 45° slope. The rope is not massless.
4. | A battery-powered toy car pushes a stuffed rabbit across the floor.
5. || Block A in FIGURE EX7.5 is heavier than block B and is sliding down the incline. All surfaces have friction. The rope is massless, and the massless pulley turns on frictionless bearings. The rope and the pulley are among the interacting objects, but you'll have to decide if they're part of the system.

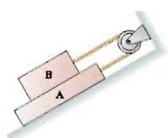

FIGURE EX7.5

FIGURE EX7.6

6. || Block A in FIGURE EX7.6 is sliding down the incline. The rope is massless, and the massless pulley turns on frictionless bearings, but the surface is not frictionless. The rope and the pulley are among the interacting objects, but you'll have to decide if they're part of the system.

Section 7.3 Newton's Third Law

7. | a. How much force does an 80 kg astronaut exert on his chair while sitting at rest on the launch pad?
   b. How much force does the astronaut exert on his chair while accelerating straight up at 10 m/s^2?
8. || FIGURE EX7.8 shows two strong magnets on opposite sides of a small table. The long-range attractive force between the magnets keeps the lower magnet in place.

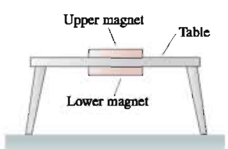

FIGURE EX7.8

   a. Draw an interaction diagram and draw free-body diagrams for both magnets and the table. Use dashed lines to connect the members of an action/reaction pair.
   b. Suppose the weight of the table is 20 N, the weight of each magnet is 2.0 N, and the magnetic force on the lower magnet is three times its weight. Find the magnitude of each of the forces shown on your free-body diagrams.
9. || A 1000 kg car pushes a 2000 kg truck that has a dead battery. When the driver steps on the accelerator, the drive wheels of the car push against the ground with a force of 4500 N. Rolling friction can be neglected.
   a. What is the magnitude of the force of the car on the truck?
   b. What is the magnitude of the force of the truck on the car?
10. || Blocks with masses of 1 kg, 2 kg, and 3 kg are lined up in a row on a frictionless table. All three are pushed forward by a 12 N force applied to the 1 kg block.
   a. How much force does the 2 kg block exert on the 3 kg block?
   b. How much force does the 2 kg block exert on the 1 kg block?
11. || A massive steel cable drags a 20 kg block across a horizontal, frictionless surface. A 100 N force applied to the cable causes the block to reach a speed of 4.0 m/s in a distance of 2.0 m. What is the mass of the cable?

Section 7.4 Ropes and Pulleys

12. | What is the tension in the rope of FIGURE EX7.12?

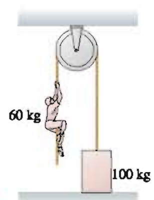

FIGURE EX7.12

13. | Jimmy has caught two fish in Yellow Creek. He has tied the line holding the 3.0 kg steelhead trout to the tail of the 1.5 kg carp. To show the fish to a friend, he lifts upward on the carp with a force of 60 N.
   a. Draw separate free-body diagrams for the trout and the carp. Label all forces, then use dashed lines to connect action/reaction pairs or forces that act as if they are a pair.
   b. Rank in order, from largest to smallest, the magnitudes of all the forces shown on your free-body diagrams. Explain your reasoning.
14. | A 2-m-long, 500 g rope pulls a 10 kg block of ice across a horizontal, frictionless surface. The block accelerates at 2.0 m/s^2. How much force pulls forward on (a) the ice, (b) the rope?

15. | The cable cars in San Francisco are pulled along their tracks by an underground steel cable that moves along at 9.5 mph. The cable is driven by large motors at a central power station and extends, via an intricate pulley arrangement, for several miles beneath the city streets. The length of a cable stretches by up to 100 ft during its lifetime. To keep the tension constant, the cable passes around a 1.5-m-diameter "tensioning pulley" that rolls back and forth on rails, as shown in FIGURE EX7.15. A 2000 kg block is attached to the tensioning pulley's cart, via a rope and pulley, and is suspended in a deep hole. What is the tension in the cable car's cable?

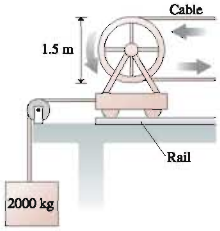

FIGURE EX7.15

16. | A 2.0 kg rope hangs from the ceiling. What is the tension at the midpoint of the rope?

