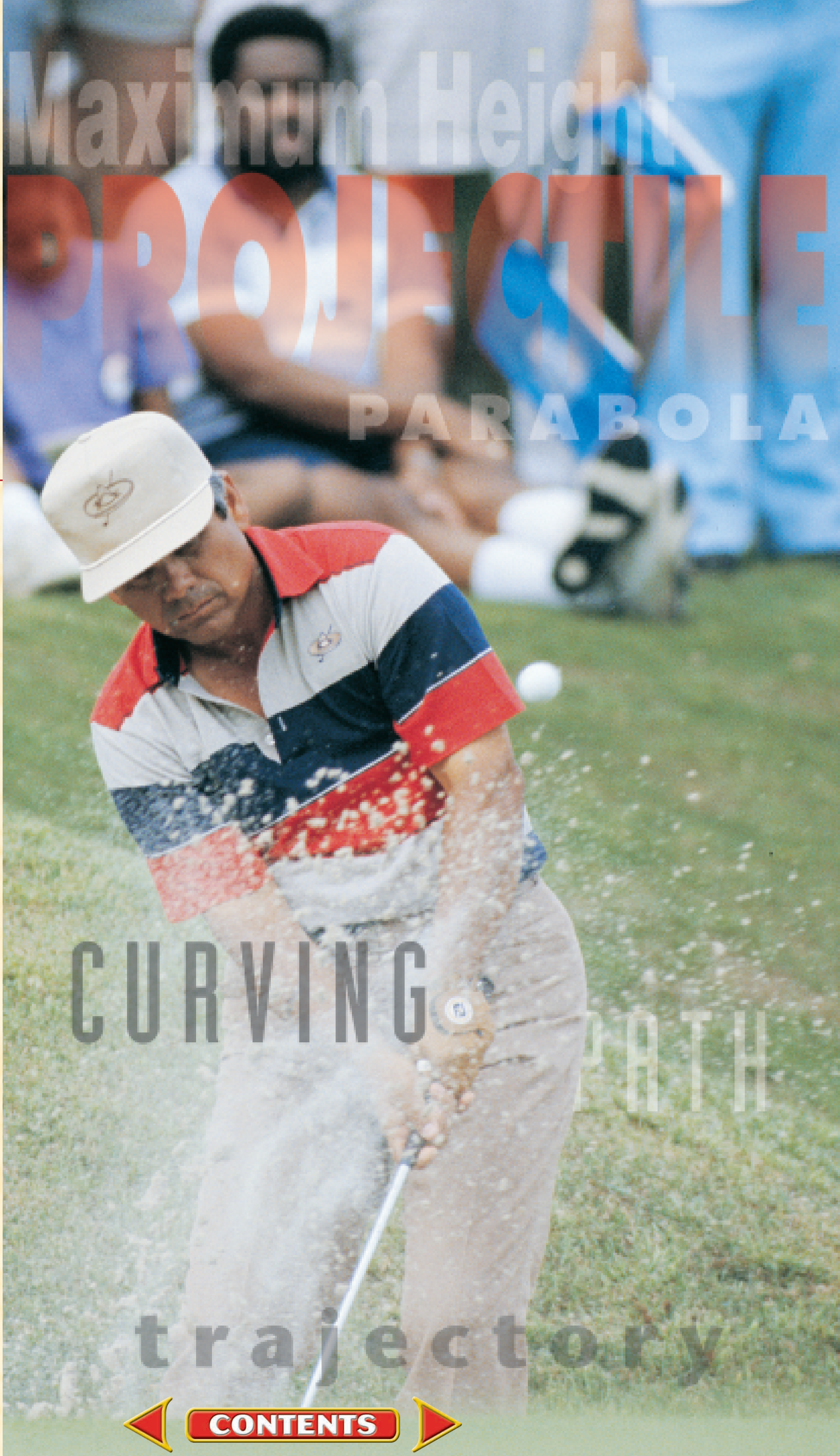
Sand Blast

More than just the golf ball was put into motion by Lee Trevino's swing. The upward swing of the golf club propels the sand along an upwardly curving path. How would you describe the motion of the sand?

Look at the text on page 158 for the answer.



CHAPTER 7 Forces and Motion in Two Dimensions

If you could observe the movement of a golf ball as it leaves a sand trap, you would see that it follows a path similar to that of the sand. All kinds of objects move through the air along a similar path. The flights of baseballs, basketballs, arrows, bullets, and rockets all follow similar courses. The path is a curve that moves upward for a distance, then turns, and moves downward. You may be familiar with this curve, called a parabola, from your math class.

Think back to your study of Newton's laws.

- An object that is at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero.
- The acceleration of an object is directly proportional to the net force on it and inversely proportional to its mass.
- Forces between two objects always come in pairs.

Can Newton's laws of motion describe the motion of the sand and the golf ball? Both the sand and the golf ball move in a horizontal direction, as well as a vertical direction, making the description more complex.

However, with your knowledge of vectors and Newton's laws, you will soon be able to predict how high the golf ball will rise above the ground, how long it will remain in the air, how fast it will be moving the instant before it hits the ground, and where it will land. The very same principles are used by scientists to determine how high a rocket will soar, how far it will travel, and where it will land. You will find that the same equations you used for solving motion problems in one dimension can be applied to the solution of problems in two dimensions.

WHAT YOU'LL LEARN

- You will use Newton's laws and your knowledge of vectors to analyze motion in two dimensions.
- You will solve problems dealing with projectile and circular motion, and demonstrate your understanding of acceleration and torque.

WHY IT'S IMPORTANT

- The worldwide space program depends fundamentally on the application of Newton's laws to the launching of space vehicles and their guidance into stable orbits.

PHYSICS Online

To find out more about forces in two dimensions, visit the Glencoe Science Web site at **science.glencoe.com**

CLICK HERE

CONTENTS

7.1 Forces in Two Dimensions

OBJECTIVES

- **Determine** the force that produces equilibrium when three forces act on an object.
- **Analyze** the motion of an object on an inclined plane with and without friction.

You already know one example of forces in two dimensions. When friction acts between two surfaces, you must take into account both the friction force that is parallel to the surface, and the normal force perpendicular to it. So far, you have considered only motion along the surface. Now you will use your skill in adding vectors to analyze two situations in which the forces on an object are at angles other than 90°.

Equilibrium and the Equilibrant

An object is in equilibrium when the net force on it is zero. When in equilibrium, an object is motionless or moves with constant velocity. According to Newton's laws, the object will not be accelerated because there is no net force on it. You have already added two force vectors to find that the net force is zero. Equilibrium also occurs when the resultant of three or more forces equals a net force of zero.

Figure 7-1a shows three forces exerted on a point object. What is the sum of ***A***, ***B***, and ***C***, or what is the net force on the object? Remember that vectors may be moved if you don't change their direction (angle) or length. **Figure 7-1b** shows the addition of the three forces, ***A***, ***B***, and ***C***. Note that the three vectors form a closed triangle. There is no net force so the sum is zero and the object is in equilibrium.

Suppose two forces are exerted on an object and the sum is not zero. How could you find a third force that, when added to the other two, would add up to zero? Such a force, one that produces equilibrium, is called the **equilibrant.**

To find the equilibrant, first find the sum of the two forces exerted on the object. This sum is the resultant force, ***R***, the single force that would produce the same effect as the two individual forces added together. The equilibrant is thus a force with a magnitude equal to the resultant, but in the opposite direction. **Figure 7-2** illustrates this procedure for two vectors, but any number of vectors could be used.

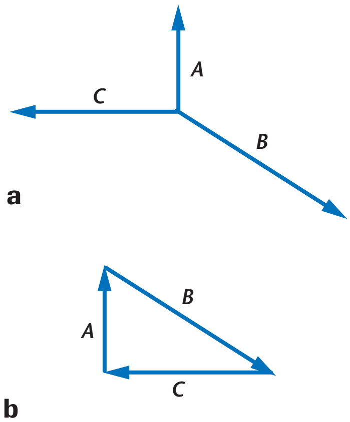


FIGURE 7–1 An object is in equilibrium when all the forces on it add up to zero.

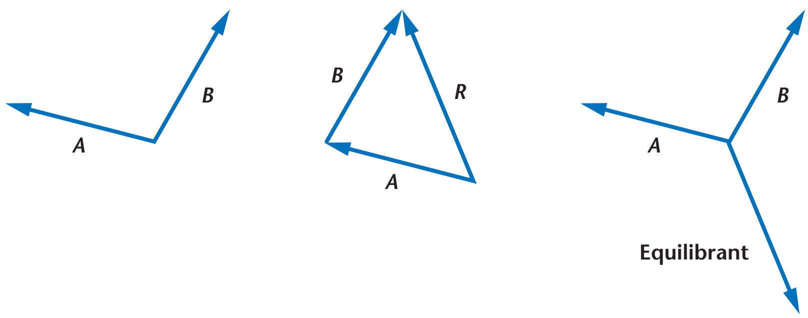
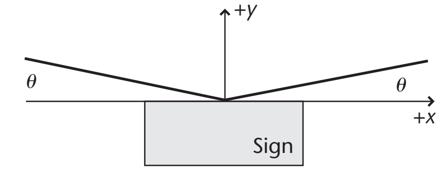


FIGURE 7–2 The equilibrant is the same magnitude as the resultant but opposite in direction.

