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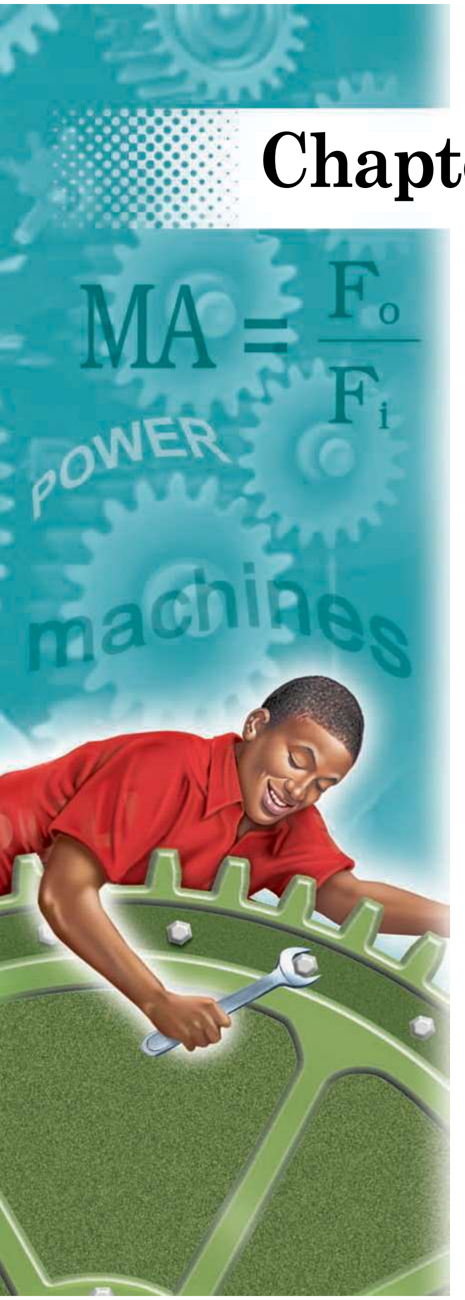

Chapter 6

Systems in Motion

There is a recurring theme in cartoon film clips. One character is racing toward another, perhaps to cause some harm. The other character turns a road sign the wrong way, sending the chaser over a cliff. What happens next in the cartoon sequence? The chaser runs off the cliff, keeps running straight out over the canyon until it sees that there is no ground directly below, and at that moment, the chaser begins falling. Perhaps the character holds up a "help" sign before hitting the canyon floor and sending up a dust cloud.

The cartoon gag provides lots of laughs, but the physics is all wrong! Do you know what the correct path of the cartoon character would be when it runs off a cliff? Projectiles, bicycle wheels, planets in orbit, and satellites are just some of the interesting systems of motion you will study in this chapter. By the way, the true path of the unfortunate cartoon character is a curve, and the name given to this curved path is trajectory. The only thing more miraculous than defying physics during the fall is that the cartoon character survives every incredible disaster, only to return to the screen more determined than ever!

Key Questions

- ✓ How should you hit a golf ball so it goes as far as possible?
- ✓ Why does a skater spin faster when she pulls her arms in toward her body?
- ✓ Why are you thrown to the outside edge of the car seat when the car makes a sharp turn?
- ✓ How do satellites continuously move around Earth without crashing into it?

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6.1 Motion in Two Dimensions

The systems we have learned about so far included only forces and motions that acted in straight lines. Of course, real-life objects do not only go in straight lines; their motion includes turns and curves. To describe a curve you need at least two dimensions (x and y). In this chapter you will learn how to apply the laws of motion to curves. Curves *always* imply acceleration and you will see that the same laws we already know still apply, but with *vectors*.

Vocabulary

displacement, projectile, trajectory, parabola, range

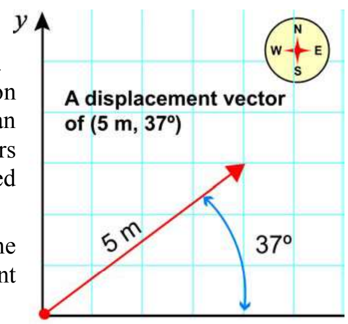
Objectives

- ✓ Define projectile.
- ✓ Recognize the independence of a projectile's horizontal and vertical velocities.
- ✓ Describe the path of a projectile.
- ✓ Calculate a projectile's horizontal or vertical distance or speed.
- ✓ Explain how a projectile's launch angle affects its range.

Displacement

The displacement vector

A vector that shows a change in position is called a **displacement** vector. Displacement is the distance and direction between the starting and ending points of an object's motion. If you walk five meters east, your displacement can be represented by a five-centimeter arrow pointing east.