17. || A mobile at the art museum has a 2.0 kg steel cat and a 4.0 kg steel dog suspended from a lightweight cable, as shown in FIGURE EX7.17. It is found that $\theta_1 = 20°$ when the center rope is adjusted to be perfectly horizontal. What are the tension and the angle of rope 3?

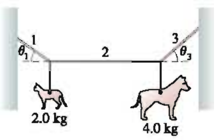

FIGURE EX7.17

Problems

18. || Block B in FIGURE P7.18 rests on a surface for which the static and kinetic coefficients of friction are 0.60 and 0.40, respectively. The ropes are massless. What is the maximum mass of block A for which the system is in equilibrium?

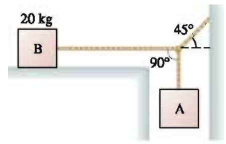

FIGURE P7.18

19. || An 80 kg spacewalking astronaut pushes off a 640 kg satellite, exerting a 100 N force for the 0.50 s it takes him to straighten his arms. How far apart are the astronaut and the satellite after 1.0 min?

20. || A massive steel cable drags a 20 kg block across a horizontal, frictionless surface. A 100 N force applied to the cable causes the block to reach a speed of 4.0 m/s in 2.0 s. What is the difference in tension between the two ends of the cable?

21. || A 1.0-m-long massive steel cable drags a 20 kg block across a horizontal, frictionless surface. A 100 N force applied to the cable causes the block to travel 4.0 m in 2.0 s. Graph the tension in the cable as a function of position along the cable, starting at the point where the cable is attached to the block.

22. || A 3.0-m-long, 2.2 kg rope is suspended from the ceiling. Graph the tension in the rope as a function of position along the rope, starting from the bottom.

23. || The sled dog in FIGURE P7.23 drags sleds A and B across the snow. The coefficient of friction between the sleds and the snow is 0.10. If the tension in rope 1 is 150 N, what is the tension in rope 2?

FIGURE P7.23

24. || While driving to work last year, I was holding my coffee mug in my left hand while changing the CD with my right hand. Then the cell phone rang, so I placed the mug on the flat part of my dashboard. Then, believe it or not, a deer ran out of the woods and on to the road right in front of me. Fortunately, my reaction time was zero, and I was able to stop from a speed of 20 m/s in a mere 50 m, just barely avoiding the deer. Later tests revealed that the static and kinetic coefficients of friction of the coffee mug on the dash are 0.50 and 0.30, respectively; the coffee and mug had a mass of 0.50 kg; and the mass of the deer was 120 kg. Did my coffee mug slide?

25. || a. Why can a car accelerate but a house cannot? Your explanation should be in terms of forces and their properties.
    b. Two-thirds of the weight of a 1500 kg car rests on the drive wheels. What is the maximum acceleration of this car on a concrete surface?

26. || A Federation starship (2.0×10^6 kg) uses its tractor beam to pull a shuttlecraft (2.0×10^4 kg) aboard from a distance of 10 km away. The tractor beam exerts a constant force of 4.0×10^4 N on the shuttlecraft. Both spacecraft are initially at rest. How far does the starship move as it pulls the shuttlecraft aboard?

27. || Bob, who has a mass of 75 kg, can throw a 500 g rock with a speed of 30 m/s. The distance through which his hand moves as he accelerates the rock from rest until he releases it is 1.0 m.
    a. What constant force must Bob exert on the rock to throw it with this speed?
    b. If Bob is standing on frictionless ice, what is his recoil speed after releasing the rock?

28. || You see the boy next door trying to push a crate down the sidewalk. He can barely keep it moving, and his feet occasionally slip. You start to wonder how heavy the crate is. You call to ask the boy his mass, and he replies "50 kg." From your recent physics class you estimate that the static and kinetic coefficients of friction are 0.8 and 0.4 for the boy's shoes, and 0.5 and 0.2 for the crate. Estimate the mass of the crate.

29. || Two packages at UPS start sliding down the 20° ramp shown in FIGURE P7.29. Package A has a mass of 5.0 kg and a coefficient of friction of 0.20. Package B has a mass of 10 kg and a coefficient of friction of 0.15. How long does it take package A to reach the bottom?

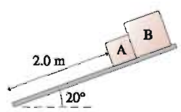

FIGURE P7.29

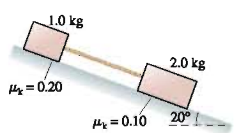

FIGURE P7.30

30. || The two blocks in FIGURE P7.30 are sliding down the incline. What is the tension in the massless string?