Example Problem

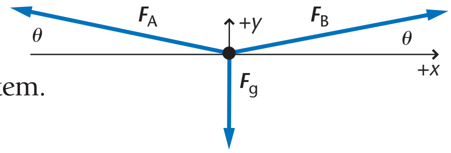
Creating Equilibrium

A 168-N sign is supported in a motionless position by two ropes that each make 22.5° angles with the horizontal. What is the tension in the ropes?



Sketch the Problem

- Draw the ropes at equal angles and establish a coordinate system.
- Draw the free-body diagram with the dot at the origin.



Calculate Your Answer

Known:

$\theta = 22.5°$

$F_g = 168$ N

Unknown:

$F_A = ?$

$F_B = ?$

Strategy:

The sum of the two rope forces and the downward weight force is zero. Write equations for equilibrium in the *x*-direction and in the *y*-direction.

Calculations:

$F_{net,x} = 0$, thus $-F_{Ax} + F_{Bx} = 0$

$-F_A\cos\theta + F_B\cos\theta = 0$

so, $F_A = F_B$

$F_{net,y} = 0$, thus $F_{Ay} + F_{By} - F_g = 0$

$F_A \sin\theta + F_B \sin\theta - F_g = 0$

$2F_A \sin\theta = F_g$

$$F_A = \frac{F_g}{2\sin 22.5°} = \frac{168\text{ N}}{2 \times 0.383}$$

$F_A = 2.20 \times 10^2$ N

Check Your Answer

- Is the unit correct? N is the only unit in the calculation.
- Do the signs make sense? Yes, the tension forces are in the positive *y*-direction.
- Is the magnitude realistic? It is greater than the weight of the sign, which is reasonable, because only the small vertical components of $\boldsymbol{F}_A$ and $\boldsymbol{F}_B$ are available to balance the sign's weight.

Practice Problems

1. The sign from the preceding example problem is now hung by ropes that each make an angle of 42° with the horizontal. What force does each rope exert?
2. An 8.0-N weight has one horizontal rope exerting a force of 6.0 N on it.
   a. What are the magnitude and direction of the resultant force on the weight?
   b. What force (magnitude and direction) is needed to put the weight into equilibrium?

Continued on next page

Math Handbook

To review **trigonometric ratios,** see the Math Handbook, Appendix A, page 745.

FIGURE 7–3 If the *x*-axis is chosen to be parallel to the road, $\boldsymbol{F}_{\mathrm{f}}$ and $\boldsymbol{F}_{\mathrm{N}}$ are parallel to the *x*- and *y*-axes respectively, but $\boldsymbol{F}_{\mathrm{g}}$ points in the direction of the center of Earth as shown.

3. Two ropes pull on a ring. One exerts a 62-N force at 30.0°, the other a 62-N force at 60.0°
   a. What is the net force on the ring?
   b. What are the magnitude and direction of the force that would cause the ring to be in equilibrium?
4. Two forces are exerted on an object. A 36-N force acts at 225° and a 48-N force acts at 315°. What are the magnitude and direction of the equilibrant?

Motion Along an Inclined Plane

The gravitational force is directed toward the center of Earth, in the downward direction. But if a vehicle such as the one in **Figure 7–3** is on a hill, there is a normal force perpendicular to the hill, and the forces of friction that will either speed up or slow down the car are parallel to the hill. What strategy should you use to find the net force that causes the car to accelerate? The most important decision to be made is what coordinate system to use.

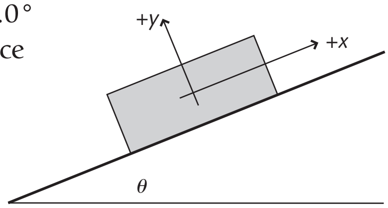
Because the direction of the vehicle's velocity and acceleration will be parallel to the hill, one axis, usually the *x*-axis, should be in that direction. The *y*-axis is, as usual, perpendicular to the *x*-axis and perpendicular, or normal, to the surface of the hill.

For such a coordinate system, the normal and friction forces are both in the direction of a coordinate axis, but the weight is not. In most problems, you'll have to find the *x*- and *y*-components of this force.

Example Problem

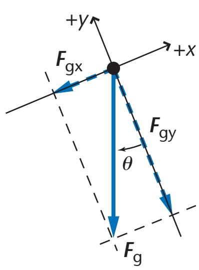
Components of Weight for an Object on an Incline

A trunk weighing 562 N is resting on a plane inclined 30.0° above the horizontal. Find the components of the weight force parallel and perpendicular to the plane.



Sketch the Problem

- Include a coordinate system with the positive *x*-axis pointing uphill.
- Draw the free-body diagram showing $\boldsymbol{F}_{\mathrm{g}}$, the components $\boldsymbol{F}_{\mathrm{gx}}$ and $\boldsymbol{F}_{\mathrm{gy}}$, and the angle θ.



Calculate Your Answer

Known:	**Unknown:**
$F_{\mathrm{g}} = 562\ \mathrm{N}$	$F_{\mathrm{gx}} = ?$
$\theta = 30.0°$	$F_{\mathrm{gy}} = ?$

Strategy:

F_{gx} and F_{gy} are negative because they point in directions opposite to the positive axes.

Vector components are scalars, but they have signs indicating their direction relative to the axes.

Calculations:

$F_{gx} = -F_g \sin\theta$

$F_{gx} = -(562\text{ N}) \sin 30.0° = -281\text{ N}$

$F_{gy} = -F_g \cos\theta$

$F_{gy} = -(562\text{ N}) \cos 30.0° = -487\text{ N}$

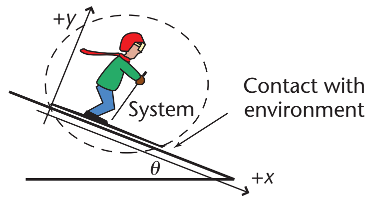
Check Your Answer

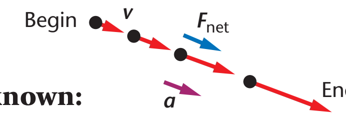
- Are the units correct? Only newtons appears in the calculations.
- Do the signs make sense? Yes, the components point in directions opposite to the positive axes.
- Are the magnitudes realistic? The values are less than F_g.

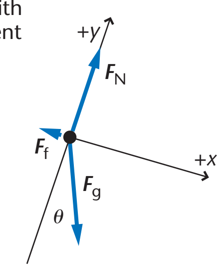
Example Problem

Skiing Downhill

A 62-kg person on skis is going down a hill sloped at 37°. The coefficient of kinetic friction between the skis and the snow is 0.15. How fast is the skier going 5.0 s after starting from rest?







Sketch the Problem

- Circle the system and identify points of contact.
- Establish a coordinate system.
- Draw a free-body diagram.
- Draw a motion diagram showing increasing $\boldsymbol{v}$, and both $\boldsymbol{a}$ and $\boldsymbol{F}_{net}$ in the $+x$ direction.

Calculate Your Answer

Known:

$m = 62\text{ kg}$ $\mu_k = 0.15$ $t = 5.0\text{ s}$

$\theta = 37°$ $v_0 = 0.0\text{ m/s}$

Unknown:

$a = ?$

$v = ?$

Strategy:

There is no acceleration in the y-direction, so the net force is zero. Solve for F_N.

Apply Newton's second law of motion to relate acceleration to the downhill force. Solve for a by substituting $\mu_k F_N$ for F_f.

Use velocity-acceleration relation to find speed.

Calculations:

y-direction:

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

$F_N - F_{gy} = 0$

$F_N = F_{gy} = mg\cos\theta$

x-direction:

$F_{net,x} = ma_x = ma$

$F_{gx} - F_f = ma$

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

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

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

$a = 9.80\text{ m/s}^2(\sin 37° - 0.15\cos 37°) = 4.7\text{ m/s}^2$

$v = v_0 + at$

$v = 0 + (4.7\text{ m/s}^2)(5.0\text{s}) = 24\text{ m/s}$

Continued on next page

Check Your Answer

- Are the units correct? Performing algebra on the units verifies that v is in m/s and a is in m/s^2.
- Do the signs make sense? Yes, because v and a are both in the $+x$ direction.
- Are the magnitudes reasonable? The velocity is fast, over 50 mph, but 37° is a steep incline, and the friction with snow is not large.

Practice Problems

5. Consider the trunk on the incline in the Example Problem.
  a. Calculate the magnitude of the acceleration.
  b. After 4.00 s, how fast would the trunk be moving?

6. For the Example Problem *Skiing Downhill*, find the x- and y-components of the weight of the skier going downhill.

7. If the skier were on a 30° downhill slope, what would be the magnitude of the acceleration?

8. After the skier on the 37° hill had been moving for 5.0 s, the friction of the snow suddenly increased making the net force on the skier zero. What is the new coefficient of friction? How fast would the skier now be going after skiing for 5.0 s?

