CHAPTER

5 Forces in Two Dimensions

Practice Problems

5.1 Vectors
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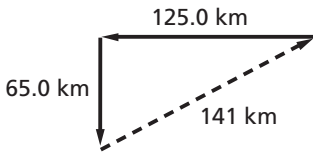
1. A car is driven 125.0 km due west, then 65.0 km due south. What is the magnitude of its displacement? Solve this problem both graphically and mathematically, and check your answers against each other.

$$R^2 = A^2 + B^2$$

$$R = \sqrt{A^2 + B^2}$$

$$= \sqrt{(65.0\ \text{km})^2 + (125.0\ \text{km})^2}$$

$$= 141\ \text{km}$$



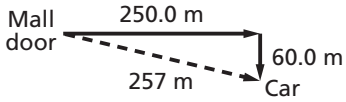
2. Two shoppers walk from the door of the mall to their car, which is 250.0 m down a lane of cars, and then turn 90° to the right and walk an additional 60.0 m. What is the magnitude of the displacement of the shoppers' car from the mall door? Solve this problem both graphically and mathematically, and check your answers against each other.

$$R^2 = A^2 + B^2$$

$$R = \sqrt{A^2 + B^2}$$

$$= \sqrt{(250.0\ \text{m})^2 + (60.0\ \text{m})^2}$$

$$= 257\ \text{m}$$



3. A hiker walks 4.5 km in one direction, then makes a 45° turn to the right and walks another 6.4 km. What is the magnitude of her displacement?

$$R^2 = A^2 + B^2 - 2AB\cos\theta$$

$$R = \sqrt{A^2 + B^2 - 2AB\cos\theta}$$

$$= \sqrt{(4.5\ \text{km})^2 + (6.4\ \text{km})^2 - 2(4.5\ \text{km})(6.4\ \text{km})(\cos 135°)}$$

$$= 1.0\times10^1\ \text{km}$$

4. An ant is crawling on the sidewalk. At one moment, it is moving south a distance of 5.0 mm. It then turns southwest and crawls 4.0 mm. What is the magnitude of the ant's displacement?

$$R^2 = A^2 + B^2 - 2AB\cos\theta$$

$$R = \sqrt{A^2 + B^2 - 2AB\cos\theta}$$

$$= \sqrt{(5.0\ \text{mm})^2 + (4.0\ \text{mm})^2 - 2(5.0\ \text{mm})(4.0\ \text{mm})(\cos 135°)}$$

$$= 8.3\ \text{mm}$$

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Solve problems 5–10 algebraically. You may also choose to solve some of them graphically to check your answers.

5. Sudhir walks 0.40 km in a direction 60.0° west of north, then goes 0.50 km due west. What is his displacement?

Identify north and west as the positive directions.

$d_{1W} = d_1 \sin\theta = (0.40\text{ km})(\sin 60.0°) = 0.35\text{ km}$

$d_{1N} = d_1 \cos\theta = (0.40\text{ km})(\cos 60.0°) = 0.20\text{ km}$

$d_{2W} = 0.50\text{ km} \quad d_{2N} = 0.00\text{ km}$

$R_W = d_{1W} + d_{2W} = 0.35\text{ km} + 0.50\text{ km} = 0.85\text{ km}$

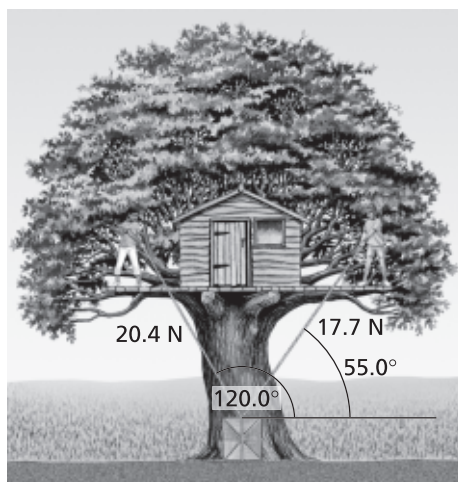
$R_N = d_{1N} + d_{2N} = 0.20\text{ km} + 0.00\text{ km} = 0.20\text{ km}$

$$R = \sqrt{R_W^2 + R_N^2}$$
$$= \sqrt{(0.85\text{ km})^2 + (0.20\text{ km})^2}$$
$$= 0.87\text{ km}$$

$$\theta = \tan^{-1}\left(\frac{R_W}{R_N}\right)$$
$$= \tan^{-1}\left(\frac{0.85\text{ km}}{0.20\text{ km}}\right)$$
$$= 77°$$

$R = 0.87\text{ km at } 77°\text{ west of north}$

6. Afua and Chrissy are going to sleep overnight in their tree house and are using some ropes to pull up a box containing their pillows and blankets, which have a total mass of 3.20 kg. The girls stand on different branches, as shown in **Figure 5-6,** and pull at the angles and with the forces indicated. Find the *x*- and *y*-components of the net force on the box. *Hint: Draw a free-body diagram so that you do not leave out a force.*



■ **Figure 5-6**

Identify up and right as positive.

$$F_{A\text{ on box},x} = F_{A\text{ on box}} \cos\theta_A$$
$$= (20.4\text{ N})(\cos 120°)$$
$$= -10.2\text{ N}$$

$$F_{A\text{ on box},y} = F_{A\text{ on box}} \sin\theta_A$$
$$= (20.4\text{ N})(\sin 120°)$$
$$= 17.7\text{ N}$$

$$F_{C\text{ on box},x} = F_{C\text{ on box}} \cos\theta_A$$
$$= (17.7\text{ N})(\cos 55°)$$

$= 10.2\ \text{N}$

$F_{\text{C on box},y} = F_{\text{C on box}} \sin \theta_A$

$= (17.7\ \text{N})(\sin 55°)$

$= 14.5\ \text{N}$

$F_{g,x} = 0.0\ \text{N}$

$F_{g,y} = -mg$

$= -(3.20\ \text{kg})(9.80\ \text{m/s}^2)$

$= -31.4\ \text{N}$

$F_{\text{net on box},x} = F_{\text{A on box},x} + F_{\text{C on box},x} + F_{g,x}$

$= -10.2\ \text{N} + 10.2\ \text{N} + 0.0\ \text{N}$

$= 0.0\ \text{N}$

$F_{\text{net on box},y} = F_{\text{A on box},y} + F_{\text{C on box},y} + F_{g,y}$

$= 17.7\ \text{N} + 14.5\ \text{N} - 31.4\ \text{N}$

$= 0.8\ \text{N}$

The net force is 0.8 N in the upward direction.

7. You first walk 8.0 km north from home, then walk east until your displacement from home is 10.0 km. How far east did you walk?

The resultant is 10.0 km. Using the Pythagorean Theorem, the distance east is

$R^2 = A^2 + B^2$, **so**

$B = \sqrt{R^2 - A^2}$

$= \sqrt{(10.0\ \text{km})^2 - (8.0\ \text{km})^2}$

$= 6.0\ \text{km}$

8. A child's swing is held up by two ropes tied to a tree branch that hangs 13.0° from the vertical. If the tension in each rope is 2.28 N, what is the combined force (magnitude and direction) of the two ropes on the swing?

The force will be straight up. Because the angles are equal, the horizontal forces will be equal and opposite and cancel out. The magnitude of this vertical force is

$F_{\text{combined}} = F_{\text{rope1 on swing}} \cos \theta + F_{\text{rope2 on swing}} \cos \theta$

$= 2F_{\text{rope2 on swing}} \cos \theta$

$= (2)(2.28\ \text{N})(\cos 13.0°)$

$= 4.44\ \text{N upward}$

9. Could a vector ever be shorter than one of its components? Equal in length to one of its components? Explain.

It could never be shorter than one of its components, but if it lies along either the *x*- or *y*-axis, then one of its components equals its length.

10. In a coordinate system in which the *x*-axis is east, for what range of angles is the *x*-component positive? For what range is it negative?

The *x*-component is positive for angles less than 90° and for angles greater than 270°. It's negative for angles greater than 90° but less than 270°.

Section Review

5.1 Vectors pages 119–125

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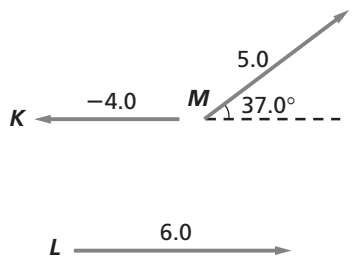
11. Distance v. Displacement Is the distance that you walk equal to the magnitude of your displacement? Give an example that supports your conclusion.

Not necessarily. For example, you could walk around the block (one km per side). Your displacement would be zero, but the distance that you walk would be 4 kilometers.

12. Vector Difference Subtract vector ***K*** from vector ***L***, shown in **Figure 5-7.**



■ **Figure 5-7**

6.0 − (−4.0) = 10.0 to the right

13. Components Find the components of vector ***M,*** shown in Figure 5-7.

$M_x = m \cos \theta$

$= (5.0)(\cos 37.0°)$

$= 4.0$ **to the right**

$M_y = m \sin \theta$

$= (5.0)(\sin 37.0°)$

$= 3.0$ **upward**

14. Vector Sum Find the sum of the three vectors shown in Figure 5-7.

$R_x = K_x + L_x + M_x$

$= -4.0 + 6.0 + 4.0$

$= 6.0$

$R_y = K_y + L_y + M_y$

$= 0.0 + 0.0 + 3.0$

$= 3.0$

$R = \sqrt{R_x^2 + R_y^2}$

$= \sqrt{6.0^2 + 3.0^2}$

$= 6.7$

$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$

$= \tan^{-1}\left(\frac{3}{6}\right)$

$= 27°$

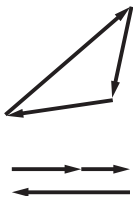
$R = 6.7$ **at** $27°$

15. Commutative Operations The order in which vectors are added does not matter. Mathematicians say that vector addition is commutative. Which ordinary arithmetic operations are commutative? Which are not?

Addition and multiplication are commutative. Subtraction and division are not.

