CAUTION
Directions of gravity and the normal force

In Problems involving a slope or an "inclined plane," avoid making errors in the directions of the normal force and gravity. The normal force on an incline is *not* vertical: it is perpendicular to the slope or plane. And gravity is *not* perpendicular to the slope—gravity acts vertically downward toward the center of the Earth.

Summary

Newton's three laws of motion are the basic classical laws describing motion.

Newton's first law (the **law of inertia**) states that if the net force on an object is zero, an object originally at rest remains at rest, and an object in motion remains in motion in a straight line with constant velocity.

Newton's second law states that the acceleration of an object is directly proportional to the net force acting on it, and inversely proportional to its mass:

$$\Sigma \vec{\mathbf{F}} = m\vec{\mathbf{a}}. \quad \textbf{(4–1)}$$

Newton's second law is one of the most important and fundamental laws in classical physics.

Newton's third law states that whenever one object exerts a force on a second object, the second object always exerts a force on the first object which is equal in magnitude but opposite in direction:

$$\vec{\mathbf{F}}_{AB} = -\vec{\mathbf{F}}_{BA} \quad \textbf{(4–2)}$$

where $\vec{\mathbf{F}}_{BA}$ is the force on object B exerted by object A.

The tendency of an object to resist a change in its motion is called **inertia**. **Mass** is a measure of the inertia of an object.

Weight refers to the **gravitational force** on an object, and is equal to the product of the object's mass m and the acceleration of gravity $\vec{\mathbf{g}}$:

$$\vec{\mathbf{F}}_G = m\vec{\mathbf{g}}. \quad \textbf{(4–3)}$$

Force, which is a vector, can be considered as a push or pull; or, from Newton's second law, force can be defined as an action capable of giving rise to acceleration. The **net force** on an object is the vector sum of all forces acting on that object.

When two objects slide over one another, the force of friction that each object exerts on the other can be written approximately as $F_{fr} = \mu_k F_N$, where F_N is the **normal force** (the force each object exerts on the other perpendicular to their contact surfaces), and μ_k is the coefficient of **kinetic friction**. If the objects are at rest relative to each other, then F_{fr} is just large enough to hold them at rest and satisfies the inequality $F_{fr} < \mu_s F_N$, where μ_s is the coefficient of **static friction**.

For solving problems involving the forces on one or more objects, it is essential to draw a **free-body diagram** for each object, showing all the forces acting on only that object. Newton's second law can be applied to the vector components for each object.

Questions

1. Why does a child in a wagon seem to fall backward when you give the wagon a sharp pull forward?
2. A box rests on the (frictionless) bed of a truck. The truck driver starts the truck and accelerates forward. The box immediately starts to slide toward the rear of the truck bed. Discuss the motion of the box, in terms of Newton's laws, as seen (*a*) by Mary standing on the ground beside the truck, and (*b*) by Chris who is riding on the truck (Fig. 4–35).

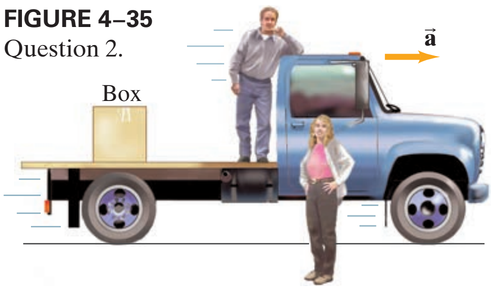

FIGURE 4–35 Question 2.

3. If an object is moving, is it possible for the net force acting on it to be zero? Explain.
4. If the acceleration of an object is zero, are no forces acting on it? Explain.
5. Only one force acts on an object. Can the object have zero acceleration? Can it have zero velocity? Explain.
6. When a golf ball is dropped to the pavement, it bounces back up. (*a*) Is a force needed to make it bounce back up? (*b*) If so, what exerts the force?
7. If you walk along a log floating on a lake, why does the log move in the opposite direction?
8. (*a*) Why do you push down harder on the pedals of a bicycle when first starting out than when moving at constant speed? (*b*) Why do you need to pedal at all when cycling at constant speed?
9. A stone hangs by a fine thread from the ceiling, and a section of the same thread dangles from the bottom of the stone (Fig. 4–36). If a person gives a sharp pull on the dangling thread, where is the thread likely to break: below the stone or above it? What if the person gives a slow and steady pull? Explain your answers.

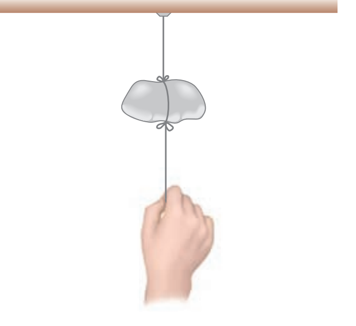

FIGURE 4–36 Question 9.

10. The force of gravity on a 2-kg rock is twice as great as that on a 1-kg rock. Why then doesn't the heavier rock fall faster?

11. (*a*) You pull a box with a constant force across a frictionless table using an attached rope held horizontally. If you now pull the rope with the same force at an angle to the horizontal (with the box remaining flat on the table), does the acceleration of the box increase, decrease, or remain the same? Explain. (*b*) What if there is friction?

12. When an object falls freely under the influence of gravity there is a net force mg exerted on it by the Earth. Yet by Newton's third law the object exerts an equal and opposite force on the Earth. Does the Earth move? Explain.

13. Compare the effort (or force) needed to lift a 10-kg object when you are on the Moon with the force needed to lift it on Earth. Compare the force needed to throw a 2-kg object horizontally with a given speed on the Moon and on Earth.

14. According to Newton's third law, each team in a tug of war (Fig. 4–37) pulls with equal force on the other team. What, then, determines which team will win?

FIGURE 4–37 Question 14. A tug of war. Describe the forces on each of the teams and on the rope.

15. When you stand still on the ground, how large a force does the ground exert on you? Why doesn't this force make you rise up into the air?

16. Whiplash sometimes results from an automobile accident when the victim's car is struck violently from the rear. Explain why the head of the victim seems to be thrown backward in this situation. Is it really?

17. Mary exerts an upward force of 40 N to hold a bag of groceries. Describe the "reaction" force (Newton's third law) by stating (*a*) its magnitude, (*b*) its direction, (*c*) *on* what object it is exerted, and (*d*) *by* what object it is exerted.