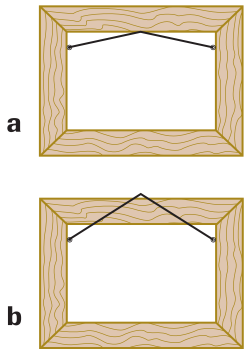


FIGURE 7–4

7.1 Section Review

1. You are to hang a painting using two lengths of wire. The wires will break if the force on them is too great. Should the painting look like **Figure 7–4a** or **b**? Explain.

2. 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.

3. The skier in the Example Problem finishes the downhill run, turns, and continues to slide uphill for a time. Draw the free-body diagram for the uphill slide. In which direction is the net force?

4. **Critical Thinking** Can the coefficient of friction ever have a value such that a skier could slide uphill at a constant velocity? Explain.

Projectile Motion

7.2

A projectile can be a football, a bullet, or a drop of water. No matter what the object is, after a **projectile** has been given an initial thrust, ignoring air resistance, it moves through the air only under the force of gravity. Its path through space is called its **trajectory.** If you know the force of the initial thrust on a projectile, you can figure out its trajectory.

OBJECTIVES

- **Recognize** that the vertical and horizontal motions of a projectile are independent.
- **Relate** the height, time in the air, and initial vertical velocity of a projectile using its vertical motion, then **determine** the range.
- **Explain** how the shape of the trajectory of a moving object depends upon the frame of reference from which it is observed.

Independence of Motion in Two Dimensions

After a golf ball leaves the golf club, what forces are exerted on the ball? If you ignore air resistance, there are no other contact forces on the golf ball. There is only the long-range force of gravity in the downward direction. How does this affect the ball's motion?

Figure 7–5 shows the trajectories of two golf balls. One was dropped, and the other was given an initial horizontal velocity of 2.0 m/s. What is similar about the two paths?

Look at the vertical positions of the balls. At each flash, the heights of the two balls are the same. Because the change in vertical position is the same for both balls, their average vertical velocities during each interval are the same. The increasingly large distances traveled vertically by the two balls, from one time interval to the next, show that the balls are accelerated downward by the force of gravity. Notice that the horizontal motion of the launched ball doesn't affect its vertical motion. A projectile launched horizontally has no initial vertical velocity. Therefore, its vertical motion is like that of a dropped object.

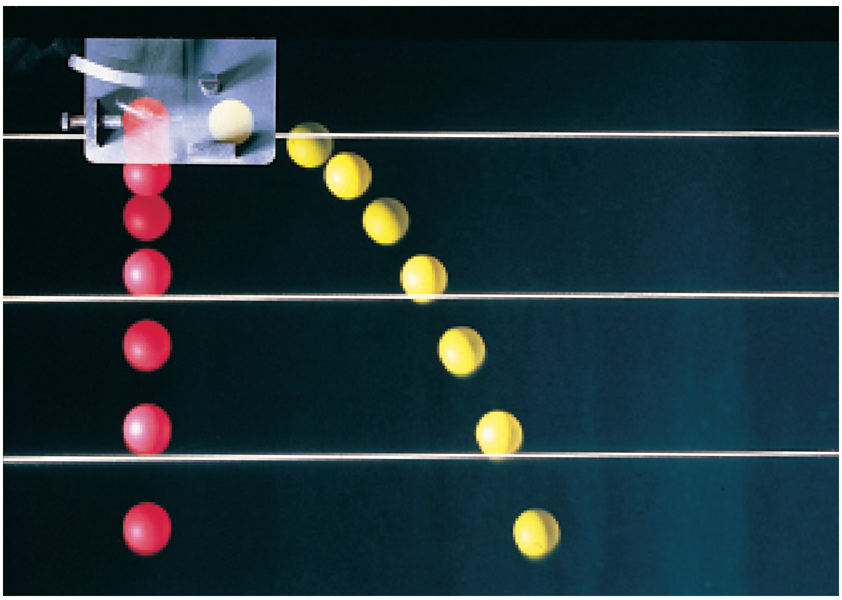


FIGURE 7–5 The ball on the right was given a horizontal velocity; the ball on the left was dropped. The balls were photographed using a strobe light that flashed 30 times each second. Note that the vertical positions of the two balls are the same at each flash of the strobe light.

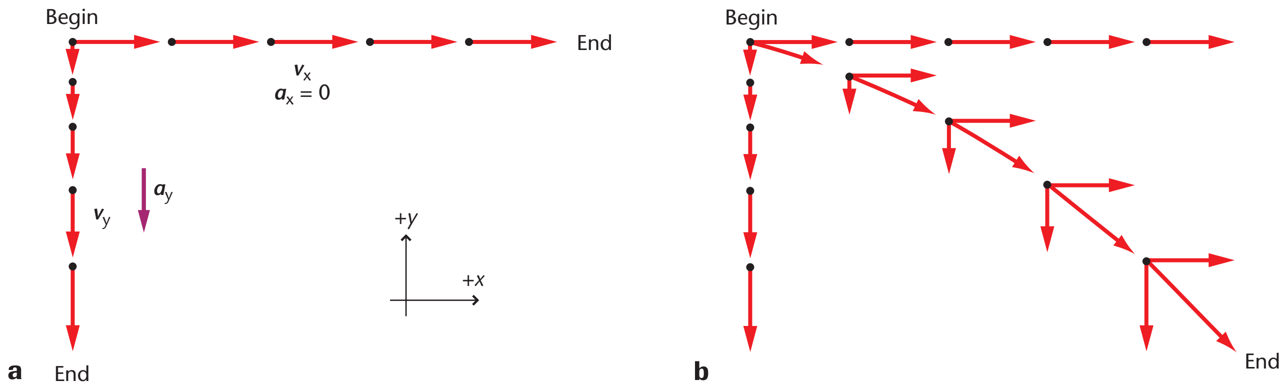


FIGURE 7–6 When the horizontal and vertical components of the ball's velocity are combined in **b,** the resultant vectors are tangent to a parabola.

Separate motion diagrams for the horizontal and vertical motions are shown in **Figure 7–6a.** The vertical motion diagram represents the motion of the dropped ball. The horizontal motion diagram shows the constant velocity in the *x*-direction of the launched ball.

In **Figure 7–6b,** the horizontal and vertical components are added to form the velocity vector for the projectile. You can see how the combination of constant horizontal velocity and uniform vertical acceleration produces a trajectory that has the shape of the mathematical curve called the parabola.

Pocket Lab

Over the Edge

Obtain two balls, one twice the mass of the other. Predict which ball will hit the floor first when you roll them over the surface of a table with the same speed and let them roll off. Predict which ball will hit the floor farther from the table. Explain your predictions.

Analyze and Conclude
Does the mass of the ball affect its motion? Is mass a factor in any of the equations for projectile motion?

Problem Solving Strategies

Projectile Motion

1. Motion in two dimensions can be solved by breaking the problem into two interconnected one-dimensional problems. For instance, projectile motion can be divided into a vertical motion problem and a horizontal motion problem.
2. The vertical motion of a projectile is exactly that of an object dropped or thrown straight up or down. A gravitational force acts on the object accelerating it by an amount ***g.*** Review Section 5.4 on Free Fall to refresh your problem solving skills for vertical motion.
3. Analyzing the horizontal motion of a projectile is the same as solving a constant velocity problem. A projectile has no thrust force and air drag is neglected, consequently there are no forces acting in the horizontal direction and thus, no acceleration, $a = 0$. To solve, use the same methods you learned in Section 5.1, Uniform Motion.
4. Vertical motion and horizontal motion are connected through the variable time. The time from the launch of the projectile to the time it hits the target is the same for vertical motion and for horizontal motion. Therefore, solving for time in one of the dimensions, vertical or horizontal, automatically gives you the time for the other dimension.

CONTENTS

Projectiles Launched Horizontally

A projectile launched horizontally has no initial vertical velocity. Therefore, its vertical motion is identical to that of a dropped object. The downward velocity increases regularly because of the acceleration due to gravity.

Example Problem

A Projectile Launched Horizontally

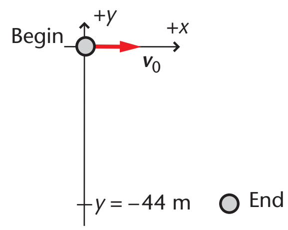
A stone is thrown horizontally at 15 m/s from the top of a cliff 44 m high.

a. How far from the base of the cliff does the stone hit the ground?

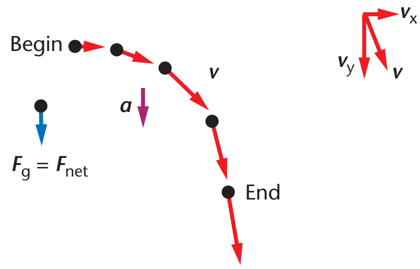
b. How fast is it moving the instant before it hits the ground?

Sketch the Problem

- Establish a coordinate system with the launch point labeled "begin"at the origin.
- The point to be labeled "end" is at $y = -44$ m; x is unknown.
- Draw a motion diagram for the trajectory showing the downward acceleration and net force.



Calculate Your Answer



Known:	**Unknown:**
$x_0 = 0$	x when $y = -44$ m
$v_{x0} = 15$ m/s	v at that time
$y_0 = 0$	
$v_{y0} = 0$	
$a = -g$	

Strategy:

a. Use the equation for the y-position to get and solve an equation for the time the stone is in the air.

b. Velocity is a vector quantity; find the two components, then the magnitude, or speed. Use the Pythagorean relationship to find v.