16. Critical Thinking A box is moved through one displacement and then through a second displacement. The magnitudes of the two displacements are unequal. Could the displacements have directions such that the resultant displacement is zero? Suppose the box was moved through three displacements of unequal magnitude. Could the resultant displacement be zero? Support your conclusion with a diagram.

No, but if there are three displacements, the sum can be zero if the three vectors form a triangle when they are placed tip-to-tail. Also, the sum of three displacements can be zero without forming a triangle if the sum of two displacements in one direction equals the third in the opposite direction.



Practice Problems

5.2 Friction pages 126–130

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17. A girl exerts a 36-N horizontal force as she pulls a 52-N sled across a cement sidewalk at constant speed. What is the coefficient of kinetic friction between the sidewalk and the metal sled runners? Ignore air resistance.

$F_N = mg = 52$ **N**

Since the speed is constant, the friction force equals the force exerted by the girl, 36 N.

$F_f = \mu_k F_N$

so $\mu_k = \frac{F_f}{F_N}$

$= \frac{36\text{ N}}{52\text{ N}}$

$= 0.69$

18. You need to move a 105-kg sofa to a different location in the room. It takes a force of 102 N to start it moving. What is the coefficient of static friction between the sofa and the carpet?

$$F_f = \mu_s F_N$$

$$\mu_s = \frac{F_f}{F_N}$$

$$= \frac{F_f}{mg}$$

$$= \frac{102\ \text{N}}{(105\ \text{kg})(9.80\ \text{m/s}^2)}$$

$$= 0.0991$$

19. Mr. Ames is dragging a box full of books from his office to his car. The box and books together have a combined weight of 134 N. If the coefficient of static friction between the pavement and the box is 0.55, how hard must Mr. Ames push the box in order to start it moving?

$$F_{\text{Ames on box}} = F_{\text{friction}}$$

$$= \mu_s F_N$$

$$= \mu_s mg$$

$$= (0.55)(134\ \text{N})$$

$$= 74\ \text{N}$$

20. Suppose that the sled in problem 17 is resting on packed snow. The coefficient of kinetic friction is now only 0.12. If a person weighing 650 N sits on the sled, what force is needed to pull the sled across the snow at constant speed?

At constant speed, applied force equals friction force, so

$$F_f = \mu_k F_N$$

$$= (0.12)(52\ \text{N} + 650\ \text{N})$$

$$= 84\ \text{N}$$

21. Suppose that a particular machine in a factory has two steel pieces that must rub against each other at a constant speed. Before either piece of steel has been treated to reduce friction, the force necessary to get them to perform properly is 5.8 N. After the pieces have been treated with oil, what will be the required force?

$$F_{\text{f, before}} = \mu_{\text{k, before}} F_N$$

$$\text{so } F_N = \frac{F_{\text{f, before}}}{\mu_{\text{k, before}}}$$

$$= \frac{5.8\ \text{N}}{0.58}$$

$$= 1.0\times10^1\ \text{N}$$

$$F_{\text{f, after}} = \mu_{\text{k, after}} F_N$$

$$= (0.06)(1.0\times10^1\ \text{N})$$

$$= 0.6\ \text{N}$$

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22. A 1.4-kg block slides across a rough surface such that it slows down with an acceleration of 1.25 m/s^2. What is the coefficient of kinetic friction between the block and the surface?

$$F_{\text{net}} = \mu_k F_N$$

$$ma = \mu_k mg$$

$$\mu_k = \frac{a}{g}$$

$$= \frac{1.25\ \text{m/s}^2}{9.80\ \text{m/s}^2}$$

$$= 0.128$$

23. You help your mom move a 41-kg bookcase to a different place in the living room. If you push with a force of 65 N and the bookcase accelerates at 0.12 m/s^2, what is the coefficient of kinetic friction between the bookcase and the carpet?

$$F_{\text{net}} = F - \mu_k F_N = F - \mu_k mg = ma$$

$$\mu_k = \frac{F - ma}{mg}$$

$$= \frac{65\ \text{N} - (41\ \text{kg})(0.12\ \text{m/s}^2)}{(41\ \text{kg})(9.80\ \text{m/s}^2)}$$

$$= 0.15$$

24. A shuffleboard disk is accelerated to a speed of 5.8 m/s and released. If the coefficient of kinetic friction between the disk and the concrete court is 0.31, how far does the disk go before it comes to a stop? The courts are 15.8 m long.

Identify the direction of the disk's motion as positive. Find the acceleration of the disk due to the force of friction.

$$F_{\text{net}} = -\mu_k F_N = -\mu_k mg = ma$$

$$a = -\mu_k g$$

Then use the equation $v_f^2 = v_i^2 + 2a(d_f - d_i)$ to find the distance.

Let $d_i = 0$ and solve for d_f.

$$d_f = \frac{v_f^2 - v_i^2}{2a}$$

$$= \frac{v_f^2 - v_i^2}{(2)(-\mu_k g)}$$

$$= \frac{(0.0\ \text{m/s})^2 - (5.8\ \text{m/s})^2}{(2)(-0.31)(9.80\ \text{m/s}^2)}$$

$$= 5.5\ \text{m}$$

25. Consider the force pushing the box in Example Problem 4. How long would it take for the velocity of the box to double to 2.0 m/s?

The initial velocity is 1.0 m/s, the final velocity is 2.0 m/s, and the acceleration is 2.0 m/s^2, so

$a = \frac{v_f - v_i}{t_f - t_i}$**; let $t_i = 0$ and solve for t_f.**

$$t_f = \frac{v_f - v_i}{a}$$

$$= \frac{2.0\ \text{m/s} - 1.0\ \text{m/s}}{2.0\ \text{m/s}^2}$$

$$= 0.50\ \text{s}$$

26. Ke Min is driving along on a rainy night at 23 m/s when he sees a tree branch lying across the road and slams on the brakes when the branch is 60.0 m in front of him. If the coefficient of kinetic friction between the car's locked tires and the road is 0.41, will the car stop before hitting the branch? The car has a mass of 2400 kg.

Choose positive direction as direction of car's movement.

$$F_{net} = -\mu_k F_N = -\mu_k mg = ma$$

$$a = -\mu_k g$$

Then use the equation $v_f^2 = v_i^2 + 2a(d_f - d_i)$ to find the distance.

Let $d_i = 0$ and solve for d_f.

$$d_f = \frac{v_f^2 - v_i^2}{2a}$$

$$= \frac{v_f^2 - v_i^2}{(2)(-\mu_k g)}$$

$$= \frac{(0.0\ \text{m/s}) - (23\ \text{m/s})^2}{(2)(-0.41)(9.80\ \text{m/s}^2)}$$

= 66 m, so he hits the branch before he can stop.

Section Review

5.2 Friction pages 126–130

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27. Friction In this section, you learned about static and kinetic friction. How are these two types of friction similar? What are the differences between static and kinetic friction?

They are similar in that they both act in a direction opposite to the motion (or intended motion) and they both result from two surfaces rubbing against each other. Both are dependent on the normal force between these two surfaces. Static friction applies when there is no relative motion between the two surfaces. Kinetic friction is the type of friction when there is relative motion. The coefficient of static friction between two surfaces is greater than the coefficient of kinetic friction between those same two surfaces.

28. Friction At a wedding reception, you notice a small boy who looks like his mass is about 25 kg, running part way across the dance floor, then sliding on his knees until he stops. If the kinetic coefficient of friction between the boy's pants and the floor is 0.15, what is the frictional force acting on him as he slides?

$$F_{friction} = \mu_k F_N$$

$$= \mu_k mg$$

$$= (0.15)(25\ \text{kg})(9.80\ \text{m/s}^2)$$

$$= 37\ \text{N}$$

29. Velocity Derek is playing cards with his friends, and it is his turn to deal. A card has a mass of 2.3 g, and it slides 0.35 m along the table before it stops. If the coefficient of kinetic friction between the card and the table is 0.24, what was the initial speed of the card as it left Derek's hand?

Identify the direction of the card's movement as positive

$F_{net} = -\mu_k F_N = -\mu_k mg = ma$

$a = -\mu_k g$

$v_f = d_i = 0$ **so**

$v_i = \sqrt{-2ad_f}$

$= \sqrt{-2(-\mu_k g)d_f}$

$= \sqrt{-2(-0.24)(9.80\ \text{m/s}^2)(0.35\ \text{m})}$

$= 1.3\ \text{m/s}$

30. Force The coefficient of static friction between a 40.0-kg picnic table and the ground below it is 0.43 m. What is the greatest horizontal force that could be exerted on the table while it remains stationary?

$F_f = \mu_s F_N$

$= \mu_s mg$

$= (0.43)(40.0\ \text{kg})(9.80\ \text{m/s}^2)$

$= 1.7\times10^2\ \text{N}$

31. Acceleration Ryan is moving to a new apartment and puts a dresser in the back of his pickup truck. When the truck accelerates forward, what force accelerates the dresser? Under what circumstances could the dresser slide? In which direction?

Friction between the dresser and the truck accelerates the dresser forward. The dresser will slide backward if the force accelerating it is greater than $\mu_s mg$.

32. Critical Thinking You push a 13-kg table in the cafeteria with a horizontal force of 20 N, but it does not move. You then push it with a horizontal force of 25 N, and it accelerates at 0.26 m/s^2. What, if anything, can you conclude about the coefficients of static and kinetic friction?