18. A father and his young daughter are ice skating. They face each other at rest and push each other, moving in opposite directions. Which one has the greater final speed? Explain.

19. A heavy crate rests on the bed of a flatbed truck. When the truck accelerates, the crate stays fixed on the truck, so it, too, accelerates. What force causes the crate to accelerate?

20. A block is given a brief push so that it slides up a ramp. After the block reaches its highest point, it slides back down, but the magnitude of its acceleration is less on the descent than on the ascent. Why?

21. Why is the stopping distance of a truck much shorter than for a train going the same speed?

22. What would your bathroom scale read if you weighed yourself on an inclined plane? Assume the mechanism functions properly, even at an angle.

MisConceptual Questions

1. A truck is traveling horizontally to the right (Fig. 4–38). When the truck starts to slow down, the crate on the (frictionless) truck bed starts to slide. In what direction could the net force be on the crate?
(*a*) No direction. The net force is zero.
(*b*) Straight down (because of gravity).
(*c*) Straight up (the normal force).
(*d*) Horizontal and to the right.
(*e*) Horizontal and to the left.

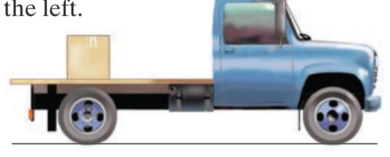

FIGURE 4–38
MisConceptual Question 1.

2. You are trying to push your stalled car. Although you apply a horizontal force of 400 N to the car, it doesn't budge, and neither do you. Which force(s) must also have a magnitude of 400 N?
(*a*) The force exerted by the car on you.
(*b*) The friction force exerted by the car on the road.
(*c*) The normal force exerted by the road on you.
(*d*) The friction force exerted by the road on you.

3. Matt, in the foreground of Fig. 4–39, is able to move the large truck because
(*a*) he is stronger than the truck.
(*b*) he is heavier in some respects than the truck.
(*c*) he exerts a greater force on the truck than the truck exerts back on him.
(*d*) the ground exerts a greater friction force on Matt than it does on the truck.
(*e*) the truck offers no resistance because its brakes are off.

FIGURE 4–39 MisConceptual Question 3.

4. A bear sling, Fig. 4–40, is used in some national parks for placing backpackers' food out of the reach of bears. As the backpacker raises the pack by pulling down on the rope, the force F needed:
(*a*) decreases as the pack rises until the rope is straight across.
(*b*) doesn't change.
(*c*) increases until the rope is straight.
(*d*) increases but the rope always sags where the pack hangs.

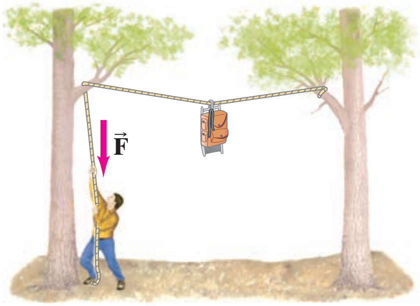

FIGURE 4–40 MisConceptual Question 4.

5. What causes the boat in Fig. 4–41 to move forward?
(*a*) The force the man exerts on the paddle.
(*b*) The force the paddle exerts on the water.
(*c*) The force the water exerts on the paddle.
(*d*) The motion of the water itself.

FIGURE 4–41 MisConceptual Question 5.

6. A person stands on a scale in an elevator. His apparent weight will be the greatest when the elevator
(*a*) is standing still.
(*b*) is moving upward at constant velocity.
(*c*) is accelerating upward.
(*d*) is moving downward at constant velocity.
(*e*) is accelerating downward.

7. When a skier skis down a hill, the normal force exerted on the skier by the hill is
(*a*) equal to the weight of the skier.
(*b*) greater than the weight of the skier.
(*c*) less than the weight of the skier.

8. A golf ball is hit with a golf club. While the ball flies through the air, which forces act on the ball? Neglect air resistance.
(*a*) The force of the golf club acting on the ball.
(*b*) The force of gravity acting on the ball.
(*c*) The force of the ball moving forward through the air.
(*d*) All of the above.
(*e*) Both (*a*) and (*c*).

9. Suppose an object is accelerated by a force of 100 N. Suddenly a second force of 100 N in the opposite direction is exerted on the object, so that the forces cancel. The object
(*a*) is brought to rest rapidly.
(*b*) decelerates gradually to rest.
(*c*) continues at the velocity it had before the second force was applied.
(*d*) is brought to rest and then accelerates in the direction of the second force.

10. You are pushing a heavy box across a rough floor. When you are initially pushing the box and it is accelerating,
(*a*) you exert a force on the box, but the box does not exert a force on you.
(*b*) the box is so heavy it exerts a force on you, but you do not exert a force on the box.
(*c*) the force you exert on the box is greater than the force of the box pushing back on you.
(*d*) the force you exert on the box is equal to the force of the box pushing back on you.
(*e*) the force that the box exerts on you is greater than the force you exert on the box.

11. A 50-N crate sits on a horizontal floor where the coefficient of static friction between the crate and the floor is 0.50. A 20-N force is applied to the crate acting to the right. What is the resulting static friction force acting on the crate?
(*a*) 20 N to the right.
(*b*) 20 N to the left.
(*c*) 25 N to the right.
(*d*) 25 N to the left.
(*e*) None of the above; the crate starts to move.

12. The normal force on an extreme skier descending a very steep slope (Fig. 4–42) can be zero if
(*a*) his speed is great enough.
(*b*) he leaves the slope (no longer touches the snow).
(*c*) the slope is greater than 75°.
(*d*) the slope is vertical (90°).

FIGURE 4–42 MisConceptual Question 12.

13. To pull an old stump out of the ground, you and a friend tie two ropes to the stump. You pull on it with a force of 500 N to the north while your friend pulls with a force of 450 N to the northwest. The total force from the two ropes is
(*a*) less than 950 N.
(*b*) exactly 950 N.
(*c*) more than 950 N.

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

Problems

[*It would be wise, before starting the Problems, to reread the Problem Solving Strategies on pages 30, 60, and 88.*]

4–4 to 4–6 Newton's Laws, Gravitational Force, Normal Force [Assume no friction.]