Calculations:

y-direction:

$v_y = -gt$

$y = y_0 - 1/2gt^2$

$$t = \sqrt{\frac{-2(y - y_0)}{g}} = \sqrt{\frac{-2y}{g}}$$

$$= \sqrt{\frac{-2(-44\text{ m})}{9.80\text{ m/s}^2}} = 3.0\text{ s}$$

x-direction:

$x = x_0 + v_{x0}t$

$x = (15\text{ m/s})(3.0\text{ s}) = 45$ m from the base

$v_y = -gt$

$v_y = -(9.80\text{ m/s}^2)(3.0\text{ s}) = -29$ m/s

$$v = \sqrt{v_x^2 + v_y^2}$$

$$v = \sqrt{(15\text{ m/s})^2 + (-29\text{ m/s})^2} = 33\text{ m/s}$$

Continued on next page

Check Your Answer

- Are the units correct? Performing algebra on the units verifies that x is in m and v is in m/s.
- Do the signs make sense? Both x and v should be positive.
- Are the magnitudes realistic? The projectile is in the air 3.0 s. The horizontal distance is about the same magnitude as the vertical distance. The final velocity is larger than the initial horizontal velocity but of the same order of magnitude.

BIOLOGY CONNECTION

Launch Angle Have you ever watched a frog jump? The launch angle of a frog's jump is approximately 45°. Jumping at this angle is innate behavior that helps the frog cover maximum distance on flat ground.

Practice Problems

9. A stone is thrown horizontally at a speed of 5.0 m/s from the top of a cliff 78.4 m high.
  a. How long does it take the stone to reach the bottom of the cliff?
  b. How far from the base of the cliff does the stone hit the ground?
  c. What are the horizontal and vertical components of the stone's velocity just before it hits the ground?

10. How would the three answers to problem 9 change if
  a. the stone were thrown with twice the horizontal speed?
  b. the stone were thrown with the same speed, but the cliff were twice as high?

11. A steel ball rolls with constant velocity across a tabletop 0.950 m high. It rolls off and hits the ground 0.352 m from the edge of the table. How fast was the ball rolling?

Sand Blast

Answers question from page 148.

Projectiles Launched at an Angle

When a projectile is launched at an angle, the initial velocity has a vertical component as well as a horizontal component. If the object is launched upward, then it rises with slowing speed, reaches the top of its path, and descends with increasing speed. This is what happens to the sand in the photo at the beginning of this chapter. **Figure 7–7a** shows the separate vertical and horizontal motion diagrams for the trajectory. The coordinate system is chosen with $+x$ horizontal and $+y$ vertical. Note the symmetry. At each point in the vertical direction, the velocity of the object as it is moving up has the same magnitude as when it is moving down, but the directions of the two velocities are opposite.

Figure 7–7b defines two quantities associated with the trajectory. One is the **maximum height,** which is the height of the projectile when the vertical velocity is zero and the projectile has only its horizontal velocity component. The other quantity depicted is the **range,** R, which is the horizontal distance the projectile travels. Not shown is the **flight time,** which is the time the projectile is in the air. In the game of football, flight time is usually called hang time.

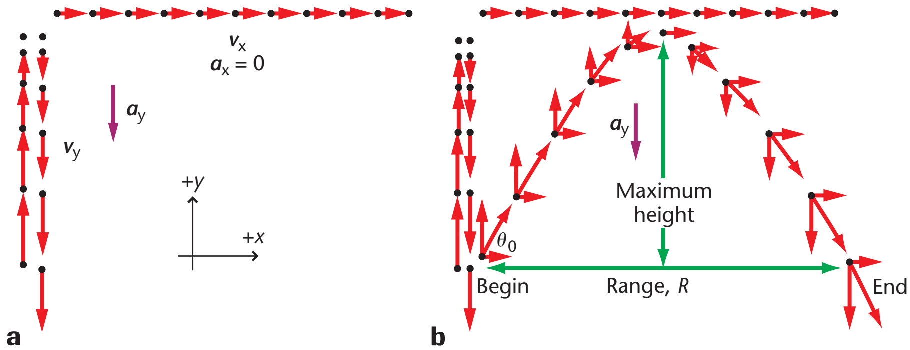
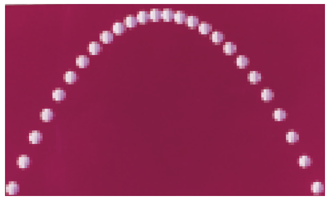


FIGURE 7–7 The vector sum of $\boldsymbol{v}_x$ and $\boldsymbol{v}_y$, at each position, points in the direction of the flight.

Example Problem

The Flight of a Ball

The ball in the strobe photo was launched with an initial velocity of 4.47 m/s at an angle of 66° above the horizontal.



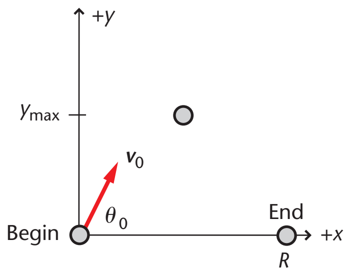
a. What was the maximum height the ball attained?

b. How long did it take the ball to return to the launching height?

c. What was its range?

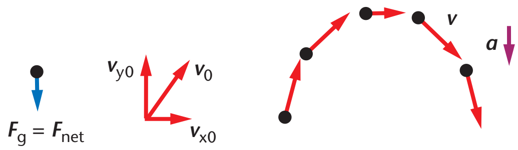
Sketch the Problem

- Establish a coordinate system. One choice for the initial position of the ball is at the origin.
- Show the positions of the ball at maximum height and at the end of the flight.
- Draw a motion diagram showing the $\boldsymbol{v}$, $\boldsymbol{a}$, and $\boldsymbol{F}_{net}$.



Calculate Your Answer

Known:	**Unknown:**
$x_0 = 0$	y, when $v_y = 0$
$y_0 = 0$	$t = ?$
$v_0 = 4.47$ m/s	x, when $y = 0$
$\theta_0 = 66°$	
$a = -g$	



Strategy:

a. Write the equations for the initial velocity components, the velocity components at time t, and the position in both directions. The vertical velocity is zero when the ball reaches maximum height. Solve the velocity equation for the time of maximum height. Substitute this time into the vertical-position equation to find the height.

b. Solve the vertical-position equation for the time of the end of the flight, when $y = 0$.

c. Substitute that time into the equation for horizontal distance to get the range.

Continued on next page

Calculations:

y-direction:

$v_{y0} = v_0 \sin \theta_0$

$v_{y0} = (4.47 \text{ m/s})\sin 66°$

$v_{y0} = 4.08 \text{ m/s}$

$v_y = v_{y0} - gt$

$y = y_0 + v_{y0}t - 1/2gt^2$

x-direction:

$v_{x0} = v_0 \cos \theta_0$

$v_x = v_{x0}$

$x = x_0 + v_{x0}t$

a. When $v_y = 0$, $t = v_{y0}/g$

$t = (4.08 \text{ m/s})/(9.80 \text{ m/s}^2)$

$t = 0.416 \text{ s}$

$y_{max} = v_{y0}t - 1/2gt^2$

$y_{max} = (4.08 \text{ m/s})(0.416 \text{ s}) - 1/2(9.80 \text{ m/s}^2)(0.416 \text{ s})^2 = 0.849 \text{ m}$

b. At landing, $y = 0$

$0 = 0 + v_{y0}t - 1/2gt^2$

$t = 2v_{y0}/g$

$= 2(4.08 \text{ m/s})/(9.80 \text{ m/s}^2)$

$= 0.833 \text{ s}$

c. At this time, $x = R$, the range

$R = v_{x0}t$

$= (4.47 \text{ m/s})(\cos 66°)(0.833 \text{ s})$

$= 1.51 \text{ m}$

Check Your Answer

- Are the units correct? Performing algebra on the units verifies that time is in s, velocity is in m/s, and distance is in m.
- Do the signs make sense? All should be positive.
- Are the magnitudes realistic? Compare them with those in the photo. The calculated flight time is 0.833 s. At 30 flashes/s, this would be 25 flashes, and 25 are visible. The scale of the photo is unknown, as it is, but the ratio of the maximum height to range is (0.849 m)/(1.51 m), or 0.562/1, in the photo.

Practice Problems

12. A player kicks a football from ground level with an initial velocity of 27.0 m/s, 30.0° above the horizontal, as shown in **Figure 7–8.** Find the ball's hang time, range, and maximum height. Assume air resistance is negligible.

13. The player then kicks the ball with the same speed, but at 60.0° from the horizontal. What is the ball's hang time, range, and maximum height?