Writing the displacement vector

Displacement is always a vector. Like the force vector, you can write a displacement vector three ways.

- With a vector diagram
- As a magnitude-angle pair
- As an x-y pair

Telling direction

For example, the diagram at right shows a displacement of five meters at 37 degrees. This vector can be abbreviated (5 m, 37°). Angles are measured from the positive x-axis in a counterclockwise direction, as shown in Figure 6.1.

A displacement vector's direction is often given using words. Directional words include left, right, up, down, north, south, east, and west. Which coordinates you use depends on the problem you are trying to solve. Sometimes you will make x horizontal and y vertical. Other times, you should choose x to be east and y to be north.

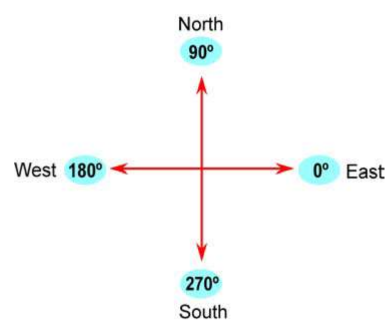


Figure 6.1: *Angles can be used to represent compass directions.*

Solving displacement problems

Displacement vectors for moving objects

When working in a straight line, you can tell the position of an object with just one distance. If the motion is curved, it takes at least two distances to tell where an object is. The motion of a basketball is described by both the *x*- and *y*-coordinates of each point along the basketball's path. The basketball's position at any time is represented by its displacement vector (Figure 6.2). To describe the motion of the basketball we need to describe how the displacement vector changes over time.

Adding displacement vectors

Displacement vectors can be added just like force (or any) vectors. To add displacements graphically, draw them to scale with each subsequent vector drawn at the end of the previous vector. The resultant vector represents the displacement for the entire trip.

For most problems, however, it is much easier to find the *x*- and *y*-components of a displacement vector. The *x*-component is the distance in the *x* direction. The *y*-component is the distance in the *y* direction.

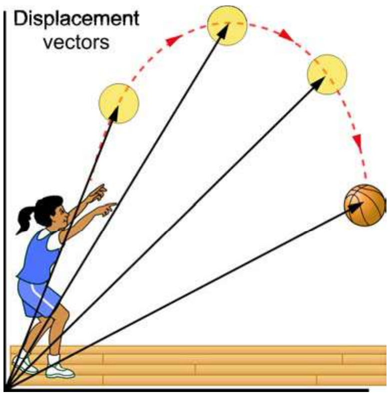


Figure 6.2: *When you throw a ball, it follows a curved path. The position of the ball is described by its displacement vector.*

Vector addition

A mouse walks 5 meters north and 12 meters west. Use a scaled drawing to find the mouse's displacement, and then use the Pythagorean theorem to check your work.

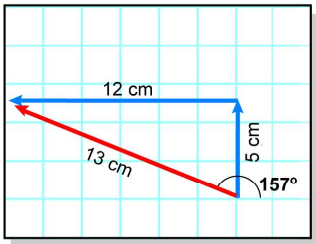
1. Looking for: You are asked for the displacement.

2. Given: You are given the distances and directions the mouse walks.

3. Relationships: Pythagorean theorem $a^2 + b^2 = c^2$

4. Solution: Make a drawing with a scale of 1 cm = 1 meter.
Pythagorean theorem:
$5^2 + 12^2 = c^2$ $169 = c^2$ $13 = c$
The mouse walks 13 meters at 157 °.

Scale: 1 cm = 1 meter



Your turn...

a. Your school is 5 kilometers south and 5 kilometers east of your house. Use a scaled drawing to find your displacement as you ride from home to school. Then check your answer with the Pythagorean theorem. **Answer:** 7.1 km southeast (or 315°)

b. A helicopter flies straight up for 100 meters and then horizontally for 100 meters. What is the displacement vector of the helicopter relative to where it started? Give your answer in x-y form assuming upward is "y." **Answer:** (100, 100) m

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The velocity vector

Velocity and force vectors Velocity is speed with direction, so velocity is a vector. As objects move in curved paths, their velocity vectors change because the direction of motion changes. The symbol $\vec{v}$ is used to represent velocity. The arrow tells you it is the velocity vector, not the speed.

What the velocity vector means Suppose a ball is launched at five meters per second at an angle of 37 degrees (Figure 6.3). At the moment after launch the velocity vector for the ball in polar coordinates is written as $\vec{v}$ = (5 m/sec, 37°). In *x*-*y* components, the same velocity vector is written as $\vec{v}$ = (4, 3) m/sec. Both representations tell you exactly how fast and in what direction the ball is moving at that moment. The *x*-component tells you how fast the ball is moving in the *x*-direction. The *y*-component tells you how fast it is moving in the *y*-direction.