From the sliding portion of your experiment you can determine that the coefficient of kinetic friction between the table and the floor is

$F_f = F_{\text{on table}} - F_2$

$\mu_k F_N = F_{\text{on table}} - ma$

$\mu_k = \dfrac{F_{\text{on table}} - ma}{mg}$

$= \dfrac{25\ \text{N} - (13\ \text{kg})(0.26\ \text{m/s})}{(13\ \text{kg})(9.80\ \text{m/s}^2)}$

$= 0.17$

All you can conclude about the coefficient of static friction is that it is between

$\mu_s = \dfrac{F_{\text{on table}}}{mg}$

$= \dfrac{20\ \text{N}}{(13\ \text{kg})(9.80\ \text{m/s}^2)}$

$= 0.16$

and $\mu_s = \dfrac{F_{\text{on table}}}{mg}$

$= \dfrac{25\ \text{N}}{(13\ \text{kg})(9.80\ \text{m/s}^2)}$

$= 0.20$

Practice Problems

5.3 Force and Motion in Two Dimensions pages 131–135

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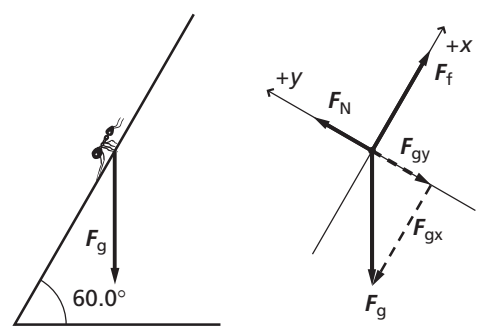
33. An ant climbs at a steady speed up the side of its anthill, which is inclined 30.0° from the vertical. Sketch a free-body diagram for the ant.



34. Scott and Becca are moving a folding table out of the sunlight. A cup of lemonade, with a mass of 0.44 kg, is on the table. Scott lifts his end of the table before Becca does, and as a result, the table makes an angle of 15.0° with the horizontal. Find the components of the cup's weight that are parallel and perpendicular to the plane of the table.

$$F_{g,\,parallel} = F_g \sin\theta$$
$$= (0.44\text{ kg})(9.80\text{ m/s}^2)(\sin 15.0°)$$
$$= 1.1\text{ N}$$
$$F_{g,\,perpendicular} = F_g \cos\theta$$
$$= (0.44\text{ kg})(9.80\text{ m/s}^2)(\cos 15.0°)$$
$$= 4.2\text{ N}$$

35. Kohana, who has a mass of 50.0 kg, is at the dentist's office having her teeth cleaned, as shown in **Figure 5-14.** If the component of her weight perpendicular to the plane of the seat of the chair is 449 N, at what angle is the chair tilted?

■ **Figure 5-14**

$$F_{g,\,perpendicular} = F_g \cos\theta = mg\cos\theta$$
$$\theta = \cos^{-1}\left(\frac{F_{g,\,perpendicular}}{mg}\right)$$
$$= \cos^{-1}\left(\frac{449\text{ N}}{(50.0\text{ kg})(9.80\text{ m/s}^2)}\right)$$
$$= 23.6°$$

36. Fernando, who has a mass of 43.0 kg, slides down the banister at his grandparents' house. If the banister makes an angle of 35.0° with the horizontal, what is the normal force between Fernando and the banister?

$$F_N = mg\cos\theta$$
$$= (43.0\text{ kg})(9.80\text{ m/s}^2)(\cos 35.0°)$$
$$= 345\text{ N}$$

37. A suitcase is on an inclined plane. At what angle, relative to the vertical, will the component of the suitcase's weight parallel to the plane be equal to half the perpendicular component of its weight?

$F_{g,\,parallel} = F_g \sin\theta$, when the angle is with respect to the horizontal

$F_{g,\,perpendicular} = F_g \cos\theta$, when the angle is with respect to the horizontal

$$F_{g,\,perpendicular} = 2F_{g,\,parallel}$$
$$2 = \frac{F_{g,\,perpendicular}}{F_{g,\,parallel}}$$
$$= \frac{F_g\cos\theta}{F_g\sin\theta}$$
$$= \frac{1}{\tan\theta}$$
$$\theta = \tan^{-1}\left(\frac{1}{2}\right)$$
$$= 26.6°\text{ relative to the horizontal, or } 63.4°\text{ relative to the vertical}$$

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38. Consider the crate on the incline in Example Problem 5.

a. Calculate the magnitude of the acceleration.

$$a = \frac{F}{m}$$
$$= \frac{F_g\sin\theta}{m}$$
$$= \frac{mg\sin\theta}{m}$$
$$= g\sin\theta$$
$$= (9.80\text{ m/s}^2)(\sin 30.0°)$$
$$= 4.90\text{ m/s}^2$$

b. After 4.00 s, how fast will the crate be moving?

$$a = \frac{v_f - v_i}{t_f - t_i};\text{ let } v_i = t_i = 0.$$

Solve for v_f.

$$v_f = at_f$$
$$= (4.90\text{ m/s}^2)(4.00\text{ s})$$
$$= 19.6\text{ m/s}$$

39. If the skier in Example Problem 6 were on a 31° downhill slope, what would be the magnitude of the acceleration?

Since $a = g(\sin\theta - \mu\cos\theta)$,

$$a = (9.80\ \text{m/s}^2)(\sin 31° - (0.15)(\cos 31°))$$
$$= 3.8\ \text{m/s}^2$$

40. Stacie, who has a mass of 45 kg, starts down a slide that is inclined at an angle of 45° with the horizontal. If the coefficient of kinetic friction between Stacie's shorts and the slide is 0.25, what is her acceleration?

$$F_{\text{Stacie's weight parallel with slide}} - F_f = ma$$

$$a = \frac{F_{\text{Stacie's weight parallel with slide}} - F_f}{m}$$

$$= \frac{mg\sin\theta - \mu_k F_N}{m}$$

$$= \frac{mg\sin\theta - \mu_k mg\cos\theta}{m}$$

$$= g(\sin\theta - \mu_k\cos\theta)$$

$$= (9.80\ \text{m/s}^2)[\sin 45° - (0.25)(\cos 45°)]$$

$$= 5.2\ \text{m/s}^2$$

41. After the skier on the 37° hill in Example Problem 6 had been moving for 5.0 s, the friction of the snow suddenly increased and made the net force on the skier zero. What is the new coefficient of friction?

$$a = g(\sin\theta - \mu_k\cos\theta)$$

$$a = g\sin\theta - g\mu_k\cos\theta$$

If $a = 0$,

$$0 = g\sin\theta - g\mu_k\cos\theta$$

$$\mu_k\cos\theta = \sin\theta$$

$$\mu_k = \frac{\sin\theta}{\cos\theta}$$

$$\mu_k = \frac{\sin 37°}{\cos 37°}$$

$$= 0.75$$

Section Review

5.3 Force and Motion in Two Dimensions pages 131–135

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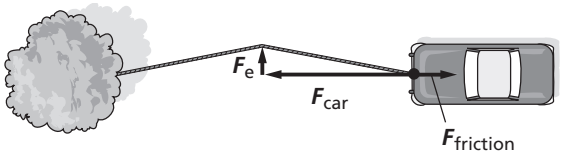
42. **Forces** One way to get a car unstuck is to tie one end of a strong rope to the car and the other end to a tree, then push the rope at its midpoint at right angles to the rope. Draw a free-body diagram and explain why even a small force on the rope can exert a large force on the car.

The vectors shown in the free body diagram indicate that even a small force perpendicular to the rope can increase the tension in the rope enough to overcome the friction force. Since $F = 2T\sin\theta$ (where θ is the angle between the rope's original position and its displaced position),

$$T = \frac{F}{2\sin\theta}$$

For smaller values of θ, the tension, T, will increase greatly.



43. Mass A large scoreboard is suspended from the ceiling of a sports arena by 10 strong cables. Six of the cables make an angle of 8.0° with the vertical while the other four make an angle of 10.0°. If the tension in each cable is 1300.0 N, what is the scoreboard's mass?

$$F_{net,y} = ma_y = 0$$

$$F_{net,y} = F_{cables\ on\ board} - F_g$$

$$= 6F_{cable}\cos\theta_6 + 4F_{cable}\cos\theta_4 - mg = 0$$

$$m = \frac{6F_{cable}\cos\theta_6 + 4F_{cable}\cos\theta_4}{g}$$

$$= \frac{6(1300.0\ \text{N})(\cos 8.0°) + 4(1300.0\ \text{N})(\cos 10.0°)}{9.80\ \text{m/s}^2}$$

$$= 1.31\times10^3\ \text{kg}$$

44. Acceleration A 63-kg water skier is pulled up a 14.0° incline by a rope parallel to the incline with a tension of 512 N. The coefficient of kinetic friction is 0.27. What are the magnitude and direction of the skier's acceleration?

$$F_N = mg\cos\theta$$

$$F_{rope\ on\ skier} - F_g - F_f = ma$$

$$F_{rope\ on\ skier} - mg\sin\theta - \mu_k mg\cos\theta = ma$$

$$a = \frac{F_{rope\ on\ skier} - mg\sin\theta - \mu_k mg\cos\theta}{m}$$

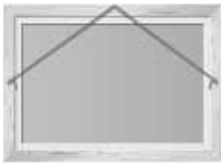
$$= \frac{512\ \text{N} - (63\ \text{kg})(9.80\ \text{m/s}^2)(\sin 14.0°) - (0.27)(63\ \text{kg})(9.80\ \text{m/s}^2)(\cos 14.0°)}{63\ \text{kg}}$$

$$= 3.2\ \text{m/s}^2\text{, up the incline}$$

45. Equilibrium You are hanging a painting using two lengths of wire. The wires will break if the force is too great. Should you hang the painting as shown in **Figures 5-15a** or **5-15b?** Explain.

■ **Figure 5-15a**

Figure 5-15b; $F_T = \dfrac{F_g}{2\sin\theta}$**, so** F_T **gets smaller as** θ **gets larger, and** θ **is larger in 5-15b.**



■ **Figure 5-15b**

46. Critical Thinking Can the coefficient of friction ever have a value such that a skier would be able to slide uphill at a constant velocity? Explain why or why not. Assume there are no other forces acting on the skier.

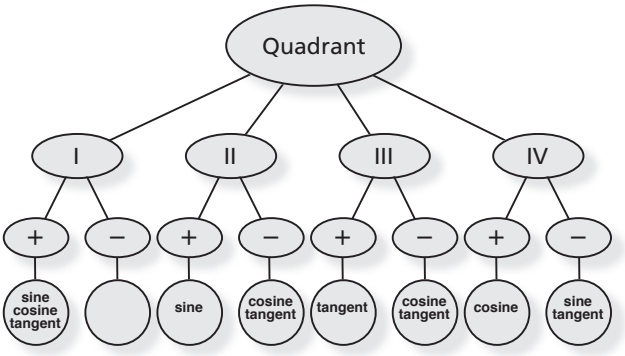
No, because both the frictional force opposing the motion of the skier and the component of Earth's gravity parallel to the slope point downhill, not uphill.