1. (I) What force is needed to accelerate a sled (mass = 55 kg) at $1.4\ \text{m/s}^2$ on horizontal frictionless ice?
2. (I) What is the weight of a 68-kg astronaut (*a*) on Earth, (*b*) on the Moon ($g = 1.7\ \text{m/s}^2$), (*c*) on Mars ($g = 3.7\ \text{m/s}^2$), (*d*) in outer space traveling with constant velocity?
3. (I) How much tension must a rope withstand if it is used to accelerate a 1210-kg car horizontally along a frictionless surface at $1.20\ \text{m/s}^2$?
4. (II) According to a simplified model of a mammalian heart, at each pulse approximately 20 g of blood is accelerated from 0.25 m/s to 0.35 m/s during a period of 0.10 s. What is the magnitude of the force exerted by the heart muscle?
5. (II) Superman must stop a 120-km/h train in 150 m to keep it from hitting a stalled car on the tracks. If the train's mass is 3.6×10^5 kg, how much force must he exert? Compare to the weight of the train (give as %). How much force does the train exert on Superman?
6. (II) A person has a reasonable chance of surviving an automobile crash if the deceleration is no more than 30 *g*'s. Calculate the force on a 65-kg person accelerating at this rate. What distance is traveled if brought to rest at this rate from 95 km/h?
7. (II) What average force is required to stop a 950-kg car in 8.0 s if the car is traveling at 95 km/h?
8. (II) Estimate the average force exerted by a shot-putter on a 7.0-kg shot if the shot is moved through a distance of 2.8 m and is released with a speed of 13 m/s.
9. (II) A 0.140-kg baseball traveling 35.0 m/s strikes the catcher's mitt, which, in bringing the ball to rest, recoils backward 11.0 cm. What was the average force applied by the ball on the glove?
10. (II) How much tension must a cable withstand if it is used to accelerate a 1200-kg car vertically upward at $0.70\ \text{m/s}^2$?
11. (II) A 20.0-kg box rests on a table. (*a*) What is the weight of the box and the normal force acting on it? (*b*) A 10.0-kg box is placed on top of the 20.0-kg box, as shown in Fig. 4–43. Determine the normal force that the table exerts on the 20.0-kg box and the normal force that the 20.0-kg box exerts on the 10.0-kg box.

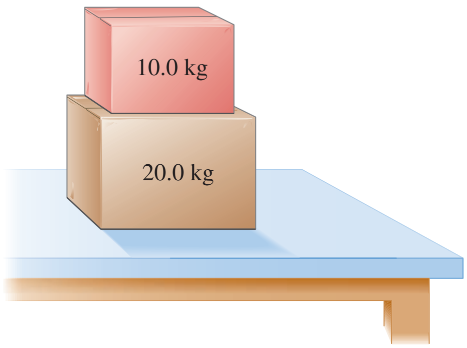

FIGURE 4–43 Problem 11.

12. (II) A 14.0-kg bucket is lowered vertically by a rope in which there is 163 N of tension at a given instant. What is the acceleration of the bucket? Is it up or down?
13. (II) A 75-kg petty thief wants to escape from a third-story jail window. Unfortunately, a makeshift rope made of sheets tied together can support a mass of only 58 kg. How might the thief use this "rope" to escape? Give a quantitative answer.
14. (II) An elevator (mass 4850 kg) is to be designed so that the maximum acceleration is 0.0680*g*. What are the maximum and minimum forces the motor should exert on the supporting cable?
15. (II) Can cars "stop on a dime"? Calculate the acceleration of a 1400-kg car if it can stop from 35 km/h on a dime (diameter = 1.7 cm). How many *g*'s is this? What is the force felt by the 68-kg occupant of the car?
16. (II) A woman stands on a bathroom scale in a motionless elevator. When the elevator begins to move, the scale briefly reads only 0.75 of her regular weight. Calculate the acceleration of the elevator, and find the direction of acceleration.
17. (II) (*a*) What is the acceleration of two falling sky divers (total mass = 132 kg including parachute) when the upward force of air resistance is equal to one-fourth of their weight? (*b*) After opening the parachute, the divers descend leisurely to the ground at constant speed. What now is the force of air resistance on the sky divers and their parachute? See Fig. 4–44.

FIGURE 4–44 Problem 17.

18. (II) The cable supporting a 2125-kg elevator has a maximum strength of 21,750 N. What maximum upward acceleration can it give the elevator without breaking?
19. (III) A person jumps from the roof of a house 2.8 m high. When he strikes the ground below, he bends his knees so that his torso decelerates over an approximate distance of 0.70 m. If the mass of his torso (excluding legs) is 42 kg, find (*a*) his velocity just before his feet strike the ground, and (*b*) the average force exerted on his torso by his legs during deceleration.

4–7 Newton's Laws and Vectors [Ignore friction.]

20. (I) A box weighing 77.0 N rests on a table. A rope tied to the box runs vertically upward over a pulley and a weight is hung from the other end (Fig. 4–45). Determine the force that the table exerts on the box if the weight hanging on the other side of the pulley weighs (*a*) 30.0 N, (*b*) 60.0 N, and (*c*) 90.0 N.

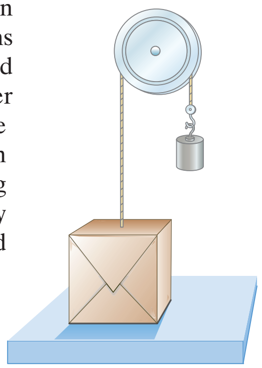

FIGURE 4–45 Problem 20.

21. (I) Draw the free-body diagram for a basketball player (*a*) just before leaving the ground on a jump, and (*b*) while in the air. See Fig. 4–46.

FIGURE 4–46 Problem 21.

22. (I) Sketch the free-body diagram of a baseball (*a*) at the moment it is hit by the bat, and again (*b*) after it has left the bat and is flying toward the outfield. Ignore air resistance.

23. (II) Arlene is to walk across a "high wire" strung horizontally between two buildings 10.0 m apart. The sag in the rope when she is at the midpoint is 10.0°, as shown in Fig. 4–47. If her mass is 50.0 kg, what is the tension in the rope at this point?