Speed is the magnitude of the velocity vector The *magnitude* of the velocity vector is the *speed* of the object. The ball in the example is moving with a speed of 5 m/sec. Speed is represented by a lower case *v without* the arrow. When a velocity vector is represented graphically, the length is proportional to speed, not distance. For example, the graph in Figure 6.3 shows the velocity vector $\vec{v}$ = (4, 3) m/sec as an arrow on a graph.

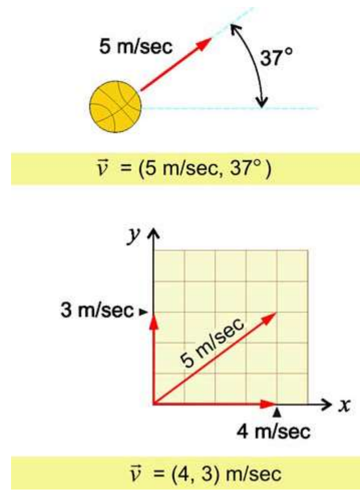

Figure 6.3: *Different ways to write a velocity vector. The length of a velocity vector is proportional to speed.*

Velocity vector

A train moves at a speed of 100 km/hr heading east. What is its velocity vector in *x*-*y* form?

1. Looking for: You are asked for the velocity vector.

2. Given: You are given speed in km/hr and direction. The train is moving east.

3. Relationships: *x*-velocity is east and *y*-velocity is north

4. Solution: $\vec{v}$ = (100,0) km/hr Note: The y-component is 0 because the train has 0 velocity heading north.

a. A race car is moving with a velocity vector of (50, 50) m/sec. Sketch the velocity vector and calculate the car's velocity. You can use the Pythagorean theorem to check your sketch. **Answer:** (70.7 m/sec, 45°)

b. A hiker walks 1,000 meters north and 5,000 meters east in 2 hours. Calculate the hiker's average velocity vector in *x*-*y* form. **Answer**: (2500, 500) m/hr or (2.5, 0.5) km/hr; [the polar coordinates are (2.6 km/hr, 11°)]

Projectile motion

Definition of projectile

Any object moving through air and affected only by gravity is called a **projectile**. Examples include a kicked soccer ball in the air, a stunt car driven off a cliff, and a skier going off a ski jump. Flying objects such as airplanes and birds are *not* projectiles, because they are affected by forces generated from their own power and not just the force of gravity.

Trajectories

The path a projectile follows is called its **trajectory**. The trajectory of a projectile is a special type of arch- or bowl-shaped curve called a **parabola**. The **range** of a projectile is the horizontal distance it travels in the air before touching the ground (Figure 6.4). A projectile's range depends on the speed and angle at which it is launched.

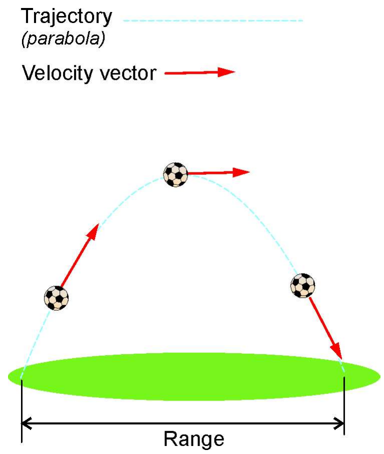

Figure 6.4: *A soccer ball in the air is a projectile. The ball's trajectory is a parabola.*

Two-dimensional motion

Projectile motion is two-dimensional because both horizontal and vertical motion happen at the same time. Both speed and direction change as a projectile moves through the air. The motion is easiest to understand by thinking about the vertical and horizontal components of motion separately.

Independence of horizontal and vertical motion

A projectile's velocity vector at any one instant has both a horizontal (v_x) and vertical (v_y) component. Separating the velocity into the two components allows us to look at them individually. The horizontal and vertical components of a projectile's velocity are *independent* of each other. The horizontal component does not affect the vertical component and vice versa. The complicated curved motion problem becomes two separate, straight-line problems like the ones you have already solved.

The horizontal and vertical components of a projectile's velocity are independent of each other.

Subscripts

Notice the subscripts (*x, y*) on the velocity components. Subscripts tell you the direction of the motion. Distance and velocity in the x-direction are identified by using *x* as a subscript. Distance and velocity in the y-direction are identified by using *y* as a subscript. It is important to carefully write the subscripts as you do projectile problems. Otherwise, you will quickly lose track of which velocity is which (Figure 6.5)!