Chapter Assessment

Concept Mapping

page 140

47. Complete the concept map below by labeling the circles with *sine, cosine,* or *tangent* to indicate whether each function is positive or negative in each quadrant.



Mastering Concepts

page 140

48. Describe how you would add two vectors graphically. (5.1)

Make scale drawings of arrows representing the vector quantities. Place the arrows for the quantities to be added tip-to-tail. Draw an arrow from the tail of the first to the tip of the last. Measure the length of that arrow and find its direction.

49. Which of the following actions is permissible when you graphically add one vector to another: moving the vector, rotating the vector, or changing the vector's length? (5.1)

allowed: moving the vector without changing length or direction

50. In your own words, write a clear definition of the resultant of two or more vectors. Do not explain how to find it; explain what it represents. (5.1)

The resultant is the vector sum of two or more vectors. It represents the quantity that results from adding the vectors.

51. How is the resultant displacement affected when two displacement vectors are added in a different order? (5.1)

It is not affected.

52. Explain the method that you would use to subtract two vectors graphically. (5.1)

Reverse the direction of the second vector and then add them.

53. Explain the difference between these two symbols: $\mathbf{A}$ and A. (5.1)

$\mathbf{A}$ is the symbol for the vector quantity. A is the signed magnitude (length) of the vector.

54. The Pythagorean theorem usually is written $c^2 = a^2 + b^2$. If this relationship is used in vector addition, what do a, b, and c represent? (5.1)

a and b represent the lengths of two vectors that are at the right angles to one another. c represents the length of the sum of the two vectors.

55. When using a coordinate system, how is the angle or direction of a vector determined with respect to the axes of the coordinate system? (5.1)

The angle is measured counterclockwise from the x-axis.

56. What is the meaning of a coefficient of friction that is greater than 1.0? How would you measure it? (5.2)

The frictional force is greater than the normal force. You can pull the object along the surface, measuring the force needed to move it at constant speed. Also measure the weight of the object.

57. **Cars** Using the model of friction described in this textbook, would the friction between a tire and the road be increased by a wide rather than a narrow tire? Explain. (5.2)

It would make no difference. Friction does not depend upon surface area.

58. Describe a coordinate system that would be suitable for dealing with a problem in which a ball is thrown up into the air. (5.3)

One axis is vertical, with the positive direction either up or down.

59. If a coordinate system is set up such that the positive x-axis points in a direction 30° above the horizontal, what should be the angle between the x-axis and the y-axis? What should be the direction of the positive y-axis? (5.3)

The two axes must be at right angles. The positive *y*-axis points 30° away from the vertical so that it is at right angles to the *x*-axis.

60. Explain how you would set up a coordinate system for motion on a hill. (5.3)

For motion on a hill, the vertical (*y*) axis is usually set up perpendicular, or normal, to the surface of the hill.

61. If your textbook is in equilibrium, what can you say about the forces acting on it? (5.3)

The net force acting on the book is zero.

62. Can an object that is in equilibrium be moving? Explain. (5.3)

Yes, Newton's first law permits motion as long as the object's velocity is constant. It cannot accelerate.

63. What is the sum of three vectors that, when placed tip to tail, form a triangle? If these vectors represent forces on an object, what does this imply about the object? (5.3)

The vector sum of forces forming a closed triangle is zero. If these are the only forces acting on the object, the net force on the object is zero and the object is in equilibrium.

64. You are asked to analyze the motion of a book placed on a sloping table. (5.3)

a. Describe the best coordinate system for analyzing the motion.
Set up the *y*-axis perpendicular to the surface of the table and the *x*-axis pointing uphill and parallel to the surface.

b. How are the components of the weight of the book related to the angle of the table?
One component is parallel to the inclined surface and the other is perpendicular to it.

65. For a book on a sloping table, describe what happens to the component of the weight force parallel to the table and the force of friction on the book as you increase the angle that the table makes with the horizontal. (5.3)

a. Which components of force(s) increase when the angle increases?
As you increase the angle the table makes with the horizontal, the component of the book's weight force along the table increases.

b. Which components of force(s) decrease?
When the angle increases, the component of the weight force normal to the table decreases and the friction force decreases.

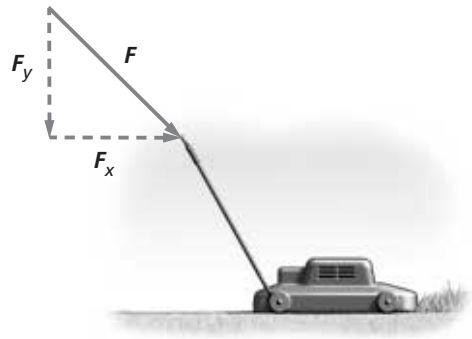
Applying Concepts

pages 140–141

66. A vector that is 1 cm long represents a displacement of 5 km. How many kilometers are represented by a 3-cm vector drawn to the same scale?

$$(3\text{ cm})\left(\frac{5\text{ km}}{1\text{ cm}}\right) = 15\text{ km}$$

67. **Mowing the Lawn** If you are pushing a lawn mower across the grass, as shown in **Figure 5-16,** can you increase the horizontal component of the force that you exert on the mower without increasing the magnitude of the force? Explain.



■ **Figure 5-16**

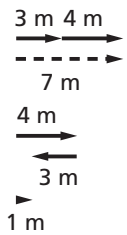
Yes, lower the handle to make the angle between the handle and the horizontal smaller.

68. A vector drawn 15 mm long represents a velocity of 30 m/s. How long should you draw a vector to represent a velocity of 20 m/s?

$$(20\ \text{m/s})\left(\frac{15\ \text{mm}}{30\ \text{m/s}}\right) = 10\ \text{mm}$$

69. What is the largest possible displacement resulting from two displacements with magnitudes 3 m and 4 m? What is the smallest possible resultant? Draw sketches to demonstrate your answers.

The largest is 7 m; the smallest is 1 m.



70. How does the resultant displacement change as the angle between two vectors increases from 0° to 180°?

The resultant increases.

71. *A* and *B* are two sides of a right triangle, where $\tan\theta = A/B$.

a. Which side of the triangle is longer if $\tan\theta$ is greater than 1.0?

A is longer.

b. Which side is longer if $\tan\theta$ is less than 1.0?

B is longer.

c. What does it mean if $\tan\theta$ is equal to 1.0?

A and B are equal in length.

72. **Traveling by Car** A car has a velocity of 50 km/h in a direction 60° north of east. A coordinate system with the positive *x*-axis pointing east and a positive *y*-axis pointing north is chosen. Which component of the velocity vector is larger, *x* or *y*?

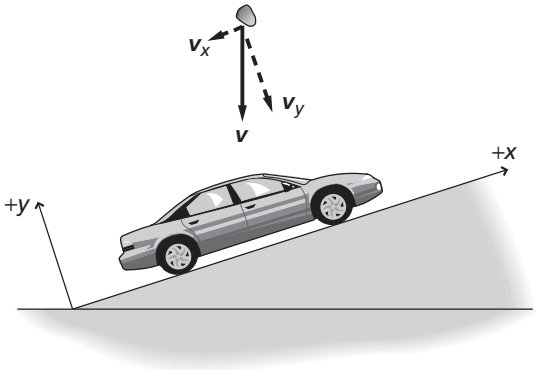
The northward component (*y*) is longer.

73. Under what conditions can the Pythagorean theorem, rather than the law of cosines, be used to find the magnitude of a resultant vector?

The Pythagorean theorem can be used only if the two vectors to be added are at right angles to one another.

74. A problem involves a car moving up a hill, so a coordinate system is chosen with the positive *x*-axis parallel to the surface of the hill. The problem also involves a stone that is dropped onto the car. Sketch the problem and show the components of the velocity vector of the stone.

One component is in the negative *x*-direction, the other in the negative *y*-direction, assuming that the positive direction points upward, perpendicular to the hill.



75. **Pulling a Cart** According to legend, a horse learned Newton's laws. When the horse was told to pull a cart, it refused, saying that if it pulled the cart forward, according to Newton's third law, there would be an equal force backwards; thus, there would be balanced forces, and, according to Newton's second law, the cart would not accelerate. How would you reason with this horse?

The equal and opposite forces referred to in Newton's third law are acting on different objects. The horse would pull on the cart, and the cart would pull on the horse. The cart would have an unbalanced net force on it (neglecting friction) and would thus accelerate.

76. **Tennis** When stretching a tennis net between two posts, it is relatively easy to pull one end of the net hard enough to remove most of the slack, but you need a winch to take the last bit of slack out of the net to make the top almost completely horizontal. Why is this true?

When stretching the net between the two posts, there is no perpendicular component upward to balance the weight of the net. All the force exerted on the net is horizontal. Stretching the net to remove the last bit of slack requires great force in order to reduce the flexibility of the net and to increase the internal forces that hold it together.

77. The weight of a book on an inclined plane can be resolved into two vector components, one along the plane, and the other perpendicular to it.

a. At what angle are the components equal?
45°

b. At what angle is the parallel component equal to zero?
0°

c. At what angle is the parallel component equal to the weight?
90°

78. **TV Towers** The transmitting tower of a TV station is held upright by guy wires that extend from the top of the tower to the ground. The force along the guy wires can be resolved into two perpendicular components. Which one is larger?

The component perpendicular to the ground is larger if the angle between the guy wire and horizontal is greater than 45°.

Mastering Problems

5.1 Vectors

pages 141–142

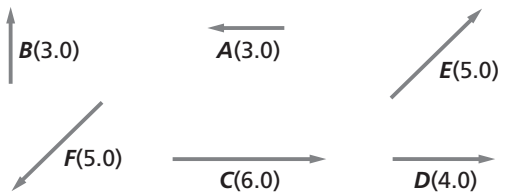
Level 1

79. **Cars** A car moves 65 km due east, then 45 km due west. What is its total displacement?