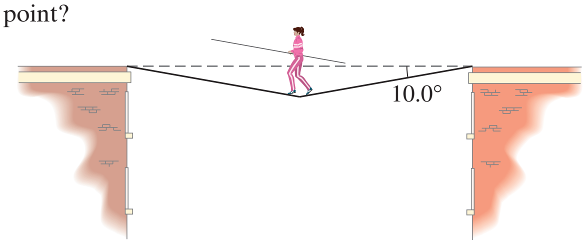

FIGURE 4–47 Problem 23.

24. (II) A window washer pulls herself upward using the bucket–pulley apparatus shown in Fig. 4–48. (*a*) How hard must she pull downward to raise herself slowly at constant speed? (*b*) If she increases this force by 15%, what will her acceleration be? The mass of the person plus the bucket is 72 kg.

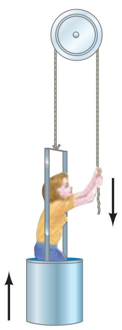

FIGURE 4–48 Problem 24.

25. (II) One 3.2-kg paint bucket is hanging by a massless cord from another 3.2-kg paint bucket, also hanging by a massless cord, as shown in Fig. 4–49. (*a*) If the buckets are at rest, what is the tension in each cord? (*b*) If the two buckets are pulled upward with an acceleration of $1.25\ \mathrm{m/s^2}$ by the upper cord, calculate the tension in each cord.

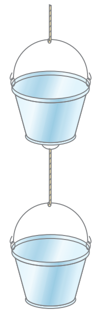

FIGURE 4–49 Problem 25.

26. (II) Two snowcats in Antarctica are towing a housing unit north, as shown in Fig. 4–50. The sum of the forces $\vec{\mathbf{F}}_A$ and $\vec{\mathbf{F}}_B$ exerted on the unit by the horizontal cables is north, parallel to the line L, and $F_A = 4500\ \mathrm{N}$. Determine F_B and the magnitude of $\vec{\mathbf{F}}_A + \vec{\mathbf{F}}_B$.

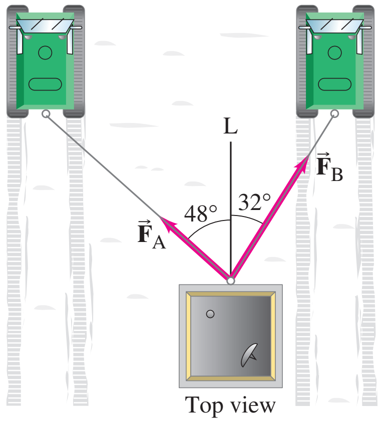

FIGURE 4–50 Problem 26.

27. (II) A train locomotive is pulling two cars of the same mass behind it, Fig. 4–51. Determine the ratio of the tension in the coupling (think of it as a cord) between the locomotive and the first car (F_{T1}), to that between the first car and the second car (F_{T2}), for any nonzero acceleration of the train.

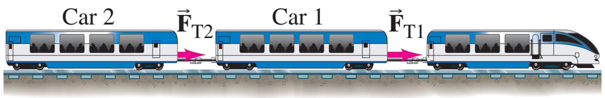

FIGURE 4–51 Problem 27.

28. (II) The two forces $\vec{\mathbf{F}}_1$ and $\vec{\mathbf{F}}_2$ shown in Fig. 4–52a and b (looking down) act on an 18.5-kg object on a frictionless tabletop. If $F_1 = 10.2\ \mathrm{N}$ and $F_2 = 16.0\ \mathrm{N}$, find the net force on the object and its acceleration for (a) and (b).

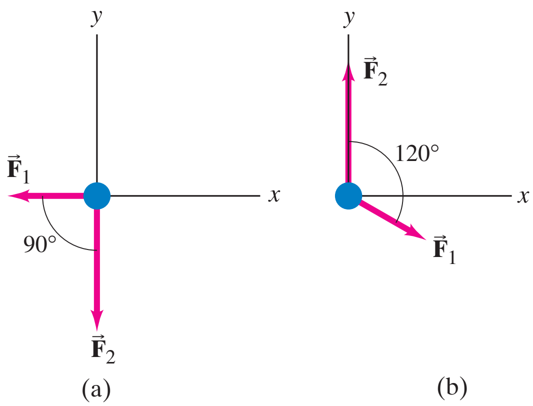

FIGURE 4–52 Problem 28.

29. (II) At the instant a race began, a 65-kg sprinter exerted a force of 720 N on the starting block at a 22° angle with respect to the ground. (*a*) What was the horizontal acceleration of the sprinter? (*b*) If the force was exerted for 0.32 s, with what speed did the sprinter leave the starting block?

30. (II) An object is hanging by a string from your rearview mirror. While you are decelerating at a constant rate from 25 m/s to rest in 6.0 s, (*a*) what angle does the string make with the vertical, and (*b*) is it toward the windshield or away from it? [*Hint*: See Example 4–15.]

31. (II) Figure 4–53 shows a block (mass m_A) on a smooth horizontal surface, connected by a thin cord that passes over a pulley to a second block (m_B), which hangs vertically. (*a*) Draw a free-body diagram for each block, showing the force of gravity on each, the force (tension) exerted by the cord, and any normal force. (*b*) Apply Newton's second law to find formulas for the acceleration of the system and for the tension in the cord. Ignore friction and the masses of the pulley and cord.

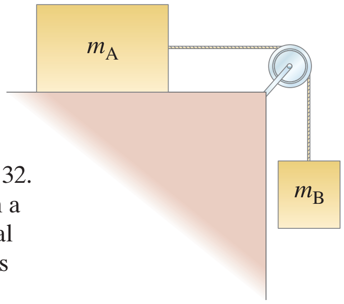

FIGURE 4–53
Problems 31 and 32. Mass m_A rests on a smooth horizontal surface; m_B hangs vertically.

32. (II) (*a*) If $m_A = 13.0\,\text{kg}$ and $m_B = 5.0\,\text{kg}$ in Fig. 4–53, determine the acceleration of each block. (*b*) If initially m_A is at rest 1.250 m from the edge of the table, how long does it take to reach the edge of the table if the system is allowed to move freely? (*c*) If $m_B = 1.0\,\text{kg}$, how large must m_A be if the acceleration of the system is to be kept at $\frac{1}{100}g$?