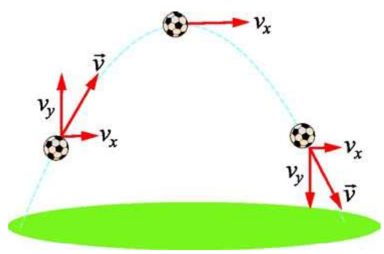

Figure 6.5: *The velocity vector of the ball has both x and y components that change during the ball's flight.*

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A ball rolling off a table

Constant horizontal velocity

A ball rolling off a table is a projectile once it leaves the tabletop. Once the ball becomes a projectile it feels no horizontal force, so its horizontal velocity is *constant.* A projectile moves the same distance horizontally each second. A ball rolling off a table at 5 meters per second moves five meters horizontally each second it is in the air (Figure 6.6). The horizontal motion looks exactly like the motion the ball would have were it rolling along the ground at 5 m/sec.

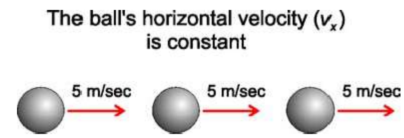
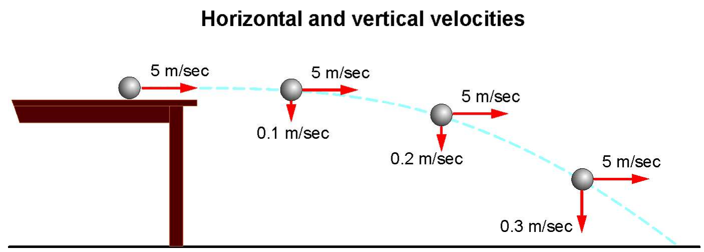


Figure 6.6: *A projectile's horizontal velocity does not change because no horizontal force acts on it.*



Vertical velocity changes

The vertical motion of the ball is more complicated because of gravity. The ball is in *free fall* in the vertical direction. Just like other examples of free fall, the ball's vertical speed increases by 9.8 m/sec each second (Figure 6.7).

VERTICAL VELOCITY

Projectile motion

$$v_y = gt$$

Vertical velocity (m/sec, downward) → v_y; *Acceleration due to gravity* (m/sec²) → g; *Time* (sec) → t

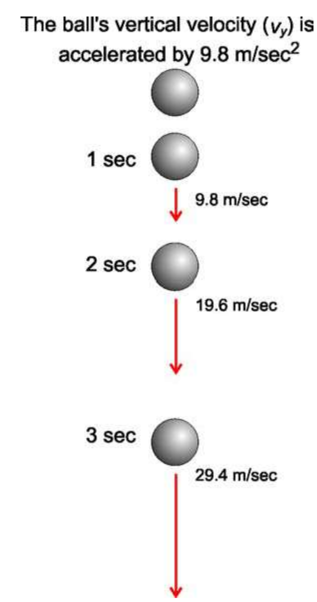


Figure 6.7: *A projectile's vertical velocity increases by 9.8 m/sec each second.*

The velocity vector

The diagram shows the velocity vector as the ball falls. The horizontal (x) velocity stays constant. The vertical (y) velocity increases because of the acceleration of gravity. As a result, both the magnitude (speed) and direction of the velocity vector change.

Horizontal and vertical distance

Horizontal distance

The horizontal distance a projectile goes is the horizontal speed (v_x) multiplied by the time (t). Because the horizontal speed is constant, the relationship between distance, speed, and time is the same as you learned in Chapter 1. If you know any two of the variables, you can use the equation below to find the (unknown) third variable.

HORIZONTAL DISTANCE
Projectile motion

$$d_x = v_x t$$

Distance (m) → d_x; *Horizontal velocity* (m/sec) → v_x; *Time* (sec) → t

Vertical distance

The vertical distance the ball falls can be calculated using the equation $d=v_{avg}t$, as we did for free fall in Chapter 2. The *average* velocity must be used because the vertical motion is accelerated. A more direct way to find the vertical distance is with the equation $d=1/2at^2$. The vertical acceleration in free fall is 9.8 m/sec^2, so the equation then becomes $d = 4.9\ t^2$. Keep in mind that this equation is only correct on Earth, when the object starts with a vertical velocity of zero (Figure 6.8).

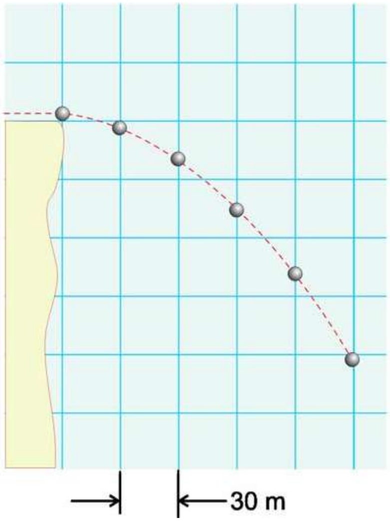
VERTICAL DISTANCE
Projectile motion

$$d_y = 4.9t^2$$

Vertical distance (m) → d_y; *Time* (seconds) → t

Caution!