31. || FIGURE P7.31 shows two 1.0 kg blocks connected by a rope. A second rope hangs beneath the lower block. Both ropes have a mass of 250 g. The entire assembly is accelerated upward at 3.0 m/s^2 by force $\vec{F}$.
    a. What is F?
    b. What is the tension at the top end of rope 1?
    c. What is the tension at the bottom end of rope 1?
    d. What is the tension at the top end of rope 2?

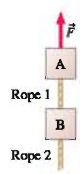

FIGURE P7.31

32. || The 1.0 kg block in FIGURE P7.32 is tied to the wall with a rope. It sits on top of the 2.0 kg block. The lower block is pulled to the right with a tension force of 20 N. The coefficient of kinetic friction at both the lower and upper surfaces of the 2.0 kg block is $\mu_k = 0.40$.
a. What is the tension in the rope holding the 1.0 kg block to the wall?
b. What is the acceleration of the 2.0 kg block?

FIGURE P7.32

FIGURE P7.33

33. || The coefficient of static friction is 0.60 between the two blocks in FIGURE P7.33. The coefficient of kinetic friction between the lower block and the floor is 0.20. Force $\vec{F}$ causes both blocks to cross a distance of 5.0 m, starting from rest. What is the least amount of time in which this motion can be completed without the top block sliding on the lower block?

34. ||| The lower block in FIGURE P7.34 is pulled on by a rope with a tension force of 20 N. The coefficient of kinetic friction between the lower block and the surface is 0.30. The coefficient of kinetic friction between the lower block and the upper block is also 0.30. What is the acceleration of the 2.0 kg block?

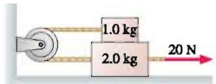

FIGURE P7.34

35. ||| A rope attached to a 20 kg wood sled pulls the sled up a 20° snow-covered hill. A 10 kg wood box rides on top of the sled. If the tension in the rope steadily increases, at what value of the tension does the box slip?

36. || The 100 kg block in FIGURE P7.36 takes 6.0 s to reach the floor after being released from rest. What is the mass of the block on the left?

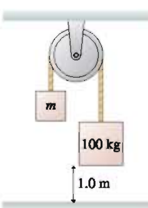

FIGURE P7.36

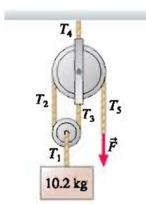

FIGURE P7.37

37. || The 10.2 kg block in FIGURE P7.37 is held in place by the massless rope passing over two massless, frictionless pulleys. Find the tensions T_1 to T_5 and the magnitude of force $\vec{F}$.

38. || The coefficient of kinetic friction between the 2.0 kg block in FIGURE P7.38 and the table is 0.30. What is the acceleration of the 2.0 kg block?

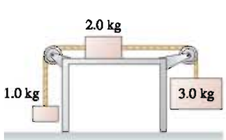

FIGURE P7.38

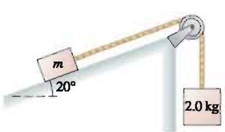

FIGURE P7.39

39. || FIGURE P7.39 shows a block of mass m resting on a 20° slope. The block has coefficients of friction $\mu_s = 0.80$ and $\mu_k = 0.50$ with the surface. It is connected via a massless string over a massless, frictionless pulley to a hanging block of mass 2.0 kg.
a. What is the minimum mass m that will stick and not slip?
b. If this minimum mass is nudged ever so slightly, it will start being pulled up the incline. What acceleration will it have?

40. || A 4.0 kg box is on a frictionless 35° slope and is connected via a massless string over a massless, frictionless pulley to a hanging 2.0 kg weight. The picture for this situation is similar to Figure P7.39.
a. What is the tension in the string if the 4.0 kg box is *held* in place, so that it cannot move?
b. If the box is then released, which way will it move on the slope?
c. What is the tension in the string once the box begins to move?

41. || The 1.0 kg physics book in FIGURE P7.41 is connected by a string to a 500 g coffee cup. The book is given a push up the slope and released with a speed of 3.0 m/s. The coefficients of friction are $\mu_s = 0.50$ and $\mu_k = 0.20$.
a. How far does the book slide?
b. At the highest point, does the book stick to the slope, or does it slide back down?