33. (III) Three blocks on a frictionless horizontal surface are in contact with each other as shown in Fig. 4–54. A force $\vec{\mathbf{F}}$ is applied to block A (mass m_A). (*a*) Draw a free-body diagram for each block. Determine (*b*) the acceleration of the system (in terms of m_A, m_B, and m_C), (*c*) the net force on each block, and (*d*) the force of contact that each block exerts on its neighbor. (*e*) If $m_A = m_B = m_C = 10.0\,\text{kg}$ and $F = 96.0\,\text{N}$, give numerical answers to (*b*), (*c*), and (*d*). Explain how your answers make sense intuitively.

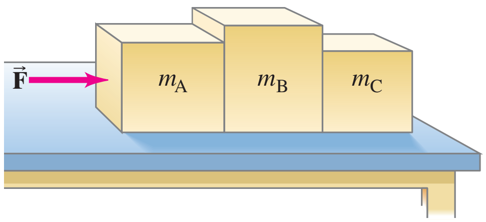

FIGURE 4–54
Problem 33.

34. (III) Suppose the pulley in Fig. 4–55 is suspended by a cord C. Determine the tension in this cord after the masses are released and before one hits the ground. Ignore the mass of the pulley and cords.

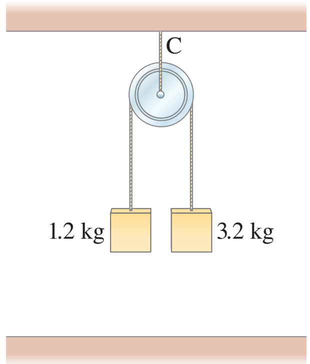

FIGURE 4–55
Problem 34.

4–8 Newton's Laws with Friction, Inclines

35. (I) If the coefficient of kinetic friction between a 22-kg crate and the floor is 0.30, what horizontal force is required to move the crate at a steady speed across the floor? What horizontal force is required if μ_k is zero?

36. (I) A force of 35.0 N is required to start a 6.0-kg box moving across a horizontal concrete floor. (*a*) What is the coefficient of static friction between the box and the floor? (*b*) If the 35.0-N force continues, the box accelerates at $0.60\,\text{m/s}^2$. What is the coefficient of kinetic friction?

37. (I) Suppose you are standing on a train accelerating at $0.20\,g$. What minimum coefficient of static friction must exist between your feet and the floor if you are not to slide?

38. (II) The coefficient of static friction between hard rubber and normal street pavement is about 0.90. On how steep a hill (maximum angle) can you leave a car parked?

39. (II) A flatbed truck is carrying a heavy crate. The coefficient of static friction between the crate and the bed of the truck is 0.75. What is the maximum rate at which the driver can decelerate and still avoid having the crate slide against the cab of the truck?

40. (II) A 2.0-kg silverware drawer does not slide readily. The owner gradually pulls with more and more force, and when the applied force reaches 9.0 N, the drawer suddenly opens, throwing all the utensils to the floor. What is the coefficient of static friction between the drawer and the cabinet?

41. (II) A box is given a push so that it slides across the floor. How far will it go, given that the coefficient of kinetic friction is 0.15 and the push imparts an initial speed of 3.5 m/s?

42. (II) A 1280-kg car pulls a 350-kg trailer. The car exerts a horizontal force of $3.6 \times 10^3\,\text{N}$ against the ground in order to accelerate. What force does the car exert on the trailer? Assume an effective friction coefficient of 0.15 for the trailer.

43. (II) Drag-race tires in contact with an asphalt surface have a very high coefficient of static friction. Assuming a constant acceleration and no slipping of tires, estimate the coefficient of static friction needed for a drag racer to cover 1.0 km in 12 s, starting from rest.

44. (II) For the system of Fig. 4–32 (Example 4–20), how large a mass would box A have to have to prevent any motion from occurring? Assume $\mu_s = 0.30$.

45. (II) In Fig. 4–56 the coefficient of static friction between mass m_A and the table is 0.40, whereas the coefficient of kinetic friction is 0.20. (*a*) What minimum value of m_A will keep the system from starting to move? (*b*) What value(s) of m_A will keep the system moving at constant speed? [Ignore masses of the cord and the (frictionless) pulley.]

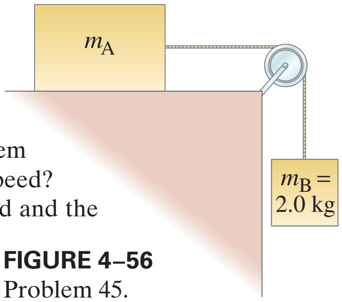

FIGURE 4–56 Problem 45.

46. (II) A small box is held in place against a rough vertical wall by someone pushing on it with a force directed upward at 28° above the horizontal. The coefficients of static and kinetic friction between the box and wall are 0.40 and 0.30, respectively. The box slides down unless the applied force has magnitude 23 N. What is the mass of the box?

47. (II) Two crates, of mass 65 kg and 125 kg, are in contact and at rest on a horizontal surface (Fig. 4–57). A 650-N force is exerted on the 65-kg crate. If the coefficient of kinetic friction is 0.18, calculate (*a*) the acceleration of the system, and (*b*) the force that each crate exerts on the other. (*c*) Repeat with the crates reversed.

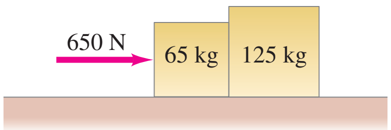

FIGURE 4–57 Problem 47.

48. (II) A person pushes a 14.0-kg lawn mower at constant speed with a force of $F = 88.0\text{ N}$ directed along the handle, which is at an angle of 45.0° to the horizontal (Fig. 4–58). (*a*) Draw the free-body diagram showing all forces acting on the mower. Calculate (*b*) the horizontal friction force on the mower, then (*c*) the normal force exerted vertically upward on the mower by the ground. (*d*) What force must the person exert on the lawn mower to accelerate it from rest to 1.5 m/s in 2.5 seconds, assuming the same friction force?