The equations above are suitable ONLY for situations where the projectile starts with zero vertical velocity, such as a ball rolling off a table. If the projectile is launched up or down at an angle, the equations are more complicated.



Time (sec)	Horizontal position (m)	Vertical drop (m)
0	0	0
1	30	4.9
2	60	19.6
3	90	44.1
4	120	78.4
5	150	122.5

Figure 6.8: *The horizontal and vertical positions of a ball rolling off a cliff at 30 meters per second.*

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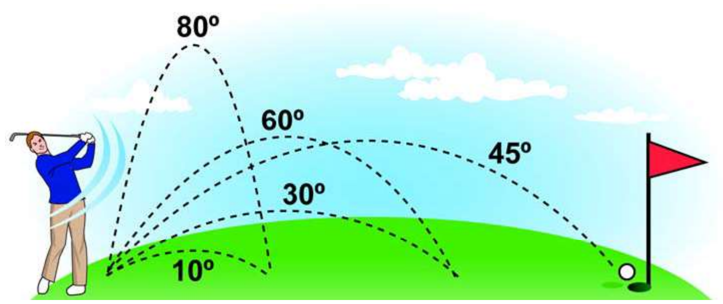
The range of a projectile

Speed and angle Suppose you are hitting golf balls and you want the ball to go as far as possible on the course. How should you hit the ball? The two factors you control are the speed with which you hit it and the angle at which you hit it. You want to hit the ball as fast as you can so that it will have as much velocity as possible. But what is the best angle at which to hit the ball?

90 degrees and zero degrees Launching the ball straight upward (90 degrees) gives it the greatest air time (Figure 6.9) and height. However, a ball flying straight up does not move horizontally at all and has a range of zero. Launching the ball completely horizontally (0 degrees) makes it roll on the ground. The ball has the greatest horizontal velocity but it hits the ground immediately, so the range is zero.

The greatest range at 45 degrees To get the greatest range, you must find a balance between horizontal and vertical motion. The vertical velocity gives the ball its air time, and the horizontal velocity causes it to move over the course. The angle that gives the greatest range is 45 degrees, halfway between horizontal and vertical.

Other angles The more the launch angle differs from 45 degrees, the smaller the range. A ball launched at 30 degrees has the same range as one launched at 60 degrees because both angles are 15 degrees away from 45. The same is true for any pair of angles adding up to 90 degrees.



Air resistance Air resistance can also affect a projectile's range. The trajectory of a projectile is usually not a perfect parabola, and the range is less than would be expected, both because of air resistance.

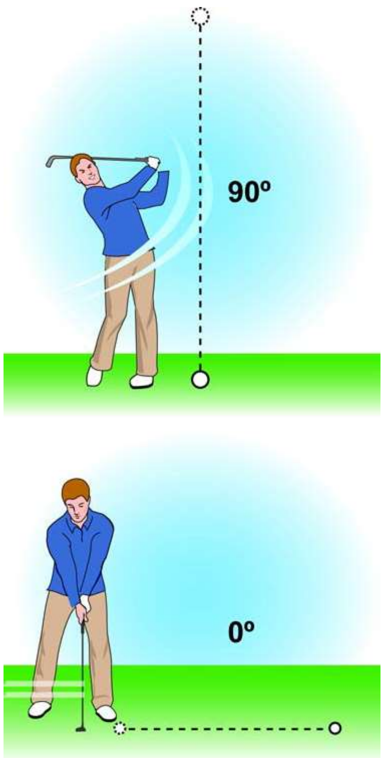


Figure 6.9: *The air time and height are greatest when a ball is hit at an angle of 90 degrees. The air time and range are zero when a ball is hit at an angle of zero degrees.*

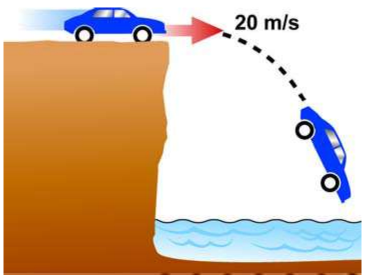
Projectile motion problems

Distinguishing between horizontal and vertical

Projectile motion problems can be tricky because you have to keep track of so many variables. When solving a problem, you should first figure out what the problem is asking you to find and whether it is a horizontal or a vertical quantity. Then you can use the right relationship to answer the question. Remember the horizontal velocity is constant and uses the distance equation for constant velocity motion. The vertical velocity changes by 9.8 m/sec each second and the vertical motion is the same as free fall.