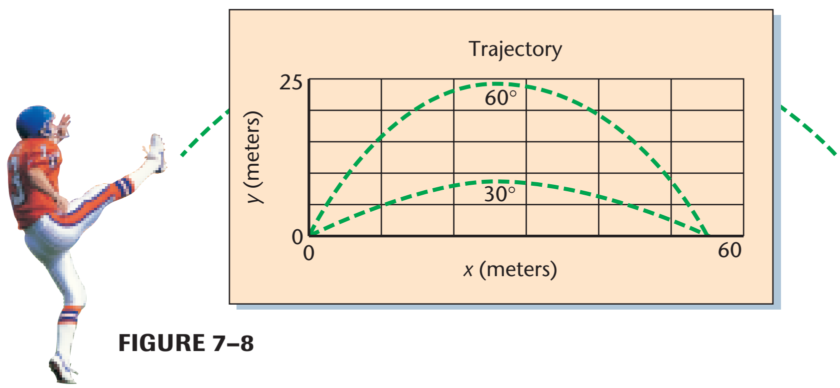


FIGURE 7–8

Trajectories Depend upon the Frame of Reference

Suppose you toss a ball up and catch it while riding in a bus. To you, the ball would seem to go straight up and down. But what would an observer on the sidewalk see? The observer would see the ball leave your hand, rise up, and return to your hand, but because the bus would be moving, your hand also would be moving. The bus, your hand, and the ball would all have the same horizontal velocity. Thus, the trajectory of the ball would be similar to that of the ball in the previous Example Problem. Although you and the observer would disagree on the horizontal motion of the ball, you would agree on the vertical motion. You would both find the vertical velocity, displacement, and time in the air to be the same.

Effects of Air Resistance

The force of air, or air resistance, has been ignored in the analysis of the motion of a projectile, but that doesn't mean that air resistance is unimportant. It's true that for some projectiles, the effect is very small. But for others, the effects are large and very complex. For example, the shape and pattern of dimples on a golf ball have been carefully designed to maximize its range. In baseball, the spin of the ball creates forces that can deflect the ball up, down, or to either side. If the spin is very slow, as in a knuckleball, the interaction of the laces with the air results in a very unpredictable trajectory. Rings, disks, and boomerangs generate enough upward force, or lift, from the air that they seem to float through the air.

Pocket Lab

Where the Ball Bounces

Place a golf ball in your hand and extend your arm sideways so that the ball is at shoulder height. Drop the ball and have a lab partner start a stopwatch when the ball strikes the floor and stop it the next time the ball strikes the floor. Predict where the ball will hit when you walk at a steady speed and drop the ball. Would the ball take the same time to bounce? Try it.

Analyze and Conclude Where does the ball hit? Does it take more time?

7.2 Section Review

1. Two baseballs are pitched horizontally from the same height but at different speeds. The faster ball crosses home plate within the strike zone, but the slower ball is below the batter's knees. Why does the faster ball not fall as far as the slower one?
2. An ice cube slides without friction across a table at constant velocity. It slides off and lands on the floor. Draw free-body diagrams of the cube at two points while it is on the table and at two points when it is in the air.
3. For the same ice cube, draw motion diagrams showing the velocity and acceleration of the ice cube both when it is on the table and in the air.
4. **Critical Thinking** Suppose an object is thrown with the same initial velocity and direction on Earth and on the moon, where g is 1/6 as large as it is on Earth. Will the following quantities change? If so, will they become larger or smaller?
   a. v_x
   b. time of flight
   c. maximum height
   d. range

The Softball Throw

Problem

What advice can you give the center fielder on your softball team on how to throw the ball to the catcher at home plate so that it gets there before the runner?

Hypothesis

Formulate a hypothesis using what you know about the horizontal and vertical motion of a projectile to advise the center fielder about how to throw the ball. Consider the factors that affect the time it will take for the ball to arrive at home plate.

Possible Materials

stopwatch
softball
football field or large open area with premeasured distances

Plan the Experiment

1. As a group, determine the variable(s) you want to measure. How do horizontal and vertical velocity affect the range?
2. Who will time the throws? How will you determine the range? Will the range be a constant or a variable? How many trials will you complete?
3. Construct a table or spreadsheet for recording data from all the trial throws. Record all your calculations in the table.
4. **Check the Plan** Make sure your teacher approves your final plan before you proceed.

Data and Observations

	Range (R) (meters)	Time (t) (seconds)	Horizontal Velocity (v_x) (m/s)	Vertical Velocity (v_y) (m/s)	Initial Velocity (v_0) (m/s)
Trial 1					
Trial 2					

Analyze and Conclude

1. **Analyzing Data** How can your data be used to determine values for v_x and v_y?
2. **Diagramming the Results** Draw a diagram that shows the relationship between R, v_x, v_y, and v_0.
3. **Calculating Results** Determine the initial values for v_x and v_y. Use the Pythagorean theorem to find the value of the initial velocity, v_0, for each trial.
4. **Analyzing Data** Was the range of each person's throw about the same? Did the initial velocity of the throws vary?
5. **Analyzing Data** Analyze and evaluate the trends in your data. How did the angle at which the ball was thrown affect the range? The time?
6. **Checking Your Hypothesis** Should the center fielder throw the ball to the catcher at home plate with a larger v_x or v_y?

Apply

1. Infer from the trends in your data why a kickoff in a football game might be made at a different angle than a punt.

Circular Motion 7.3

Can an object be accelerated if its speed remains constant? Yes, because velocity is a vector quantity; just as a change in speed means that there is a change in velocity, so too does a change in direction indicate a change in velocity. Consider an object moving in a circle at constant speed. **Figure 7–9** shows a person riding on a merry-go-round moving at a steady speed. That person is in **uniform circular motion.** So is a sock among the clothes spinning in a washing machine. Uniform circular motion is the movement of an object or point mass at constant speed around a circle with a fixed radius.

OBJECTIVES

- **Explain** the acceleration of an object moving in a circle at constant speed.
- **Describe** how centripetal acceleration depends upon the object's speed and the radius of the circle.
- **Recognize** the direction of the force that causes centripetal acceleration.
- **Explain** how the rate of circular motion is changed by exerting torque on it.

Describing Circular Motion

An object's position relative to the center of the circle is given by the position vector ***r***, shown in **Figure 7–10a.** As the object moves around the circle, the length of the position vector doesn't change, but its direction does. To find the object's velocity, you need to find its displacement vector over a time interval. The change in position, or the object's displacement, is represented by $\Delta \boldsymbol{r}$. **Figure 7–10b** shows two position vectors, $\boldsymbol{r}_1$ at the beginning of a time interval, and $\boldsymbol{r}_2$ at the end of the time interval. In the vector diagram, $\boldsymbol{r}_1$ and $\boldsymbol{r}_2$ are subtracted to give the resultant $\Delta \boldsymbol{r}$, the displacement during the time interval. Recall that a moving object's average velocity is $\Delta \boldsymbol{d}/\Delta t$, so for an object in circular motion $\bar{\boldsymbol{v}} = \Delta \boldsymbol{r}/\Delta t$. The velocity vector has the same direction as the displacement but a different length. You can see in **Figure 7–10a** that the velocity is at right angles to the position vector and tangent to its circular path. As the velocity vector moves around the circle, its direction changes but its length remains the same.

What is the direction of the object's acceleration? **Figure 7–11a** shows the velocity vectors $\boldsymbol{v}_1$ and $\boldsymbol{v}_2$ at the beginning and end of a time interval. The difference in the two vectors, $\Delta \boldsymbol{v}$, is found by subtracting the vectors, as shown in **Figure 7–11b.** The acceleration, $\boldsymbol{a} = \Delta \boldsymbol{v}/\Delta t$, is in the same direction as $\Delta \boldsymbol{v}$, that is, toward the center of the circle. As the

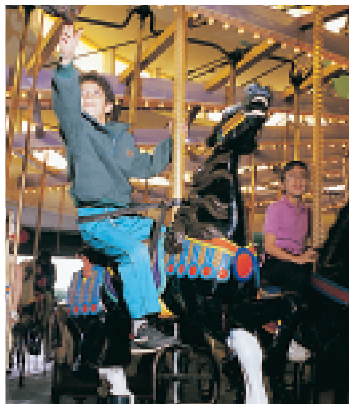


FIGURE 7–9 The rider is in uniform circular motion.

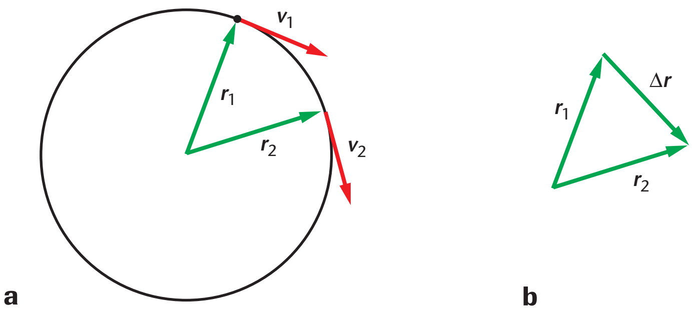
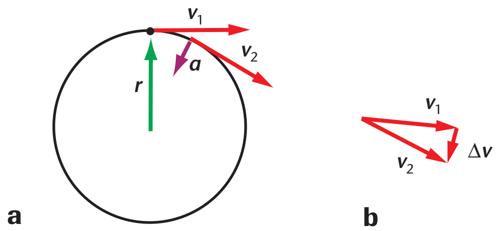


FIGURE 7–10 The displacement, Δr, of an object in circular motion, divided by the time interval in which the displacement occurs, is the object's average velocity.