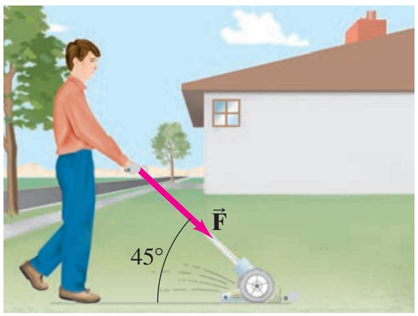

FIGURE 4–58 Problem 48.

49. (II) A wet bar of soap slides down a ramp 9.0 m long inclined at 8.0°. How long does it take to reach the bottom? Assume $\mu_k = 0.060$.

50. (II) A skateboarder, with an initial speed of 2.0 m/s, rolls virtually friction free down a straight incline of length 18 m in 3.3 s. At what angle θ is the incline oriented above the horizontal?

51. (II) Uphill escape ramps are sometimes provided to the side of steep downhill highways for trucks with overheated brakes. For a simple 11° upward ramp, what minimum length would be needed for a runaway truck traveling 140 km/h? Note the large size of your calculated length. (If sand is used for the bed of the ramp, its length can be reduced by a factor of about 2.)

52. (II) The block shown in Fig. 4–59 has mass $m = 7.0\text{ kg}$ and lies on a fixed smooth frictionless plane tilted at an angle $\theta = 22.0°$ to the horizontal. (*a*) Determine the acceleration of the block as it slides down the plane. (*b*) If the block starts from rest 12.0 m up the plane from its base, what will be the block's speed when it reaches the bottom of the incline?

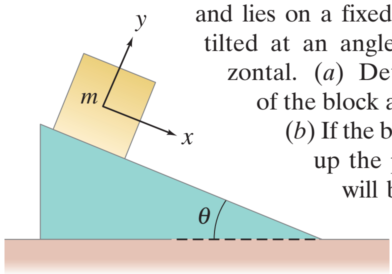

FIGURE 4–59 Block on inclined plane. Problems 52 and 53.

53. (II) A block is given an initial speed of 4.5 m/s up the 22.0° plane shown in Fig. 4–59. (*a*) How far up the plane will it go? (*b*) How much time elapses before it returns to its starting point? Ignore friction.

54. (II) The crate shown in Fig. 4–60 lies on a plane tilted at an angle $\theta = 25.0°$ to the horizontal, with $\mu_k = 0.19$. (*a*) Determine the acceleration of the crate as it slides down the plane. (*b*) If the crate starts from rest 8.15 m up along the plane from its base, what will be the crate's speed when it reaches the bottom of the incline?

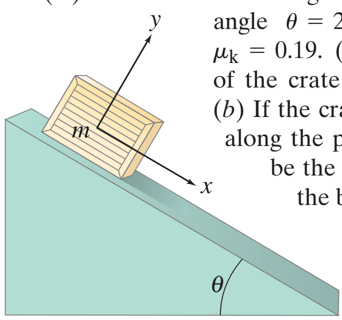

FIGURE 4–60 Crate on inclined plane. Problems 54 and 55.

55. (II) A crate is given an initial speed of 3.0 m/s up the 25.0° plane shown in Fig. 4–60. (*a*) How far up the plane will it go? (*b*) How much time elapses before it returns to its starting point? Assume $\mu_k = 0.12$.

56. (II) A car can decelerate at -3.80 m/s^2 without skidding when coming to rest on a level road. What would its deceleration be if the road is inclined at 9.3° and the car moves uphill? Assume the same static friction coefficient.

57. (II) A skier moves down a 12° slope at constant speed. What can you say about the coefficient of friction, μ_k? Assume the speed is low enough that air resistance can be ignored.

58. (II) The coefficient of kinetic friction for a 22-kg bobsled on a track is 0.10. What force is required to push it down along a 6.0° incline and achieve a speed of 60 km/h at the end of 75 m?

59. (III) A child slides down a slide with a 34° incline, and at the bottom her speed is precisely half what it would have been if the slide had been frictionless. Calculate the coefficient of kinetic friction between the slide and the child.

60. (III) Two masses $m_A = 2.0\,\text{kg}$ and $m_B = 5.0\,\text{kg}$ are on inclines and are connected together by a string as shown in Fig. 4–61. The coefficient of kinetic friction between each mass and its incline is $\mu_k = 0.30$. If m_A moves up, and m_B moves down, determine their acceleration. [Ignore masses of the (frictionless) pulley and the cord.]

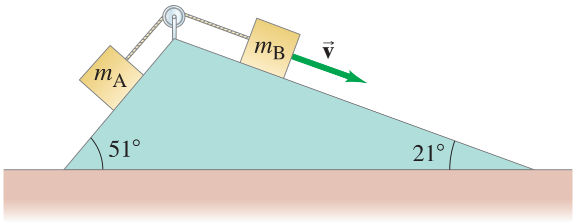

FIGURE 4–61 Problem 60.

61. (III) (*a*) Suppose the coefficient of kinetic friction between m_A and the plane in Fig. 4–62 is $\mu_k = 0.15$, and that $m_A = m_B = 2.7\,\text{kg}$. As m_B moves down, determine the magnitude of the acceleration of m_A and m_B, given $\theta = 34°$. (*b*) What smallest value of μ_k will keep the system from accelerating? [Ignore masses of the (frictionless) pulley and the cord.]

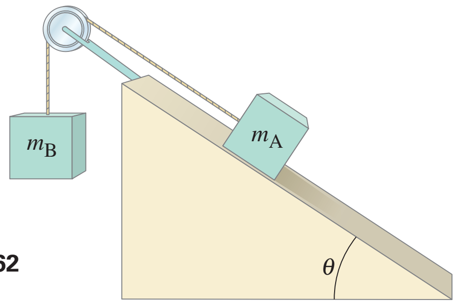

FIGURE 4–62 Problem 61.

General Problems

62. A 2.0-kg purse is dropped from the top of the Leaning Tower of Pisa and falls 55 m before reaching the ground with a speed of 27 m/s. What was the average force of air resistance?

63. A crane's trolley at point P in Fig. 4–63 moves for a few seconds to the right with constant acceleration, and the 870-kg load hangs on a light cable at a 5.0° angle to the vertical as shown. What is the acceleration of the trolley and load?