Projectile motion

A stunt driver steers a car off a cliff at a speed of 20 m/sec. He lands in the lake below two seconds later. Find the horizontal distance the car travels and the height of the cliff.



1. Looking for: You are asked for the vertical and horizontal distances.

2. Given: You are given the time in seconds and initial horizontal speed in m/sec.

3. Relationships: Horizontal: $d_x = v_x t$ Vertical: $d_y = 4.9t^2$

4. Solution: Horizontal: $d_x = (20 \text{ m/sec})(2 \text{ sec}) = 40$ meters
Vertical: $d_y = (4.9 \text{ m/sec}^2)(2 \text{ sec})^2 = (4.9 \text{ m/sec}^2)(4 \text{ sec}^2) =$ 19.6 meters

Your turn...

a. Repeat the above problem with a time of three seconds instead of two. **Answer:** 60 meters, 44.1 meters

b. You kick a soccer ball and it travels a horizontal distance of 12 meters during the 1.5 seconds it is in the air. What was the ball's initial horizontal speed? **Answer:** 8 m/sec

6.1 Section Review

1. What is the word for the horizontal distance a projectile travels?
2. What does it mean to say a projectile's horizontal and vertical velocity are independent of each other?
3. A football is kicked down a field. Describe what happens to its horizontal and vertical velocities as it moves through the air.
4. What launch angle gives a projectile its greatest range?

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6.2 Circular Motion

Circular motion occurs when a force causes an object to curve in a full circle. The planets orbiting the sun, a child on a merry-go-round, and a basketball spinning on a fingertip are examples of circular motion.

Vocabulary

circular motion, revolve, angular speed, linear speed, circumference

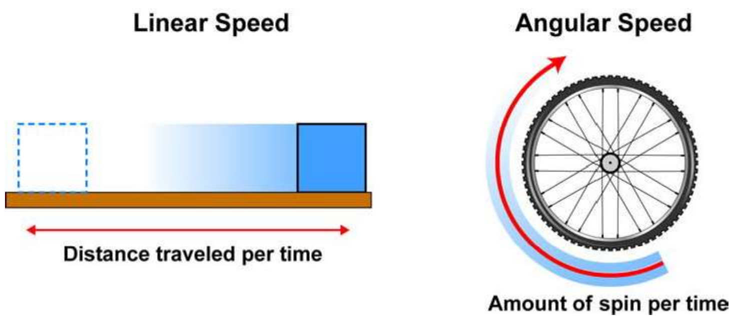
Objectives

- ✓ Distinguish between rotation and revolution
- ✓ Calculate angular speed
- ✓ Explain how angular speed, linear speed, and distance are related

Describing circular motion

Rotating and revolving A basketball spinning on your fingertip and a child on a merry-go-round both have circular motion. Each moves around its axis of rotation**.** The basketball's axis runs from your finger up through the center of the ball (Figure 6.10). The child's axis is a vertical line in the center of the merry-go-round. While their motions are similar, there is a difference. The ball's axis is *internal* or inside the object. We say an object *rotates* about its axis when the axis is internal. A child on a merry-go-round moves around an axis that is *external* or outside him. An object **revolves** when it moves around an external axis.

Angular speed When an object moves in a line, we can measure its linear speed. Linear speed is the distance traveled per unit of time. **Angular speed** is the amount an object in circular motion spins per unit of time. Angular speed can describe either the rate of revolving or the rate of rotating.



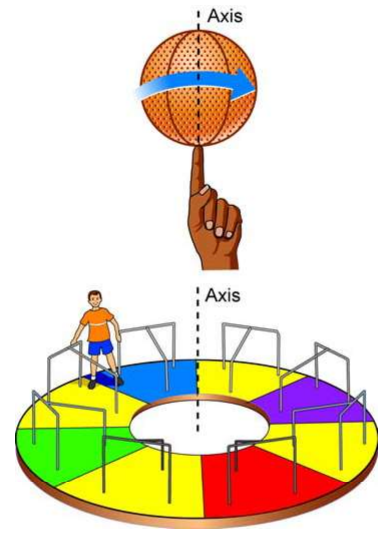


Figure 6.10: *The basketball rotates and the child revolves.*

Angular speed

Units of angular speed Circular motion is described by angular speed. The angular speed is the rate at which something turns. The rpm, or rotation per minute, is commonly used for angular speed. Another common unit is angle per unit of time. There are 360 degrees in a full rotation, so one rotation per minute is the same angular speed as 360 degrees per minute (Figure 6.11).

Calculating angular speed To calculate angular speed you divide the number of rotations or the number of degrees an object has rotated by the time taken. For example, if a basketball turns 15 times in three seconds, its angular speed is five rotations per second (15 rotations ÷ 3 sec).