$65\text{ km} + (-45\text{ km}) = 2.0\times10^1\text{ km}$

$\Delta d = 2.0\times10^1\text{ km, east}$

80. Find the horizontal and vertical components of the following vectors, as shown in **Figure 5-17.**



■ **Figure 5-17**

a. E

$E_x = E\cos\theta$
$= (5.0)(\cos 45°)$
$= 3.5$

$E_y = E\sin\theta$
$= (5.0)(\sin 45°)$
$= 3.5$

b. F

$F_x = F\cos\theta$
$= (5.0)(\cos 225°)$
$= -3.5$

$F_y = F\sin\theta$
$= (5.0)(\sin 225°)$
$= -3.5$

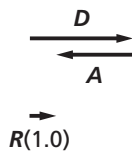
c. A

$A_x = A\cos\theta$
$= (3.0)(\cos 180°)$
$= -3.0$

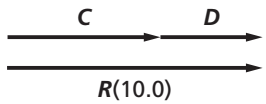
$A_y = A\sin\theta$
$= (3.0)(\sin 180°)$
$= 0.0$

81. Graphically find the sum of the following pairs of vectors, whose lengths and directions are shown in Figure 5-17.

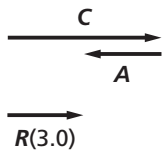
a. ***D*** and ***A***



b. ***C*** and ***D***



c. ***C*** and ***A***

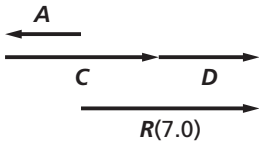


d. ***E*** and ***F***

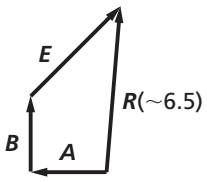
Level 2

82. Graphically add the following sets of vectors, as shown in Figure 5-17.

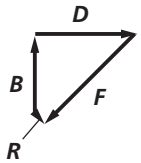
a. ***A, C,*** and ***D***



b. ***A, B,*** and ***E***



c. ***B, D,*** and ***F***



83. You walk 30 m south and 30 m east. Find the magnitude and direction of the resultant displacement both graphically and algebraically.

$$R^2 = A^2 + B^2$$

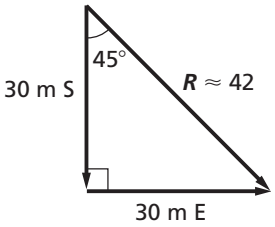
$$R = \sqrt{(30\text{ m})^2 + (30\text{ m})^2}$$

$$= 40\text{ m}$$

$$\tan\theta = \frac{30\text{ m}}{30\text{ m}} = 1$$

$$\theta = 45°$$

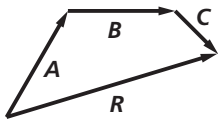
R = 40 m, 45° east of south



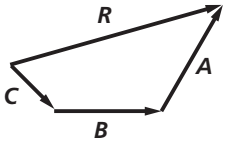
The difference in the answers is due to significant digits being considered in the calculation.

84. **Hiking** A hiker's trip consists of three segments. Path ***A*** is 8.0 km long heading 60.0° north of east. Path ***B*** is 7.0 km long in a direction due east. Path ***C*** is 4.0 km long heading 315° counterclockwise from east.

a. Graphically add the hiker's displacements in the order ***A, B, C.***



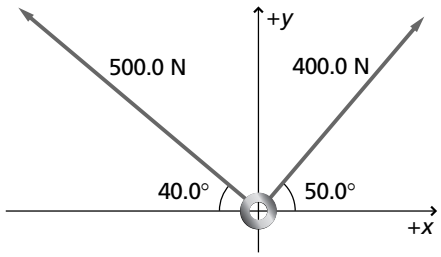
b. Graphically add the hiker's displacements in the order ***C, B, A.***



c. What can you conclude about the resulting displacements?

You can add vectors in any order. The result is always the same.

85. What is the net force acting on the ring in **Figure 5-18?**



■ **Figure 5-18**

$$R^2 = A^2 + B^2$$

$$R = \sqrt{A^2 + B^2}$$

$$= \sqrt{(500.0\text{ N})^2 + (400.0\text{ N})^2}$$

$$= 640.3\text{ N}$$

$$\tan\theta = \frac{A}{B}$$

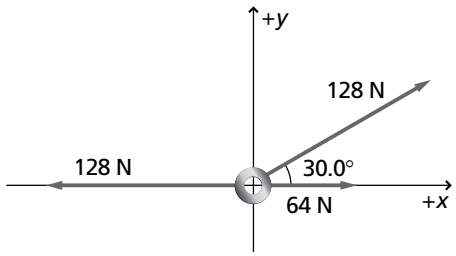
$$\theta = \tan^{-1}\left(\frac{A}{B}\right)$$

$$= \tan^{-1}\left(\frac{500.0}{400.0}\right)$$

$$= 51.34° \text{ from } B$$

The net force is 640.3 N at 51.34°

86. What is the net force acting on the ring in **Figure 5-19?**



■ **Figure 5-19**

$$A = -128\text{ N} + 64\text{ N}$$

$$= -64\text{ N}$$

$$A_x = A\cos\theta_A$$

$$= (-64\text{ N})(\cos 180°)$$

$$= -64\text{ N}$$

$$A_y = A\sin\theta_A$$

$$= (-64\text{ N})(\sin 180°)$$

$$= 0\text{ N}$$

$$B_x = B\cos\theta_B$$

$$= (128\text{ N})(\cos 30.0°)$$

$$= 111\text{ N}$$

$$B_y = B\sin\theta_B$$

$$= (128\text{ N})(\sin 30.0°)$$

$$= 64\text{ N}$$

$$R_x = A_x + B_x$$

$$= -64\text{ N} + 111\text{ N}$$

$$= 47\text{ N}$$

$$R_y = A_y + B_y$$

$$= 0\text{ N} + 64\text{ N}$$

$$= 64\text{ N}$$

$$R = \sqrt{R_x^2 + R_y^2}$$

$$= \sqrt{(47\text{ N})^2 + (64\text{ N})^2}$$

$$= 79\text{ N}$$

$$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$$

$$= \tan^{-1}\left(\frac{64}{47}\right)$$

$$= 54°$$

Level 3

87. **A Ship at Sea** A ship at sea is due into a port 500.0 km due south in two days. However, a severe storm comes in and blows it 100.0 km due east from its original position. How far is the ship from its destination? In what direction must it travel to reach its destination?

$$R^2 = A^2 + B^2$$

$$R = \sqrt{(100.0\text{ km})^2 + (500.0\text{ km})^2}$$

$$= 509.9\text{ km}$$

$$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$$

$$= \tan^{-1}\left(\frac{500.0}{100.0}\right)$$

$$= 78.69°$$

$$R = 509.9\text{ km, } 78.69° \text{ south of west}$$

88. **Space Exploration** A descent vehicle landing on Mars has a vertical velocity toward the surface of Mars of 5.5 m/s. At the same time, it has a horizontal velocity of 3.5 m/s.

a. At what speed does the vehicle move along its descent path?

$$R^2 = A^2 + B^2$$

$$R = \sqrt{(5.5\text{ m/s})^2 + (3.5\text{ m/s})^2}$$

$$v = R = 6.5\text{ m/s}$$

b. At what angle with the vertical is this path?

$$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$$

$$= \tan^{-1}\left(\frac{5.5}{3.5}\right)$$

= 58° from horizontal, which is 32° from vertical

89. **Navigation** Alfredo leaves camp and, using a compass, walks 4 km E, then 6 km S, 3 km E, 5 km N, 10 km W, 8 km N, and, finally, 3 km S. At the end of three days, he is lost. By drawing a diagram, compute how far Alfredo is from camp and which direction he should take to get back to camp.

Take north and east to be positive directions. North: −6 km + 5 km + 8 km − 3 km = 4 km. East: 4 km + 3 km − 10 km = −3 km. The hiker is 4 km north and 3 km west of camp. To return to camp, the hiker must go 3 km east and 4 km south.

$$R^2 = A^2 + B^2$$

$$R = \sqrt{(3\text{ km})^2 + (4\text{ km})^2}$$

$$= 5\text{ km}$$

$$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$$

$$= \tan^{-1}\left(\frac{4\text{ km}}{3\text{ km}}\right)$$

$$= 53°$$

R = 5 km, 53° south of east

5.2 Friction

page 142

Level 1

90. If you use a horizontal force of 30.0 N to slide a 12.0-kg wooden crate across a floor at a constant velocity, what is the coefficient of kinetic friction between the crate and the floor?

$$F_f = \mu_k F_N = \mu_k mg = F_{horizontal}$$

$$\mu_k = \frac{F_{horizontal}}{mg}$$

$$= \frac{30.0\text{ N}}{(12.0\text{ kg})(9.80\text{ m/s}^2)}$$

$$= 0.255$$

91. A 225-kg crate is pushed horizontally with a force of 710 N. If the coefficient of friction is 0.20, calculate the acceleration of the crate.

$$ma = F_{net} = F_{appl} - F_f$$

where $F_f = \mu_k F_N = \mu_k mg$

Therefore

$$a = \frac{F_{appl} - \mu_k mg}{m}$$

$$= \frac{710\text{ N} - (0.20)(225\text{ kg})(9.80\text{ m/s}^2)}{225\text{ kg}}$$

$$= 1.2\text{ m/s}^2$$

Level 2

92. A force of 40.0 N accelerates a 5.0-kg block at 6.0 m/s^2 along a horizontal surface.

a. How large is the frictional force?

$$ma = F_{net} = F_{appl} - F_f$$

$$\text{so } F_f = F_{appl} - ma$$

$$= 40.0\text{ N} - (5.0\text{ kg})(6.0\text{ m/s}^2)$$

$$= 1.0\times10^1\text{ N}$$

b. What is the coefficient of friction?