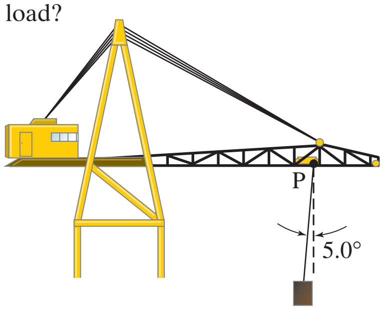

FIGURE 4–63 Problem 63.

64. A 75.0-kg person stands on a scale in an elevator. What does the scale read (in N and in kg) when (*a*) the elevator is at rest, (*b*) the elevator is climbing at a constant speed of 3.0 m/s, (*c*) the elevator is descending at 3.0 m/s, (*d*) the elevator is accelerating upward at $3.0\,\text{m/s}^2$, (*e*) the elevator is accelerating downward at $3.0\,\text{m/s}^2$?

65. If a bicyclist of mass 65 kg (including the bicycle) can coast down a 6.5° hill at a steady speed of 6.0 km/h because of air resistance, how much force must be applied to climb the hill at the same speed (and the same air resistance)?

66. A city planner is working on the redesign of a hilly portion of a city. An important consideration is how steep the roads can be so that even low-powered cars can get up the hills without slowing down. A particular small car, with a mass of 920 kg, can accelerate on a level road from rest to 21 m/s (75 km/h) in 12.5 s. Using these data, calculate the maximum steepness of a hill.

67. Francesca dangles her watch from a thin piece of string while the jetliner she is in accelerates for takeoff, which takes about 16 s. Estimate the takeoff speed of the aircraft if the string makes an angle of 25° with respect to the vertical, Fig. 4–64.

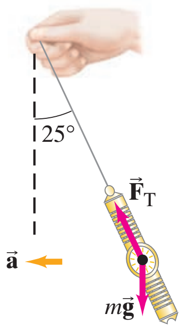

FIGURE 4–64 Problem 67.

68. (*a*) What minimum force F is needed to lift the piano (mass M) using the pulley apparatus shown in Fig. 4–65? (*b*) Determine the tension in each section of rope: F_{T1}, F_{T2}, F_{T3}, and F_{T4}. Assume pulleys are massless and frictionless, and that ropes are massless.

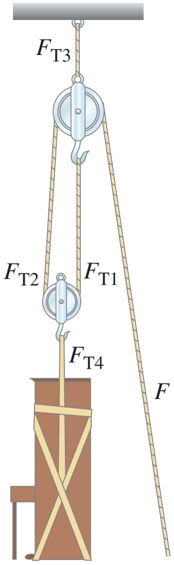

FIGURE 4–65 Problem 68.

69. In the design of a supermarket, there are to be several ramps connecting different parts of the store. Customers will have to push grocery carts up the ramps and it is desirable that this not be too difficult. The engineer has done a survey and found that almost no one complains if the force required is no more than 18 N. Ignoring friction, at what maximum angle θ should the ramps be built, assuming a full 25-kg cart?

70. A jet aircraft is accelerating at $3.8\ \mathrm{m/s^2}$ as it climbs at an angle of 18° above the horizontal (Fig. 4–66). What is the total force that the cockpit seat exerts on the 75-kg pilot?

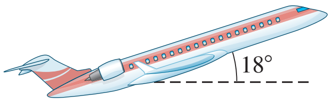

FIGURE 4–66 Problem 70.

71. A 7180-kg helicopter accelerates upward at $0.80\ \mathrm{m/s^2}$ while lifting a 1080-kg frame at a construction site, Fig. 4–67. (*a*) What is the lift force exerted by the air on the helicopter rotors? (*b*) What is the tension in the cable (ignore its mass) which connects the frame to the helicopter? (*c*) What force does the cable exert on the helicopter?

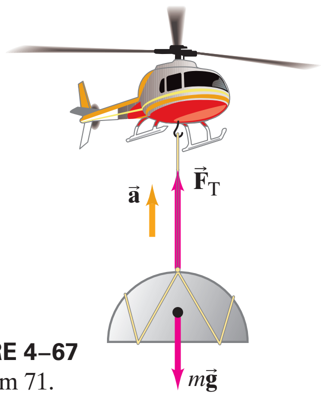

FIGURE 4–67 Problem 71.

72. A "doomsday" asteroid with a mass of 1.0×10^{10} kg is hurtling through space. Unless the asteroid's speed is changed by about 0.20 cm/s, it will collide with Earth and cause tremendous damage. Researchers suggest that a small "space tug" sent to the asteroid's surface could exert a gentle constant force of 2.5 N. For how long must this force act?

73. Three mountain climbers who are roped together in a line are ascending an icefield inclined at 31.0° to the horizontal (Fig. 4–68). The last climber slips, pulling the second climber off his feet. The first climber is able to hold them both. If each climber has a mass of 75 kg, calculate the tension in each of the two sections of rope between the three climbers. Ignore friction between the ice and the fallen climbers.

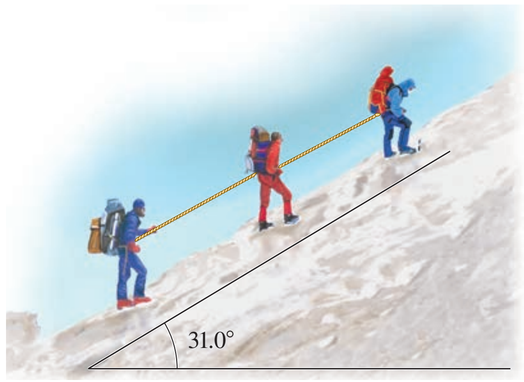

FIGURE 4–68 Problem 73.

74. As shown in Fig. 4–69, five balls (masses 2.00, 2.05, 2.10, 2.15, 2.20 kg) hang from a crossbar. Each mass is supported by "5-lb test" fishing line which will break when its tension force exceeds 22.2 N (= 5.00 lb). When this device is placed in an elevator, which accelerates upward, only the lines attached to the 2.05 and 2.00 kg masses do not break. Within what range is the elevator's acceleration?

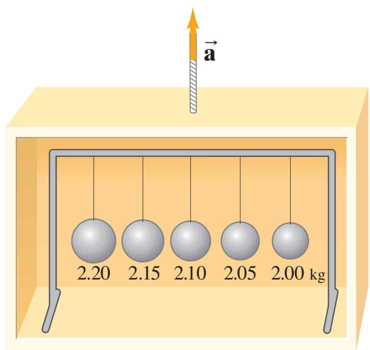

FIGURE 4–69 Problem 74.