ANGULAR SPEED

$$\textit{Angular speed} = \frac{\text{rotations or degrees}}{\text{time}}$$

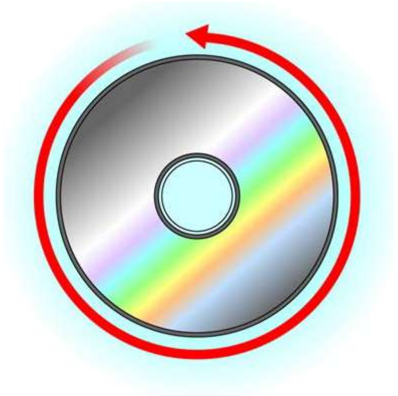


Figure 6.11: *One rotation is the same as 360 degrees.*

Calculating angular speed

A merry-go-round makes 10 rotations in 2 minutes. What is its angular speed in rpm?

1. Looking for: You are asked for the angular speed in rotations per minute and degrees per minute.

2. Given: You are given the number of rotations and the time in minutes.

3. Relationships: $\text{angular speed} = \frac{\text{rotations or degrees}}{\text{time}}$

4. Solution: $\text{angular speed} = \frac{10 \text{ rotations}}{2 \text{ minutes}} = 5 \text{ RPM}$

Your turn...

a. Calculate the angular speed of a bicycle wheel that spins 1,000 times in 5 minutes. **Answer:** 200 rpm

b. A bowling ball rolls at two rotations per second. What is its angular speed in degrees per second? **Answer:** 720 degrees/sec

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Relating angular speed, linear speed, and distance

Angular speed is the same

Each point on a rotating object has the same angular speed. Suppose three children sit on a merry-go-round (Figure 6.12). When the merry-go-round rotates once, each child makes one revolution. The time for one revolution is the same for all three children, so their angular speeds are the same.

Distance during a revolution

The linear speed of each child is *not* the same because they travel different distances. The distance depends on how far each child is sitting from the center. Dwayne sits near the edge. He moves in the biggest circle and travels the greatest distance during a revolution. Ryan moves in a medium circle and travels a smaller distance. Huong sits exactly in the center of the merry-go-round, so she does not revolve at all. She rotates about the axis in the center.

Linear speed depends on radius

The linear speed of a person on a merry-go-round is the distance traveled around the circle divided by the time. The distance depends on the radius of the circle in which the person moves. Therefore the linear speed also depends on the radius. Dwayne moves in a circle with the largest radius, so his linear speed is the fastest. Two people sitting at different places on the same merry-go-round always have the same *angular* speed. But the person sitting farther from the center has the faster **linear speed**.

Circumference

The distance traveled during one revolution equals the **circumference** of the circle. The radius of the circle equals the person's distance from the axis of rotation at the center. A person sitting two meters from the center of a merry-go-round travels in a circle with twice the circumference of that of a person sitting one meter from the center. The person sitting two meters away therefore has twice the linear speed.

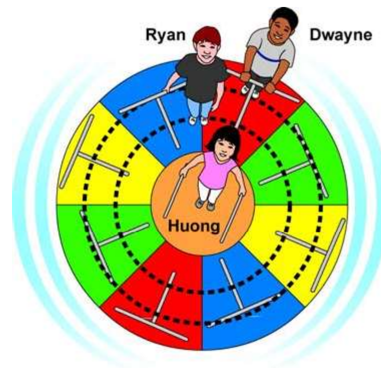
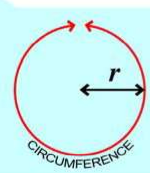


Figure 6.12: *Each child has the same angular speed, but Dwayne has the fastest linear speed.*

CIRCUMFERENCE OF A CIRCLE

Circumference (m) *Radius* (m)

$$C = 2\pi r$$



Solving linear speed problems

Calculating linear speed

The linear speed of any point on a rotating object is directly proportional to the distance between the point and the axis of rotation. You can calculate the linear speed of any point if you know the time it takes to make one revolution and the distance it is from the axis of rotation. If you are given the angular speed, you can determine how much time it takes to make one revolution.

LINEAR SPEED
From angular speed

$$v = \frac{2\pi r}{t}$$

Linear speed (m/sec) → v; *Radius* (meters) → r; *Time for one revolution* (seconds) → t

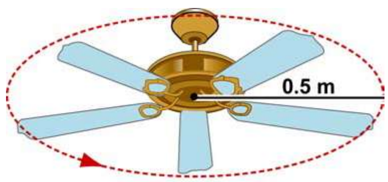


Figure 6.13: *What is the linear speed of the tip of the fan blade?*

Calculating linear speed

The blades on a ceiling fan spin at 60 rotations per minute (Figure 6.13). The fan has a radius of 0.5 meter. Calculate the linear speed of a point at the outer edge of a blade in meters per second.