FIGURE 7–11 The direction of the change in velocity is toward the center of the circle and so the acceleration vector also points to the center of the circle.



Pocket Lab

Target Practice

Tie a 1.0-m length of string onto a one-hole rubber stopper. *Note:* Everyone in the classroom should be wearing goggles. Swing the stopper around your head in a horizontal circle. Release the string from your hand when the string is lined up with a spot on the wall. Repeat the experiment until the stopper flies toward the spot on the wall.

Analyze and Conclude Did the stopper travel toward the spot on the wall? What does this indicate about the direction of the velocity compared to the orientation of the string?

FIGURE 7–12 When the thrower lets go, the hammer moves in a straight line tangent to the point of release.

object moves around the circle, the direction of the acceleration vector changes, but its length remains the same. The acceleration of an object in uniform circular motion always points in toward the center of the circle, and for that reason it is called center-seeking or **centripetal acceleration.**

Centripetal Acceleration

What is the magnitude of the centripetal acceleration? Compare the triangle made from the position vectors in **Figure 7–10b** with the triangle made by the velocity vectors in **Figure 7–11b.** The angle between $\boldsymbol{r}_1$ and $\boldsymbol{r}_2$ is the same as that between $\boldsymbol{v}_1$ and $\boldsymbol{v}_2$. Therefore, the two triangles formed by subtracting the two sets of vectors are similar triangles, and the ratios of the lengths of two corresponding sides are equal. Thus, $\Delta r/r = \Delta v/v$. The equation is not changed if both sides are divided by Δt.

$$\frac{\Delta r}{r\Delta t} = \frac{\Delta v}{v\Delta t}$$

But $v = \Delta r/\Delta t$ and $a = \Delta v/\Delta t$. Substituting these expressions, the following equation is obtained.

$$\frac{v}{r} = \frac{a}{v}$$

Solve this equation for the acceleration and give it the special symbol a_c for centripetal acceleration.

Centripetal Acceleration (using velocity) $a_c = \dfrac{v^2}{r}$

Centripetal acceleration always points toward the center of the circular motion.

How can you measure the speed of an object moving in a circle? One way is to measure its period, T, the time needed for the object to make a complete revolution. During this time, it travels a distance equal to the circumference of the circle, $2\pi r$. The object's speed, then, is represented by $v = 2\pi r/T$.

If this expression is substituted for v in the equation for centripetal acceleration, the following equation is obtained.

$$a_c = \frac{(2\pi r/T)^2}{r} = \frac{4\pi^2 r}{T^2}$$

CONTENTS

What causes an object to have a centripetal acceleration? There must be a net force on the object in the direction of the acceleration, toward the center of the circle. For Earth circling the sun, the force is the sun's gravitational force on Earth. When a hammer thrower swings the hammer, as in **Figure 7-12,** the force is the tension in the chain attached to the massive ball. When a car turns around a bend, the inward force is the frictional force of the road on the tires. Sometimes, the necessary net force that causes centripetal acceleration is called a **centripetal force.**

This, however, can be misleading. To understand centripetal acceleration, you must identify the agent of the contact or long-range force that causes the acceleration. Then you can write Newton's second law for the component in the direction of the acceleration in the following way.

Newton's Second Law $F_{net} = ma_c$

$$F_{net} = \frac{mv^2}{r}$$

$$F_{net} = m\left(\frac{4\pi^2 r}{T^2}\right)$$

When solving circular motion problems, choose a coordinate system in the usual way, with one axis in the direction of the acceleration. But remember that for circular motion, the direction of the acceleration is always toward the center of the circle. Rather than labeling this axis x or y, call it c, for centripetal. The other axis, which, as always, must be perpendicular to the first, is in the direction of the velocity, tangent to the circle. It is labeled *tang* for tangential. The next Example Problem shows the labeled coordinate axes.

In the case of the hammer thrower, the purpose of circular motion is to give the hammer great speed. In what direction does the ball fly when the thrower releases the chain? Once the contact force of the chain is gone, there is no force accelerating the ball toward the center of a circle, so the hammer flies off in the direction of its velocity, which is tangent to the circle. After release, only gravitational force acts on the ball, and it moves like any other projectile.

HELP WANTED

CIVIL ENGINEER

Federal agencies need civil engineers to fill positions as inspectors of roads, bridges, airports, and water/waste systems. An analytical mind, a bachelor's degree in civil engineering, and excellent communication skills (oral and written) are required.

Apply your generalized training or any specialized experience you may have to a position that can be an important step in your professional career. For information contact:

American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, VA 20191-4400

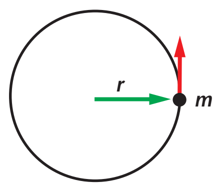
Example Problem

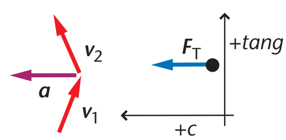
Uniform Circular Motion

A 13-g rubber stopper is attached to a 0.93-m string. The stopper is swung in a horizontal circle, making one revolution in 1.18 s. Find the tension force exerted by the string on the stopper.

Sketch the Problem

- In your sketch, include the radius and the direction of motion.
- Establish a coordinate system labeled tang and c. Show that the directions of a and FT are parallel to c.





Continued on next page

Calculate Your Answer

Known:	Unknown:	Calculations:
$m = 13$ g	$F_T = ?$	$a_c = 4\pi^2 r/T^2$
$r = 0.93$ m		$a_c = 4(3.14)^2(0.93 \text{ m})/(1.18 \text{ s})^2 = 26 \text{ m/s}^2$
$T = 1.18$ s		$F_T = ma = (0.013 \text{ kg})(26 \text{ m/s}^2) = 0.34$ N

Check Your Answer

- Are the units correct? Performing algebra on the units verifies that a is in m/s^2 and F is in N.
- Do the signs make sense? The signs should all be positive.
- Are the magnitudes realistic? The force is almost three times the weight of the stopper, but the acceleration is almost three times that of gravity, so the answer is reasonable.

Practice Problems

14. Consider the following changes to the Example Problem.
  a. The mass is doubled, but all other quantities remain the same. What would be the effect on the velocity, acceleration, and force?
  b. The radius is doubled, but all other quantities remain the same. What would be the effect on the velocity, acceleration, and force?
  c. The period of revolution is half as large, but all other quantities remain the same. What would be the effect on the velocity, acceleration, and force?

15. A runner moving at a speed of 8.8 m/s rounds a bend with a radius of 25 m.
  a. What is the centripetal acceleration of the runner?
  b. What agent exerts the force on the runner?

16. Racing on a flat track, a car going 32 m/s rounds a curve 56 m in radius.
  a. What is the car's centripetal acceleration?
  b. What minimum coefficient of static friction between the tires and road would be needed for the car to round the curve without slipping?

Pocket Lab

Falling Sideways

Will a ball dropped straight down hit the floor before or after a ball that is tossed directly sideways at the same instant? Try it. You may need to repeat the experiment several times before you are sure of your results. Toss the ball sideways and not up or down.

Analyze and Conclude
Compare the downward force on each ball. Compare the distance that each ball falls in the vertical direction.

A Nonexistent Force

If a car in which you are riding stops suddenly, you will be thrown forward into your seat belt. Is there a forward force on you? No, because according to Newton's first law, you will continue moving with the same velocity unless there is a net force acting on you. The seat belt applies the force that accelerates you to a stop. Similarly, if a car makes a sharp

CONTENTS

Physics & Technology

Looping Roller Coasters

How do roller coaster cars stay on the tracks when they are upside down? The answer involves the speed of the cars, the shape of the loop, and the laws of physics that govern circular motion.

Roller coaster cars try to move in a straight line, but they are prevented from doing so by the tracks which force them along a curving path. Wheels and tracks will remain in contact as long as the forward motion of the cars is great enough, and the curvature of the tracks is tight enough.

The curving tracks and the forward motion of the cars combine to create centripetal acceleration directed toward the center of the curving path. The magnitude of the acceleration is inversely proportional to the radius of the loop. The smaller the radius, the greater the acceleration. Forces associated with centripetal acceleration are measured in units of g. The greater the g force experienced by a roller coaster rider, the heavier the rider feels. The smaller the g force, the lighter the rider feels. Most of the thrills of roller coaster riding result from constantly changing g forces.

Most roller coaster loops are shaped like a teardrop. The upper arc of the loop has a smaller radius of curvature than the lower arc and so the acceleration at the top is greater than at the bottom. The higher acceleration at the top helps maintain contact between the wheels and the track. If the high acceleration were maintained everywhere in the loop, the riders would experience higher g forces than most people would find comfortable.

Thinking Critically Describe how physics influences the careers of roller coaster designers. Which of Newton's laws of motion explains why the roller coaster car wheels and the tracks stay in contact at the top of the loop? Explain.

left turn, a passenger on the right side may be thrown against the right door. Is there an outward force on the passenger? **Figure 7–13** shows such a car turning to the left as viewed from above. A passenger would continue to move straight ahead if it were not for the force of the door acting in the direction of the acceleration, that is, toward the center of the circle. So there is no outward force on the passenger. The so-called centrifugal, or outward force, is a fictitious, nonexistent force. Newton's laws, which are used in nonaccelerating frames of reference, can explain motion in both straight lines and circles.