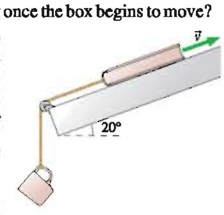

FIGURE P7.41

42. || The 2000 kg cable car shown in FIGURE P7.42 descends a 200-m-high hill. In addition to its brakes, the cable car controls its speed by pulling an 1800 kg counterweight up the other side of the hill. The rolling friction of both the cable car and the counterweight are negligible.
a. How much braking force does the cable car need to descend at constant speed?
b. One day the brakes fail just as the cable car leaves the top on its downward journey. What is the runaway car's speed at the bottom of the hill?

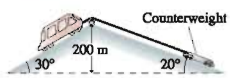

FIGURE P7.42

43. || The century-old *ascensores* in Valparaiso, Chile, are small cable cars that go up and down the steep hillsides. As FIGURE P7.43 shows, one car ascends as the other descends. The cars use a two-cable arrangement to compensate for friction; one cable passing around a large pulley connects the cars, the second is pulled by a small motor. Suppose the mass of both cars (with passengers) is 1500 kg, the coefficient of rolling friction is 0.020, and the cars move at constant speed. What is the tension in the (a) the connecting cable and (b) the cable to the motor?

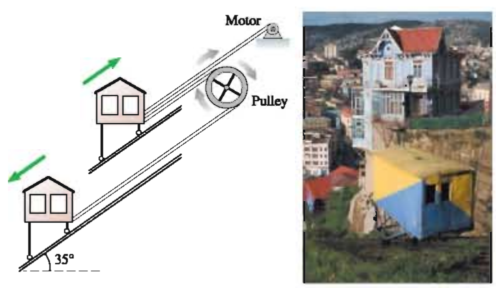

FIGURE P7.43

44. || A house painter uses the chair and pulley arrangement of FIGURE P7.44 to lift himself up the side of a house. The painter's mass is 70 kg and the chair's mass is 10 kg. With what force must he pull down on the rope in order to accelerate upward at $0.20\ m/s^2$?

FIGURE P7.44

45. ||| A 70 kg tightrope walker stands at the center of a rope. The rope supports are 10 m apart and the rope sags 10° at each end. The tightrope walker crouches down, then leaps straight up with an acceleration of $8.0\ m/s^2$ to catch a passing trapeze. What is the tension in the rope as he jumps?

46. || Find an expression for the magnitude of the horizontal force F in FIGURE P7.46 for which m_1 does not slip either up or down along the wedge. All surfaces are frictionless.

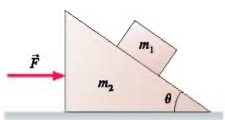

FIGURE P7.46

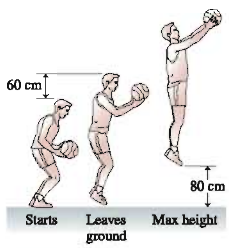

FIGURE P7.47

47. || A 100 kg basketball player can leap straight up in the air to a height of 80 cm, as shown in FIGURE P7.47. You can understand how by analyzing the situation as follows:

a. The player bends his legs until the upper part of his body has dropped by 60 cm, then he begins his jump. Draw separate free-body diagrams for the player and for the floor *as* he is jumping, but before his feet leave the ground.
b. Is there a net force on the player as he jumps (before his feet leave the ground)? How can that be? Explain.
c. With what speed must the player leave the ground to reach a height of 80 cm?
d. What was his acceleration, assumed to be constant, as he jumped?
e. Suppose the player jumps while standing on a bathroom scale that reads in newtons. What does the scale read before he jumps, as he is jumping, and after his feet leave the ground?

Problems 48 and 49 show the free-body diagrams of two interacting systems. For each of these, you are to

a. Write a realistic problem for which these are the correct free-body diagrams. Be sure that the answer your problem requests is consistent with the diagrams shown.
b. Finish the solution of the problem.

48.

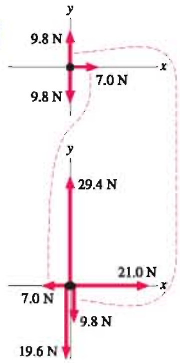

FIGURE P7.48

49.