75. A coffee cup on the horizontal dashboard of a car slides forward when the driver decelerates from 45 km/h to rest in 3.5 s or less, but not if she decelerates in a longer time. What is the coefficient of static friction between the cup and the dash? Assume the road and the dashboard are level (horizontal).

76. A roller coaster reaches the top of the steepest hill with a speed of 6.0 km/h. It then descends the hill, which is at an average angle of 45° and is 45.0 m long. What will its speed be when it reaches the bottom? Assume $\mu_k = 0.12$.

77. A motorcyclist is coasting with the engine off at a steady speed of 20.0 m/s but enters a sandy stretch where the coefficient of kinetic friction is 0.70. Will the cyclist emerge from the sandy stretch without having to start the engine if the sand lasts for 15 m? If so, what will be the speed upon emerging?

78. The 70.0-kg climber in Fig. 4–70 is supported in the "chimney" by the friction forces exerted on his shoes and back. The static coefficients of friction between his shoes and the wall, and between his back and the wall, are 0.80 and 0.60, respectively. What is the minimum normal force he must exert? Assume the walls are vertical and that the static friction forces are both at their maximum. Ignore his grip on the rope.

FIGURE 4–70 Problem 78.

79. A 28.0-kg block is connected to an empty 2.00-kg bucket by a cord running over a frictionless pulley (Fig. 4–71). The coefficient of static friction between the table and the block is 0.45 and the coefficient of kinetic friction between the table and the block is 0.32. Sand is gradually added to the bucket until the system just begins to move. (*a*) Calculate the mass of sand added to the bucket. (*b*) Calculate the acceleration of the system. Ignore mass of cord.

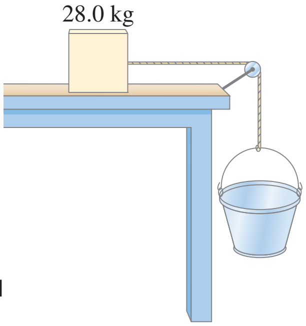

FIGURE 4–71 Problem 79.

80. A 72-kg water skier is being accelerated by a ski boat on a flat ("glassy") lake. The coefficient of kinetic friction between the skier's skis and the water surface is $\mu_k = 0.25$ (Fig. 4–72). (*a*) What is the skier's acceleration if the rope pulling the skier behind the boat applies a horizontal tension force of magnitude $F_T = 240$ N to the skier $(\theta = 0°)$? (*b*) What is the skier's horizontal acceleration if the rope pulling the skier exerts a force of $F_T = 240$ N on the skier at an upward angle $\theta = 12°$? (*c*) Explain why the skier's acceleration in part (*b*) is greater than that in part (*a*).

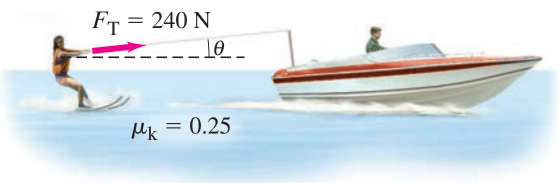

FIGURE 4–72 Problem 80.

81. (*a*) If the horizontal acceleration produced briefly by an earthquake is a, and if an object is going to "hold its place" on the ground, show that the coefficient of static friction with the ground must be at least $\mu_s = a/g$. (*b*) The famous Loma Prieta earthquake that stopped the 1989 World Series produced ground accelerations of up to $4.0\,\mathrm{m/s^2}$ in the San Francisco Bay Area. Would a chair have started to slide on a floor with coefficient of static friction 0.25?

82. Two blocks made of different materials, connected by a thin cord, slide down a plane ramp inclined at an angle θ to the horizontal, Fig. 4–73 (block B is above block A). The masses of the blocks are m_A and m_B, and the coefficients of friction are μ_A and μ_B. If $m_A = m_B = 5.0\,\mathrm{kg}$, and $\mu_A = 0.20$ and $\mu_B = 0.30$, determine (*a*) the acceleration of the blocks and (*b*) the tension in the cord, for an angle $\theta = 32°$.

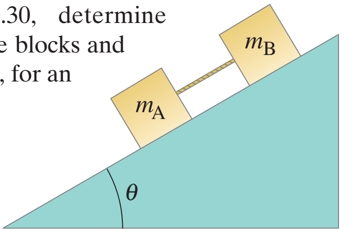

FIGURE 4–73
Problem 82.

83. A car starts rolling down a 1-in-4 hill (1-in-4 means that for each 4 m traveled along the sloping road, the elevation change is 1 m). How fast is it going when it reaches the bottom after traveling 55 m? (*a*) Ignore friction. (*b*) Assume an effective coefficient of friction equal to 0.10.

84. A 65-kg ice skater coasts with no effort for 75 m until she stops. If the coefficient of kinetic friction between her skates and the ice is $\mu_k = 0.10$, how fast was she moving at the start of her coast?

Search and Learn

1. In the equation for static friction in Section 4–8, what is the significance of the $<$ sign? When should you use the equals sign in the static friction equation?

2. Referring to Example 4–21, show that if a skier moves at constant speed straight down a slope of angle θ, then the coefficient of kinetic friction between skis and snow is $\mu_k = \tan\theta$.

3. (*a*) Show that the minimum stopping distance for an automobile traveling on a level road at speed v is equal to $v^2/(2\,\mu_s\,g)$, where μ_s is the coefficient of static friction between the tires and the road, and g is the acceleration of gravity. (*b*) What is this distance for a 1200-kg car traveling 95 km/h if $\mu_s = 0.65$? (*c*) What would it be if the car were on the Moon (the acceleration of gravity on the Moon is about $g/6$) but all else stayed the same?

ANSWERS TO EXERCISES

A: No force is needed. The car accelerates out from under the cup, which tends to remain at rest. Think of Newton's first law (see Example 4–1).
B: (*a*).
C: (i) The same; (ii) the tennis ball; (iii) Newton's third law for part (i), second law for part (ii).
D: (*b*).
E: (*b*).
F: (*b*).
G: (*c*).
H: Yes; no.