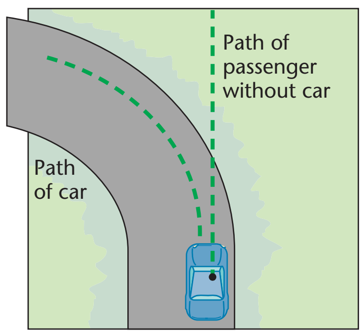


FIGURE 7–13 The passenger would move forward in a straight line if the car did not exert an inward force.

Changing Circular Motion: Torque

In relation to uniform circular motion, you have considered objects such as a person on a merry-go-round and a sock spinning in a washing machine. These can be considered point masses. Now, consider rigid rotating objects. A **rigid rotating object** is a mass that rotates around its own axis. For example, the merry-go-round itself is a rotating object turning on a central axis. A spinning washing machine tub and a revolving

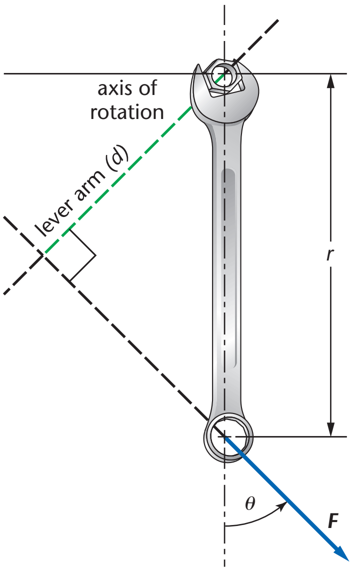


FIGURE 7–14 Torque is the product of the lever arm and the applied force.

door are rotating objects. An ordinary door is also a rigid rotating object, although it usually rotates only through a portion of a circle.

How do you make a door rotate about its axis of rotation, which is its hinges? You exert a force. But where? Pushing on the hinges has little effect, but pushing as far from them as possible starts the door rotating easily. In what direction should you push? Perpendicular to the door is effective; pushing toward the hinges is not.

To open the door most easily, you push at a distance from the hinges (axis of rotation) and in a direction perpendicular to the door. This information about distance and direction is combined in one concept called the **lever arm.** The lever arm in **Figure 7–14** is defined as the perpendicular distance from the axis of rotation to a line along which the force acts. The product of the force and the lever arm is called **torque.** The greater the torque, the greater the change in rotational motion. Thus, torque plays the role of force for rotational motion.

Torque can stop, start, or change the direction of rotation. To stop the door from opening, or to close it, you exert a force in the opposite direction. To start the lug nuts moving when you are changing a tire, you use a lug wrench to apply torque. Sometimes additional length is added to these wrenches to increase the torque.

A seesaw is another example of torque. If a seesaw is balanced, there is no net torque. How, then, do two children, one small, the other large, manage to balance? Each child must exert a torque of the same magnitude but opposite in direction. Because torque is the product of the lever arm, d, and the weight of a child, mg, the smaller child must sit farther from the axis of rotation, or the pivot point. The seesaw will balance when $m_A g d_A = m_B g d_B$. This concept is the basis for the design of triple beam balances which you may have used in your science courses.

7.3 Section Review

1. What is the direction of the force that acts on the clothes in the spin cycle of a washing machine? What exerts the force?
2. You are sitting on the back seat of a car that is going around a curve to the right. Sketch motion and free-body diagrams to answer the following questions.
   - **a.** What is the direction of your acceleration?
   - **b.** What is the direction of the net force acting on you?
   - **c.** What exerts that force?
3. **Critical Thinking** Thanks to Earth's daily rotation, you always move with uniform circular motion. What supplies the force that accelerates you? How does this motion affect your apparent weight?

CHAPTER 7 REVIEW

Key Terms

7.1
- equilibrant

7.2
- projectile
- trajectory
- maximum height
- range
- flight time

7.3
- uniform circular motion
- centripetal acceleration
- centripetal force
- rigid rotating object
- lever arm
- torque

Summary

7.1 Forces in Two Dimensions

- The force that must be exerted on an object in order to put it in equilibrium is called the equilibrant.
- The equilibrant is found by finding the sum of all forces on an object, then applying a force with the same magnitude but opposite direction.
- An object on an inclined plane has a component of the force of gravity in a direction parallel to the plane; the component can accelerate the object down the plane.

7.2 Projectile Motion

- The vertical and horizontal motions of a projectile are independent.
- Projectile problems are solved by first using the vertical motion to relate height, time in the air, and initial vertical velocity. Then the range, the distance traveled horizontally, is found.
- The range of a projectile depends upon the acceleration due to gravity and upon both components of the initial velocity.

7.3 Circular Motion

- An object moving in a circle at constant speed is accelerating toward the center of the circle (centripetal acceleration).
- Centripetal acceleration depends directly on the square of the object's speed and inversely on the radius of the circle.
- A force must be exerted in the centripetal direction to cause that acceleration.
- The torque that changes the velocity of circular motion is proportional to the force applied and the lever arm.

Key Equations

7.3

$$a_c = \frac{v^2}{r} \qquad F_{net} = ma_c$$

Reviewing Concepts

Section 7.1

1. Explain how you would set up a coordinate system for motion on a hill.
2. If your textbook is in equilibrium, what can you say about the forces acting on it?
3. Can an object in equilibrium be moving? Explain.
4. 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. You are asked to analyze the motion of a book placed on a sloping table.
   - **a.** Describe the best coordinate system for analyzing the motion.
   - **b.** How are the components of the weight of the book related to the angle of the table?
6. For the book on the sloping table, describe what happens to the component of the weight force along the table and the friction force on the book as you increase the angle the table makes with the horizontal.

a. Which components of force(s) increase when the angle increases?
b. Which components of force(s) decrease?

Section 7.2

7. Consider the trajectory of the ball shown in **Figure 7–15.**
   a. Where is the magnitude of the vertical-velocity component greatest?
   b. Where is the magnitude of the horizontal-velocity component largest?
   c. Where is the vertical velocity smallest?
   d. Where is the acceleration smallest?

FIGURE 7–15

8. A student is playing with a radio-controlled race car on the balcony of a sixth-floor apartment. An accidental turn sends the car through the railing and over the edge of the balcony. Does the time it takes the car to fall depend upon the speed it had when it left the balcony?
9. An airplane pilot flying at constant velocity and altitude drops a heavy crate. Ignoring air resistance, where will the plane be relative to the crate when the crate hits the ground? Draw the path of the crate as seen from an observer on the ground.

Section 7.3

10. Can you go around a curve
    a. with zero acceleration? Explain
    b. with constant acceleration? Explain.
11. To obtain uniform circular motion, how must the net force depend on the speed of the moving object?
12. If you whirl a yo-yo about your head in a horizontal circle, in what direction must a force act on the yo-yo? What exerts the force?
13. In general, a long-handled wrench removes a stuck bolt more easily than a short-handled wrench does. Explain.

Applying Concepts

14. If you are pushing a lawnmower across the grass, can you increase the horizontal component of the force you exert on the mower without increasing the magnitude of the force? Explain.
15. 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?
16. 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 slack out of the net to make the top almost completely horizontal. Why is this true?
17. The weight of a book on an inclined plane can be resolved into two vector components, one along the plane, the other perpendicular to it.
    a. At what angle are the components equal?
    b. At what angle is the parallel component equal to zero?
    c. At what angle is the parallel component equal to the weight?
18. Review projectile motion. Analyze how the horizontal motion can be uniform, while the vertical motion is accelerated. Critique projectile motion equations presented in this book when drag due to air is taken into consideration.
19. A batter hits a pop-up straight up over home plate at an initial velocity of 20 m/s. The ball is caught by the catcher at the same height that it was hit. At what velocity does the ball land in the catcher's mitt? Neglect air resistance.
20. In baseball, a fastball takes about 1/2 s to reach the plate. Assuming that such a pitch is thrown horizontally, compare the distance the ball falls in the first 1/4 s with the distance it falls in the second 1/4 s.
21. You throw a rock horizontally. In a second throw, you gave it even more speed.
    a. How would the time it took to hit the ground be affected? Neglect air resistance.
    b. How would the increased speed affect the distance from the edge of the cliff to where the stone hit the ground?
22. A zoologist standing on a cliff aims a tranquilizer gun at a monkey hanging from a distant tree branch. The barrel of the gun is horizontal. Just as the zoologist pulls the trigger, the monkey lets go and begins to fall. Will the dart hit the monkey? Neglect air resistance.

23. A quarterback threw a football at 24 m/s at a 45° angle. If it took the ball 3.0 s to reach the top of its path, how long was it in the air?

24. You are working on improving your performance in the long jump and believe that the information in this chapter can help. Does the height you reach make any difference? What does influence the length of your jump?

25. Imagine that you are sitting in a car tossing a ball straight up into the air.
a. If the car is moving at constant velocity, will the ball land in front of, behind, or in your hand?
b. If the car rounds a curve at constant speed, where will the ball land?