$$F_f = \mu_k F_N = \mu_k mg$$

$$\text{so } \mu_k = \frac{F_f}{mg}$$

$$= \frac{1.0\times10^1\text{ N}}{(5.0\text{ kg})(9.80\text{ m/s}^2)}$$

$$= 0.20$$

93. Moving Appliances Your family just had a new refrigerator delivered. The delivery man has left and you realize that the refrigerator is not quite in the right position, so you plan to move it several centimeters. If the refrigerator has a mass of 180 kg, the coefficient of kinetic friction between the bottom of the refrigerator and the floor is 0.13, and the static coefficient of friction between these same surfaces is 0.21, how hard do you have to push horizontally to get the refrigerator to start moving?

$$F_{\text{on fridge}} = F_{\text{friction}}$$
$$= \mu_s F_N$$
$$= \mu_s mg$$
$$= (0.21)(180\text{ kg})(9.80\text{ m/s}^2)$$
$$= 370\text{ N}$$

Level 3

94. Stopping at a Red Light You are driving a 2500.0-kg car at a constant speed of 14.0 m/s along a wet, but straight, level road. As you approach an intersection, the traffic light turns red. You slam on the brakes. The car's wheels lock, the tires begin skidding, and the car slides to a halt in a distance of 25.0 m. What is the coefficient of kinetic friction between your tires and the wet road?

$$F_f = \mu_k F_N = ma$$
$$-\mu_k mg = \frac{m(v_f^2 - v_i^2)}{2\Delta d} \text{ where } v_f = 0$$

(The minus sign indicates the force is acting opposite to the direction of motion.)

$$\mu_k = \frac{v_i^2}{2dg}$$
$$= \frac{(14.0\text{ m/s})^2}{2(25.0\text{ m})(9.80\text{ m/s}^2)}$$
$$= 0.400$$

5.3 Force and Motion in Two Dimensions

pages 142–143

Level 1

95. An object in equilibrium has three forces exerted on it. A 33.0-N force acts at 90.0° from the *x*-axis and a 44.0-N force acts at 60.0° from the *x*-axis. What are the magnitude and direction of the third force?

First, find the magnitude of the sum of these two forces. The equilibrant will have the same magnitude but opposite direction.

$$F_1 = 33.0\text{ N}, 90.0°$$
$$F_2 = 44.0\text{ N}, 60.0°$$
$$F_3 = ?$$
$$F_{1x} = F_1 \cos\theta_1$$
$$= (33.0\text{ N})(\cos 90.0°)$$
$$= 0.0\text{ N}$$
$$F_{1y} = F_1 \sin\theta_1$$
$$= (33.0\text{ N})(\sin 90.0°)$$
$$= 33.0\text{ N}$$
$$F_{2x} = F_2 \cos\theta_2$$
$$= (44.0\text{ N})(\cos 60.0°)$$
$$= 22.0\text{ N}$$
$$F_{2y} = F_2 \sin\theta_2$$
$$= (44.0\text{ N})(\sin 60.0°)$$
$$= 38.1\text{ N}$$
$$F_{3x} = F_1x + F_2x$$
$$= 0.0\text{ N} + 22.0\text{ N}$$
$$= 22.0\text{ N}$$
$$F_{3y} = F_1y + F_2y$$
$$= 33.0\text{ N} + 38.1\text{ N}$$
$$= 71.1\text{ N}$$
$$F_3 = \sqrt{F_{3x}^2 + F_{3y}^2}$$
$$= \sqrt{(22.0\text{ N})^2 + (71.1\text{ N})^2}$$
$$= 74.4\text{ N}$$

For equilibrium, the sum of the components must equal zero, so

$$\theta = \tan^{-1}\left(\frac{F_{3y}}{F_{3x}}\right) + 180.0°$$

$$= \tan^{-1}\left(\frac{71.1\ \text{N}}{22.0\ \text{N}}\right) + 180.0°$$

$$= 253°$$

$$F_3 = 74.4\ \text{N}, 253°$$

Level 2

96. Five forces act on an object: (1) 60.0 N at 90.0°, (2) 40.0 N at 0.0°, (3) 80.0 N at 270.0°, (4) 40.0 N at 180.0°, and (5) 50.0 N at 60.0°. What are the magnitude and direction of a sixth force that would produce equilibrium?

Solutions by components

$$F_1 = 60.0\ \text{N}, 90.0°$$

$$F_2 = 40.0\ \text{N}, 0.0°$$

$$F_3 = 80.0\ \text{N}, 270.0°$$

$$F_4 = 40.0\ \text{N}, 180.0°$$

$$F_5 = 50.0\ \text{N}, 60.0°$$

$$F_6 = ?$$

$$F_{1x} = F_1 \cos\theta_1$$
$$= (60.0\ \text{N})(\cos 90.0°) = 0.0\ \text{N}$$

$$F_{1y} = F_1 \sin\theta_1 = (60.0\ \text{N})(\sin 90.0°)$$
$$= 60.0\ \text{N}$$

$$F_{2x} = F_2 \cos\theta_2 = (40.0\ \text{N})(\cos 0.0°)$$
$$= 40.0\ \text{N}$$

$$F_{2y} = F_2 \sin\theta_2 = (40.0\ \text{N})(\sin 0.0°)$$
$$= 0.0\ \text{N}$$

$$F_{3x} = F_3 \cos\theta_3 = (80.0\ \text{N})(\cos 270.0°)$$
$$= 0.0\ \text{N}$$

$$F_{3y} = F_3 \sin\theta_3 = (80.0\ \text{N})(\sin 270.0°)$$
$$= -80.0\ \text{N}$$

$$F_{4x} = F_4 \cos\theta_4 = (40.0\ \text{N})(\cos 180.0°)$$
$$= -40.0\ \text{N}$$

$$F_{4y} = F_4 \sin\theta_4 = (40.0\ \text{N})(\sin 180.0°)$$
$$= 0.0\ \text{N}$$

$$F_{5x} = F_5 \cos\theta_5 = (50.0\ \text{N})(\cos 60.0°)$$
$$= 25.0\ \text{N}$$

$$F_{5y} = F_5 \sin\theta_5 = (50.0\ \text{N})(\sin 60.0°)$$
$$= 43.3\ \text{N}$$

$$F_{6x} = F_{1x} + F_{2x} + F_{3x} + F_{4x} + F_{5x}$$
$$= 0.0\ \text{N} + 40.0\ \text{N} + 0.0\ \text{N} + (-40.0\ \text{N}) + 25.0\ \text{N}$$
$$= 25.0\ \text{N}$$

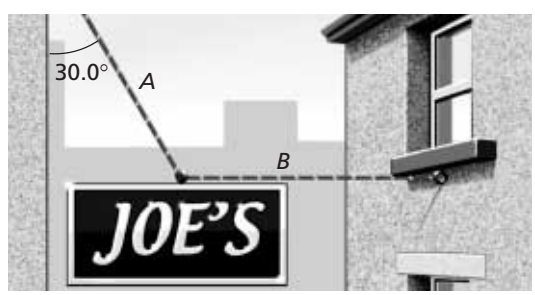
$$F_{6y} = F_{1y} + F_{2y} + F_{3y} + F_{4y} + F_{5y}$$
$$= 60.0\ \text{N} + 0.0\ \text{N} + (-80.0\ \text{N}) + 0.0\ \text{N} + 43.3\ \text{N}$$
$$= 23.3\ \text{N}$$

$$F_6 = \sqrt{F_{6x}^2 + F_{6y}^2}$$
$$= \sqrt{(25.0\ \text{N})^2 + (23.3\ \text{N})^2}$$
$$= 34.2\ \text{N}$$

$$\theta_6 = \tan^{-1}\left(\frac{F_{6y}}{F_{6x}}\right) + 180.0°$$
$$= \tan^{-1}\left(\frac{23.3\ \text{N}}{25.0\ \text{N}}\right) + 180.0°$$
$$= 223°$$

$$F_6 = 34.2\ \text{N}, 223°$$

97. Advertising Joe wishes to hang a sign weighing 7.50×10^2 N so that cable *A*, attached to the store, makes a 30.0° angle, as shown in **Figure 5-20.** Cable *B* is horizontal and attached to an adjoining building. What is the tension in cable *B*?



■ **Figure 5-20**

Solution by components. The sum of the components must equal zero, so

$F_{Ay} - F_g = 0$

so $F_{Ay} = F_g$

$= 7.50\times10^2$ N

$F_{Ay} = F_A \sin 60.0°$

so $F_A = \dfrac{F_{Ay}}{\sin 60.0°}$

$= \dfrac{7.50\times10^2 \text{ N}}{\sin 60.0°}$

$= 866$ N

Also, $F_B - F_A = 0$, so

$F_B = F_A$

$= F_A \cos 60.0°$

$= (866 \text{ N})(\cos 60.0°)$

$= 433$ N, right

98. A street lamp weighs 150 N. It is supported by two wires that form an angle of 120.0° with each other. The tensions in the wires are equal.

a. What is the tension in each wire supporting the street lamp?

$F_g = 2T \sin \theta$

so $T = \dfrac{F_g}{2 \sin \theta}$

$= \dfrac{150 \text{ N}}{(2)(\sin 30.0°)}$

$= 1.5\times10^2$ N

b. If the angle between the wires supporting the street lamp is reduced to 90.0°, what is the tension in each wire?

$T = \dfrac{F_g}{2 \sin \theta}$

$= \dfrac{150 \text{ N}}{(2)(\sin 45°)}$

$= 1.1\times10^2$ N

99. A 215-N box is placed on an inclined plane that makes a 35.0° angle with the horizontal. Find the component of the weight force parallel to the plane's surface.

$F_{parallel} = F_g \sin \theta$

$= (215 \text{ N})(\sin 35.0°)$

$= 123$ N

Level 3

100. **Emergency Room** You are shadowing a nurse in the emergency room of a local hospital. An orderly wheels in a patient who has been in a very serious accident and has had severe bleeding. The nurse quickly explains to you that in a case like this, the patient's bed will be tilted with the head downward to make sure the brain gets enough blood. She tells you that, for most patients, the largest angle that the bed can be tilted without the patient beginning to slide off is 32.0° from the horizontal.

a. On what factor or factors does this angle of tilting depend?