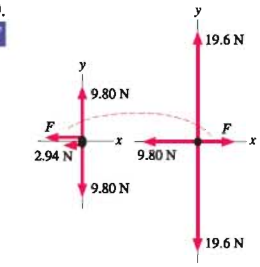

FIGURE P7.49

Challenge Problems

50. A 100 g ball of clay is thrown horizontally with a speed of 10 m/s toward a 900 g block resting on a frictionless surface. It hits the block and sticks. The clay exerts a constant force on the block during the 10 ms it takes the clay to come to rest relative to the block. After 10 ms, the block and the clay are sliding along the surface as a single system.

a. What is their speed after the collision?
b. What is the force of the clay on the block during the collision?
c. What is the force of the block on the clay?

NOTE ▶ This problem can be worked using the conservation laws you will be learning in the next few chapters. However, here you're asked to solve the problem using Newton's laws. ◀

51. In FIGURE CP7.51, find an expression for the acceleration of m_1. Assume the table is frictionless.
Hint: Think carefully about the acceleration constraint.

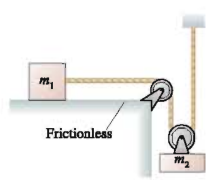

FIGURE CP7.51

52. What is the acceleration of the 2.0 kg block in FIGURE CP7.52 across the frictionless table?
Hint: Think carefully about the acceleration constraint.

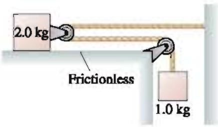

FIGURE CP7.52

53. FIGURE CP7.53 shows a 200 g hamster sitting on an 800 g wedge-shaped block. The block, in turn, rests on a spring scale.
   a. Initially, static friction is sufficient to keep the hamster from moving. In this case, the hamster and the block are effectively a single 1000 g mass and the scale should read 9.8 N. Show that this is the case by treating the hamster and the block as *separate* objects and analyzing the forces.

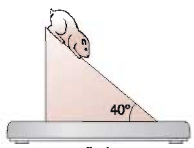

FIGURE CP7.53

   b. An extra-fine lubricating oil having $\mu_s = \mu_k = 0$ is sprayed on the top surface of the block, causing the hamster to slide down. Friction between the block and the scale is large enough that the block does *not* slip on the scale. What does the scale read as the hamster slides down?

54. FIGURE CP7.54 shows three hanging masses connected by massless strings over two massless, frictionless pulleys.
   a. Find the acceleration constraint for this system. It is a single equation relating a_{1y}, a_{2y}, and a_{3y}.
   Hint: y_A isn't constant.
   b. Find an expression for the tension in string A.
   Hint: You should be able to write four second-law equations. These, plus the acceleration constraint, are five equations in five unknowns.
   c. Suppose: $m_1 = 2.5$ kg, $m_2 = 1.5$ kg, and $m_3 = 4.0$ kg. Find the acceleration of each.
   d. The 4.0 kg mass would appear to be in equilibrium. Explain why it accelerates.

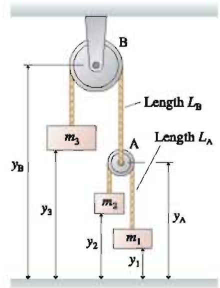

FIGURE CP7.54

STOP TO THINK ANSWERS

Stop to Think 7.1: The gravitational force and the tension force are incorrectly identified as an action/reaction pair. Force $\vec{T}_{\text{L on F}}$ should be paired with force $\vec{T}_{\text{F on L}}$. Gravity is the pull of the entire earth, so $(\vec{F}_G)_F$ should be paired with a force pulling up on the entire earth.

Stop to Think 7.2: c. Newton's third law says that the force of A on B is *equal* and opposite to the force of B on A. This is always true. The speed of the objects isn't relevant.

Stop to Think 7.3: b. $F_{\text{B on H}} = F_{\text{H on B}}$ and $F_{\text{A on B}} = F_{\text{B on A}}$ because these are action/reaction pairs. Box B is slowing down and therefore must have a net force to the left. So from Newton's second law we also know that $F_{\text{H on B}} > F_{\text{A on B}}$.

Stop to Think 7.4: Equal to. Each block is hanging in equilibrium, with no net force, so the upward tension force is *mg*.

Stop to Think 7.5: Less than. Block B is *accelerating* downward, so the net force on B must point down. The only forces acting on B are the tension and gravity, so $T_{\text{S on B}} < (F_G)_B$.

Stop to Think 7.6: c. Newton's third law says that the force of A on B is *equal* and opposite to the force of B on A. This is always true. The mass of the objects isn't relevant.