26. You swing one yo-yo around your head in a horizontal circle, then you swing another one with twice the mass, but you don't change the length of the string or the period. How do the tensions in the strings differ?

27. The curves on a race track are banked to make it easier for cars to go around the curves at high speed. Draw a free-body diagram of a car on a banked curve. From the motion diagram, find the direction of the acceleration.
a. What exerts the force in the direction of the acceleration?
b. Can you have such a force without friction?

28. Which is easier for turning a stuck screw, a screwdriver with a large diameter or one with a long handle?

29. Some doors have a doorknob in the center rather than close to the edge. Do these doors require more or less force to produce the same torque as a standard door of the same width and mass?

Problems

Section 7.1

30. An object in equilibrium has three forces exerted on it. A 33-N force acts at 90° from the *x*-axis and a 44-N force acts at 60°. What are the magnitude and direction of the third force?

31. A street lamp weighs 150 N. It is supported by two wires that form an angle of 120° with each other. The tensions in the wires are equal.
a. What is the tension in each wire?
b. If the angle between the wires is reduced to 90.0°, what is the tension in each wire?

32. 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.

33. Five forces act on an object: (1) 60.0 N at 90°, (2) 40.0 N at 0°, (3) 80.0 N.0 at 270°, (4) 40.0 N at 180°, and (5) 50.0 N at 60° What are the magnitude and direction of a sixth force that would produce equilibrium?

34. 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 7–16.** Cable B is horizontal and attached to an adjoining building. What is the tension in cable B?

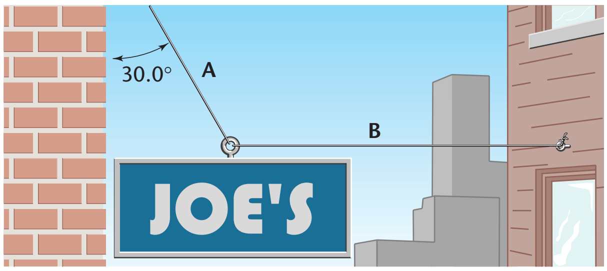


FIGURE 7–16

35. You pull your 18-kg suitcase at constant speed on a horizontal floor by exerting a 43-N force on the handle, which makes an angle θ with the horizontal. The force of friction on the suitcase is 27 N.
a. What angle does the handle make with the horizontal?
b. What is the normal force on the suitcase?
c. What is the coefficient of friction?

36. You push a 325-N trunk up a 20.0° inclined plane at a constant velocity by exerting a 211-N force parallel to the plane's surface.
a. What is the component of the trunk's weight parallel to the plane?
b. What is the sum of all forces parallel to the plane's surface?
c. What are the magnitude and direction of the friction force?
d. What is the coefficient of friction?

37. What force must be exerted on the trunk in problem 36 so that it would slide down the plane with a constant velocity? In which direction should the force be exerted?

38. A 2.5-kg block slides down a 25° inclined plane with constant acceleration. The block starts from rest at the top. At the bottom, its velocity is 0.65 m/s. The incline is 1.6 m long.
   a. What is the acceleration of the block?
   b. What is the coefficient of friction?
   c. Does the result of either **a** or **b** depend on the mass of the block?

Section 7.2

39. You accidentally throw your car keys horizontally at 8.0 m/s from a cliff 64 m high. How far from the base of the cliff should you look for the keys?

40. A toy car runs off the edge of a table that is 1.225 m high. If the car lands 0.400 m from the base of the table,
   a. how long did it take the car to fall?
   b. how fast was the car going on the table?

41. You take a running leap off a high-diving platform. You were running at 2.8 m/s and hit the water 2.6 s later. How high was the platform, and how far from the edge of the platform did you hit the water? Neglect air resistance.

42. An arrow is shot at 30.0° above the horizontal. Its velocity is 49 m/s and it hits the target.
   a. What is the maximum height the arrow will attain?
   b. The target is at the height from which the arrow was shot. How far away is it?

43. A pitched ball is hit by a batter at a 45° angle and just clears the outfield fence, 98 m away. Assume that the fence is at the same height as the pitch and find the velocity of the ball when it left the bat. Neglect air resistance.

44. The two baseballs in **Figure 7–17** were hit with the same speed, 25 m/s. Draw separate graphs of y versus t and x versus t for each ball.

45. An airplane traveling 1001 m above the ocean at 125 km/h is to drop a box of supplies to shipwrecked victims below.
   a. How many seconds before being directly overhead should the box be dropped?

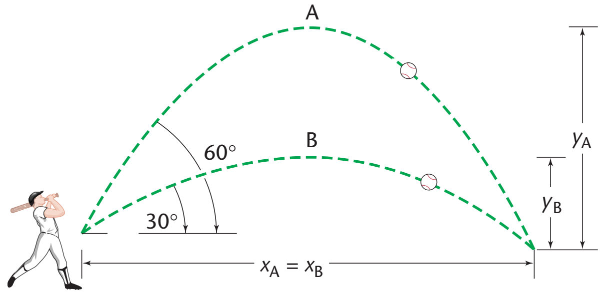


FIGURE 7–17

   b. What is the horizontal distance between the plane and the victims when the box is dropped?

46. Divers in Acapulco dive from a cliff that is 61 m high. If the rocks below the cliff extend outward for 23 m, what is the minimum horizontal velocity a diver must have to clear the rocks?

47. A dart player throws a dart horizontally at a speed of 12.4 m/s. The dart hits the board 0.32 m below the height from which it was thrown. How far away is the player from the board?

48. A basketball player tries to make a half-court jump shot, releasing the ball at the height of the basket. Assuming that the ball is launched at 51.0°, 14.0 m from the basket, what speed must the player give the ball?

Section 7.3

49. A 615-kg racing car completes one lap in 14.3 s around a circular track with a radius of 50.0 m. The car moves at constant speed.
   a. What is the acceleration of the car?
   b. What force must the track exert on the tires to produce this acceleration?

50. An athlete whirls in a 7.00-kg hammer tied to the end of a 1.3-m chain in a horizontal circle. The hammer makes one revolution in 1.0 s.
   a. What is the centripetal acceleration of the hammer?
   b. What is the tension in the chain?

51. A coin is placed on a vinyl stereo record making 33 1/3 revolutions per minute.
   a. In what direction is the acceleration of the coin?
   b. Find the magnitude of the acceleration when the coin is placed 5.0, 10.0, and 15.0 cm from the center of the record.

c. What force accelerates the coin?

d. In which of the three radii listed in **b** would the coin be most likely to fly off? Why?

52. According to the *Guinness Book of World Records* (1990) the highest rotary speed ever attained was 2010 m/s (4500 mph). The rotating rod was 15.3 cm (6 in.) long. Assume that the speed quoted is that of the end of the rod.

a. What is the centripetal acceleration of the end of the rod?

b. If you were to attach a 1.0-g object to the end of the rod, what force would be needed to hold it on the rod?

53. Early skeptics of the idea of a rotating Earth said that the fast spin of Earth would throw people at the equator into space. The radius of Earth is about 6.38×10^3 km. Show why this objection is wrong by calculating

a. the speed of a 97-kg person at the equator.

b. the force needed to accelerate the person in the circle.

c. the weight of the person.

d. the normal force of Earth on the person, that is, the person's apparent weight.

54. The carnival ride shown in **Figure 7–18** has a 2.0-m radius and rotates once each 0.90 s.

a. Find the speed of a rider.

b. Find the centripetal acceleration of a rider.

c. What produces this acceleration?

d. When the floor drops down, riders are held up by friction. Draw motion and free-body diagrams of the situation.

e. What coefficient of static friction is needed to keep the riders from slipping?

55. Friction provides the force needed for a car to travel around a flat, circular race track. What is the maximum speed at which a car can safely travel if the radius of the track is 80.0 m and the coefficient of friction is 0.40?

FIGURE 7–18

Extra Practice For more practice solving problems, go to Extra Practice Problems, Appendix B.

Critical Thinking Problems

56. A ball on a light string moves in a vertical circle. Analyze and describe the motion of this system. Be sure to consider the effects of gravity and tension. Is this system in uniform circular motion? Explain your answer.

57. Consider a roller coaster loop. Are the cars traveling through the loop in uniform circular motion? Explain. What about the ride in **Figure 7–18?**

58. A 3-point jump shot is released 2.2 m above the ground, 6.02 m from the basket, which is 3.05 m high. For launch angles of 30° and 60°, find the speed needed to make the basket.

59. For which angle in problem 58 is it more important that the player get the speed right? To explore this question, vary the speed at each angle by 5% and find the change in the range of the throw.

Going Further

Applying Computers and Calculators Ken Griffey, Jr. hits a belt-high (1.0 m) fastball down the left-field line in Fenway Park. The ball is hit with an initial velocity of 42.0 m/s at 26°. The left-field wall in Fenway Park is 96.0 m from home plate at the foul pole and is 14 m high. Write the equation for the height of the ball, y, as a function of its distance from home plate, x. Use a computer or graphing calculator to plot the path of the ball. Trace along the path to find how high above the ground the ball is at the wall. Is it a home run?

a. What is the minimum speed at which the ball could be hit and clear the wall?

b. If the initial velocity of a ball is 42.0 m/s, for what range of angles will the ball go over the wall?