The coefficient of static friction between the patient and the bed's sheets.

b. Find the coefficient of static friction between a typical patient and the bed's sheets.

$F_{g\ parallel\ to\ bed} = mg \sin \theta$

$= F_f$

$= \mu_s F_N$

$= \mu_s mg \cos \theta$

so $\mu_s = \dfrac{mg \sin \theta}{mg \cos \theta}$

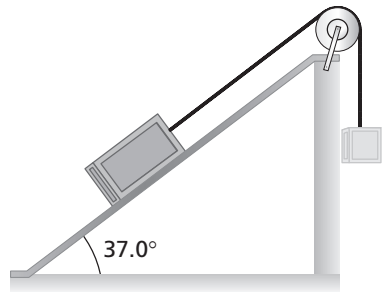
$= \dfrac{\sin \theta}{\cos \theta}$

$= \tan \theta$

$= \tan 32.0°$

$= 0.625$

101. Two blocks are connected by a string over a frictionless, massless pulley such that one is resting on an inclined plane and the other is hanging over the top edge of the plane, as shown in **Figure 5-21.** The hanging block has a mass of 16.0 kg, and the one on the plane has a mass of 8.0 kg. The coefficient of kinetic friction between the block and the inclined plane is 0.23. The blocks are released from rest.



■ **Figure 5-21**

a. What is the acceleration of the blocks?

$$F = m_{\text{both}}a = F_{\text{g hanging}} - F_{\parallel\text{plane}} - F_{\text{f plane}}$$

$$\text{so } a = \frac{m_{\text{hanging}}g - F_{\text{g plane}}\sin\theta - \mu_k F_{\text{g plane}}\cos\theta}{m_{\text{both}}}$$

$$= \frac{m_{\text{hanging}}g - m_{\text{plane}}g\sin\theta - \mu_k m_{\text{plane}}g\cos\theta}{m_{\text{both}}}$$

$$= \frac{g(m_{\text{hanging}} - m_{\text{plane}}\sin\theta - \mu_k m_{\text{plane}}\cos\theta)}{m_{\text{hanging}} + m_{\text{plane}}}$$

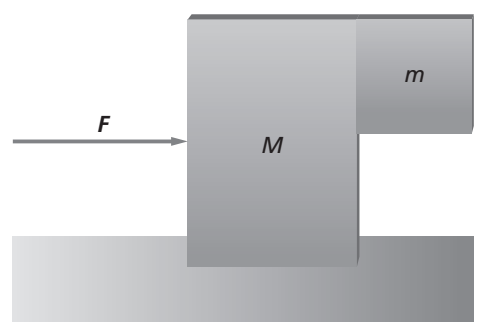
$$= \frac{(9.80\text{ m/s}^2)(16.0\text{ kg} - (8.0\text{ kg})(\sin 37.0°) - (0.23)(8.0\text{ kg})(\cos 37.0°))}{(16.0\text{ kg} + 80\text{ kg})}$$

$$= 4.0\text{ m/s}^2$$

b. What is the tension in the string connecting the blocks?

$$F_T = F_g - F_a$$
$$= mg - ma$$
$$= m(g - a)$$
$$= (16.0\text{ kg})(9.80\text{ m/s}^2 - 4.0\text{ m/s}^2)$$
$$= 93\text{ N}$$

102. In **Figure 5-22,** a block of mass *M* is pushed with such a force, *F*, that the smaller block of mass *m* does not slide down the front of it. There is no friction between the larger block and the surface below it, but the coefficient of static friction between the two blocks is μ_s. Find an expression for *F* in terms of *M*, *m*, μ_s, and *g*.



■ **Figure 5-22**

Smaller block:

$$F_{\text{f, M on m}} = \mu_s F_{\text{N, M on m}} = mg$$

$$F_{\text{N, M on m}} = \frac{mg}{\mu_s} = ma$$

$$a = \frac{g}{\mu_s}$$

Larger block:

$$F - F_{\text{N, m on M}} = Ma$$

$$F - \frac{mg}{\mu_s} = \frac{Mg}{\mu_s}$$

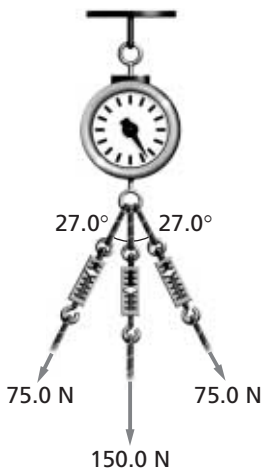
$$F = \frac{g}{\mu_s}(m + M)$$

Mixed Review

pages 143–144

Level 1

103. The scale in **Figure 5-23** is being pulled on by three ropes. What net force does the scale read?



■ **Figure 5-7**

Find the *y*-component of the two side ropes and then add them to the middle rope.

$$F_y = F\cos\theta$$

$$= (75.0\text{ N})(\cos 27.0°)$$

$$= 66.8\text{ N}$$

$$F_{y,\text{ total}} = F_{y,\text{ left}} + F_{y,\text{ middle}} + F_{y,\text{ right}}$$

$$= 66.8\text{ N} + 150.0\text{ N} + 66.8\text{ N}$$

$$= 283.6\text{ N}$$

104. **Sledding** A sled with a mass of 50.0 kg is pulled along flat, snow-covered ground. The static friction coefficient is 0.30, and the kinetic friction coefficient is 0.10.

a. What does the sled weigh?

$$F_g = mg = (50.0\text{ kg})(9.80\text{ m/s}^2)$$

$$= 4.90\times10^2\text{ N}$$

b. What force will be needed to start the sled moving?

$$F_f = \mu_s F_N$$

$$= \mu_s F_g$$

$$= (0.30)(4.90\times10^2\text{ N})$$

$$= 1.5\times10^2\text{ N}$$

c. What force is needed to keep the sled moving at a constant velocity?

$$F_f = \mu_s F_N$$

$$= \mu_s F_g$$

$$= (0.10)(4.90\times10^2\text{ N})$$

$$= 49\text{ N, kinetic friction}$$

d. Once moving, what total force must be applied to the sled to accelerate it at 3.0 m/s^2?

$$ma = F_{net} = F_{appl} - F_f$$

$$\text{so } F_{appl} = ma + F_f$$

$$= (50.0\text{ kg})(3.0\text{ m/s}^2) + 49\text{ N}$$

$$= 2.0\times10^2\text{ N}$$

Level 2

105. **Mythology** Sisyphus was a character in Greek mythology who was doomed in Hades to push a boulder to the top of a steep mountain. When he reached the top, the boulder would slide back down the mountain and he would have to start all over again. Assume that Sisyphus slides the boulder up the mountain without being able to roll it, even though in most versions of the myth, he rolled it.

a. If the coefficient of kinetic friction between the boulder and the mountainside is 0.40, the mass of the boulder is 20.0 kg, and the slope of the mountain is a constant 30.0°, what is the force that Sisyphus must exert on the boulder to move it up the mountain at a constant velocity?

$$F_{\text{S on rock}} - F_{g\parallel\text{to slope}} - F_f$$

$$= F_{\text{S on rock}} - mg\sin\theta -$$

$$\mu_k mg\cos\theta = ma = 0$$

$$F_{\text{S on rock}} = mg\sin\theta + \mu_k mg\cos\theta$$

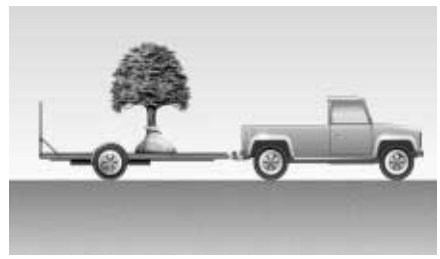
$$= mg(\sin\theta + \mu_k \cos\theta)$$
$$= (20.0\text{ kg})(9.80\text{ m/s}^2)$$
$$(\sin 30.0° + (0.40)(\cos 30.0°))$$
$$= 166\text{ N}$$

b. If Sisyphus pushes the boulder at a velocity of 0.25 m/s and it takes him 8.0 h to reach the top of the mountain, what is the mythical mountain's vertical height?

$$h = d\sin\theta$$
$$= vt\sin\theta$$
$$= (0.25\text{ m/s})(8.0\text{ h})(3600\text{ s/h})(\sin 30.0°)$$
$$= 3.6\times10^3\text{ m} = 3.6\text{ km}$$

Level 3

106. Landscaping A tree is being transported on a flatbed trailer by a landscaper, as shown in **Figure 5-24.** If the base of the tree slides on the tree will the trailer, fall over and be damaged. If the coefficient of static friction between the tree and the trailer is 0.50, what is the minimum stopping distance of the truck, traveling at 55 km/h, if it is to accelerate uniformly and not have the tree slide forward and fall on the trailer?



■ **Figure 5-24**

$$F_{truck} = -F_f = -\mu_s F_N = -\mu_s mg = ma$$

$$a = \frac{-\mu_s mg}{m} = -\mu_s g$$
$$= -(0.50)(9.80\text{ m/s}^2)$$
$$= -4.9\text{ m/s}^2$$

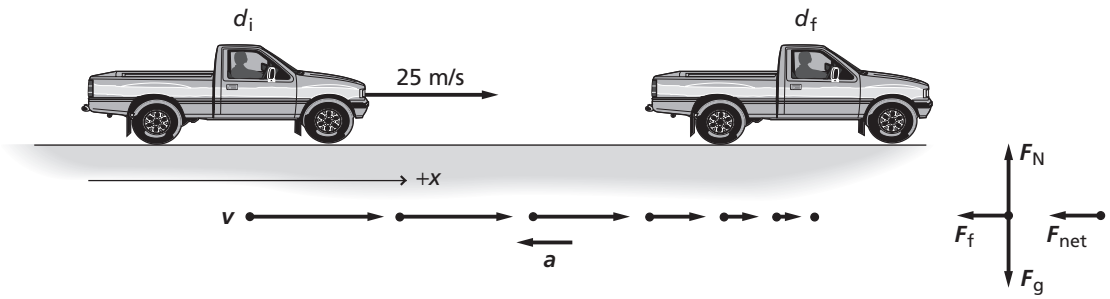
$v_f^2 = v_i^2 + 2a\Delta d$ with $v_f = 0$,

$$\text{so } \Delta d = -\frac{v_i^2}{2a}$$
$$= \frac{-\left((55\text{ km/h})\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)\right)^2}{(2)(-4.9\text{ m/s}^2)}$$
$$= 24\text{ m}$$

Thinking Critically

page 144

107. Use Models Using the Example Problems in this chapter as models, write an example problem to solve the following problem. Include the following sections: Analyze and Sketch the Problem, Solve for the Unknown (with a complete strategy), and Evaluate the Answer. A driver of a 975-kg car traveling 25 m/s puts on the brakes. What is the shortest distance it will take for the car to stop? Assume that the road is concrete, the force of friction of the road on the tires is constant, and the tires do not slip.



Analyze and Sketch the Problem

- **Choose a coordinate system with a positive axis in the direction of motion.**
- **Draw a motion diagram.**
- **Label *v* and *a*.**
- **Draw the free-body diagram.**

Known:	**Unknown:**
$d_i = 0$	$d_f = ?$
$v_i = 25$ m/s	
$v_f = 0$	
$m = 975$ kg	
$\mu_s = 0.80$	

Solve for the Unknown

Solve Newton's second law for *a*.

$-F_{net} = ma$

$-F_f = ma$ **Substitute** $-F_f = -F_{net}$

$-\mu F_N = ma$ **Substitute** $F_f = \mu F_N$

$-\mu mg = ma$ **Substitute** $F_N = mg$

$a = -\mu g$

Use the expression for acceleration to solve for distance.

$v_f^2 = v_i^2 + 2a(d_f - d_i)$

$$d_f = d_i + \frac{v_f^2 - v_i^2}{2a}$$

$$= d_i + \frac{v_f^2 - v_i^2}{(2)(-\mu g)}$$ **Substitute** $a = -\mu g$

$$= 0.0\text{ m} + \frac{(0.0\text{ m/s})^2 - (25\text{ m/s})^2}{(2)(-0.65)(9.80\text{ m/s})^2}$$

Substitute $d_i = 0.0$ m, $v_f = 0.0$ m/s, $v_i = 25$ m/s, $\mu = 0.65$, $g = 9.80$ m/s^2

$$= 49\text{ m}$$

108. **Analyze and Conclude** Margaret Mary, Doug, and Kako are at a local amusement park and see an attraction called the Giant Slide, which is simply a very long and high inclined plane. Visitors at the amusement park climb a long flight of steps to the top of the 27° inclined plane and are given canvas sacks. They sit on the sacks and slide down the 70-m-long plane. At the time when the three friends walk past the slide, a 135-kg man and a 20-kg boy are each at the top preparing to slide down. "I wonder how much less time it will take the man to slide down than it will take the boy," says Margaret Mary. "I think the boy will take less time," says Doug. "You're both wrong," says Kako. "They will reach the bottom at the same time."

a. Perform the appropriate analysis to determine who is correct.

$$F_{net} = F_g - F_f$$

$$= F_g \sin\theta - \mu_k F_N$$

$$= mg \sin\theta - \mu_k mg \cos\theta = ma$$

$a = g(\sin\theta - \mu_k \cos\theta)$, so the acceleration is independent of the mass. They will tie, so Kako is correct.

b. If the man and the boy do not take the same amount of time to reach the of the slide, calculate how many seconds of difference there will be between the two times.

They will reach the bottom at the same time.

Writing in Physics

page 144

109. Investigate some of the techniques used in industry to reduce the friction between various parts of machines. Describe two or three of these techniques and explain the physics of how they work.

Answers will vary and may include lubricants and reduction of the normal force to reduce the force of friction.

110. **Olympics** In recent years, many Olympic athletes, such as sprinters, swimmers, skiers, and speed skaters, have used modified equipment to reduce the effects of friction and air or water drag. Research a piece of equipment used by one of these types of athletes and the way it has changed over the years. Explain how physics has impacted these changes.

Answers will vary.

Cumulative Review

page 144

111. Add or subtract as indicated and state the answer with the correct number of significant digits. (Chapter 1)

a. 85.26 g + 4.7 g

90.0 g

b. 1.07 km + 0.608 km

1.68 km

c. 186.4 kg − 57.83 kg

128.6 kg

d. 60.08 s − 12.2 s

47.9 s

112. You ride your bike for 1.5 h at an average velocity of 10 km/h, then for 30 min at 15 km/h. What is your average velocity? (Chapter 3)

Average velocity is the total displacement divided by the total time.

$$\bar{v} = \frac{d_f - d_i}{t_f - t_i}$$

$$= \frac{v_1 t_1 + v_2 t_2 - d_i}{t_1 + t_2 - t_i}$$

$d_i = t_i = 0$, so

$$\bar{v} = \frac{v_1 t_1 + v_2 t_2}{t_1 + t_2}$$

$$= \frac{(10\ \text{km/h})(1.5\ \text{h}) + (15\ \text{km/h})(0.5\ \text{h})}{1.5\ \text{h} + 0.5\ \text{h}}$$

$$= 10\ \text{km/h}$$

113. A 45-N force is exerted in the upward direction on a 2.0-kg briefcase. What is the acceleration of the briefcase? (Chapter 4)

$$F_{net} = F_{applied} - F_g = F_{applied} - mg$$

$$= ma$$

$$\text{so } a = \frac{F_{applied} - mg}{m}$$

$$= \frac{45\ \text{N} - (2.0\ \text{kg})(9.80\ \text{m/s}^2)}{2.0\ \text{kg}}$$

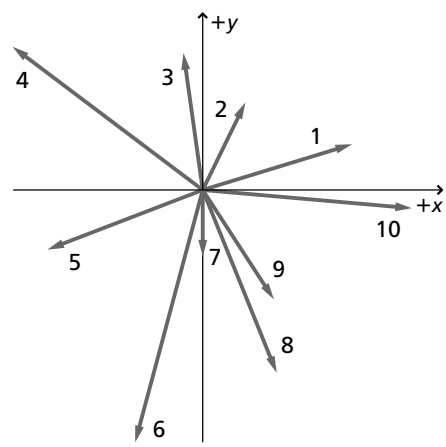
$$= 13\ \text{m/s}^2$$

Challenge Problem

page 132

Find the equilibrant for the following forces.

F_1 = 61.0 N at 17.0° north of east
F_2 = 38.0 N at 64.0° north of east
F_3 = 54.0 N at 8.0° west of north
F_4 = 93.0 N at 53.0° west of north
F_5 = 65.0 N at 21.0° south of west
F_6 =102.0 N at 15.0° west of south
F_7 =26.0 N south
F_8 = 77.0 N at 22.0° east of south
F_9 =51.0 N at 33.0° east of south
F_{10} = 82.0 N at 5.0° south of east



$$F_{1x} = (61.0\ \text{N})(\cos 17.0°) = 58.3\ \text{N}$$
$$F_{1y} = (61.0\ \text{N})(\sin 17.0°) = 17.8\ \text{N}$$

$$F_{2x} = (38.0\ \text{N})(\cos 64.0°) = 16.7\ \text{N}$$
$$F_{2y} = (38.0\ \text{N})(\sin 64.0°) = 34.2\ \text{N}$$

$$F_{3x} = -(54.0\ \text{N})(\sin 8.0°) = -7.52\ \text{N}$$
$$F_{3y} = (54.0\ \text{N})(\cos 8.0°) = 53.5\ \text{N}$$

$$F_{4x} = -(93.0\ \text{N})(\sin 53.0°) = -74.3\ \text{N}$$
$$F_{4y} = (93.0\ \text{N})(\cos 53.0°) = 56.0\ \text{N}$$

$$F_{5x} = -(65.0\ \text{N})(\cos 21.0°) = -60.7\ \text{N}$$
$$F_{5y} = -(65.0\ \text{N})(\sin 21.0°) = -23.3\ \text{N}$$

$$F_{6x} = -(102\ \text{N})(\sin 15.0°) = -26.4\ \text{N}$$
$$F_{6y} = -(102\ \text{N})(\cos 15.0°) = -98.5\ \text{N}$$

Chapter 5 continued

$F_{7x} = 0.0\text{ N}$

$F_{7y} = -26.0\text{ N}$

$F_{8x} = (77.0\text{ N})(\sin 22.0°) = 28.8\text{ N}$

$F_{8y} = -(77.0\text{ N})(\cos 22.0°) = -71.4\text{ N}$

$F_{9x} = (51.0\text{ N})(\sin 33.0°) = 27.8\text{ N}$

$F_{9y} = -(51.0\text{ N})(\cos 33.0°) = -42.8\text{ N}$

$F_{10x} = (82.0\text{ N})(\cos 5.0°) = 81.7\text{ N}$

$F_{10y} = -(82.0\text{ N})(\sin 5.0°) = -7.15\text{ N}$

$$F_x = \sum_{i=1}^{10} F_{ix}$$
$$= 44.38\text{ N}$$

$$F_y = \sum_{i=1}^{10} F_{iy}$$
$$= -107.65\text{ N}$$

$$F_R = \sqrt{(F_x)^2 + (F_y)^2}$$
$$= \sqrt{(44.38\text{ N})^2 + (-107.65\text{ N})^2}$$
$$= 116\text{ N}$$

$$\theta_R = \tan^{-1}\left(\frac{F_y}{F_x}\right)$$
$$= \tan^{-1}\left(\frac{-107.65\text{ N}}{44.38\text{ N}}\right)$$
$$= -67.6°$$

$F_{\text{equilibrant}} = 116\text{ N at } 112.4°$

$= 116\text{ N at } 22.4°\text{ W of N}$