1. Looking for: You are asked for the linear speed in meters per second.

2. Given: You are given the angular speed in rpm and the radius in meters.

3. Relationships: $v = \frac{2\pi r}{t}$

4. Solution: The blades spin at 60 rotations per minute, so they make 60 rotations in 60 seconds. Therefore it takes one second to make one rotation.

$$v = \frac{(2\pi)(0.5 \text{ m})}{1 \text{ sec}} = 3.14 \text{ m/sec}$$

Your turn...

a. Calculate the linear speed of a point 0.25 meter from the center of the fan. **Answer:** 1.57 m/sec

b. The fan slows to 30 rpm. Calculate the linear speed of a point at the outer edge of a blade and 0.25 meter from the center. **Answer:** 1.57 m/sec, 0.79 m

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Rolling

Linear and rotational motion

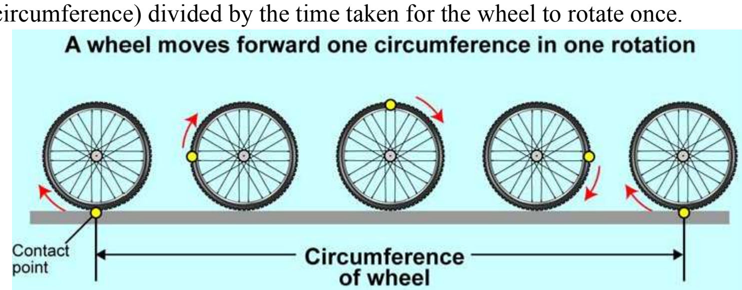
Rolling is a combination of linear motion and rotational motion (Figure 6.14). Linear motion occurs when an entire object moves from one place to another. Holding a bicycle wheel up in the air and moving it to the right is an example of linear motion. Rotational motion occurs when an object spins around an axis that stays in place. If you lift a bicycle's front wheel off the ground and make it spin, the spinning wheel is in rotational motion.

Rolling motion

Rolling is a combination of linear and rotational motion. As a wheel rolls, its axis moves in a line. Look at the motion of the axis in the picture below. As the wheel rolls, its axis moves in a straight line. The linear speed of a bicycle riding on the wheel is equal to the linear speed of the wheel's axis.

Linear distance equals circumference

The distance the bicycle moves depends on the wheel's size and angular speed. When the wheel makes one full rotation, the bicycle goes forward one circumference. The point that was contacting the ground at the beginning of the rotation travels once around the circle. The linear speed of the bicycle is therefore equal to the distance the point moves around the circle (the circumference) divided by the time taken for the wheel to rotate once.



6.2 Section Review

1. Give your own examples of an object rotating and an object revolving.
2. List two units in which angular speed can be measured.
3. Several U.S. cities have rotating restaurants high atop buildings. Does every person in such a rotating restaurant have the same angular speed and linear speed? Explain.

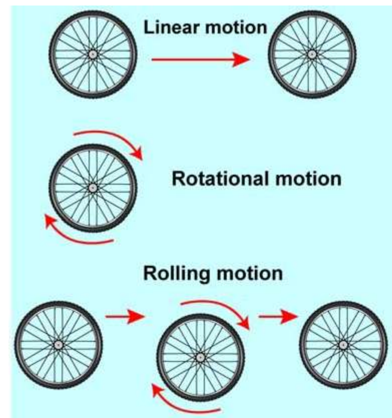


Figure 6.14: *Rolling is a combination of linear and rotational motion.*

Speedometers

A bicycle speedometer uses a small magnet on the front wheel to measure speed. Before using it, you must enter in your wheel's circumference. The speedometer divides the circumference by the time for the magnet to revolve and displays the speed. It can also measure distance by counting rotations. A car's speedometer works in a similar way. It is programmed for tires of a certain size. If tires of the wrong radius are used, the speed and distance measurements will be inaccurate.

6.3 Centripetal Force, Gravitation, and Satellites

Force is needed to accelerate an object. We usually think of acceleration as a change in speed, but it can also be a change in direction. An object moving in a circle is constantly changing direction, so a force must act on it. In this section you will learn how force can create circular motion. You will also learn about the force that keeps planets, moons, and satellites in orbit.

Vocabulary

centripetal force, centrifugal force, law of universal gravitation, gravitational constant, satellite, orbit, ellipse

Objectives

✓ Explain how a centripetal force causes circular motion
✓ List the factors that affect centripetal force
✓ Describe the relationship between gravitational force, mass, and distance
✓ Relate centripetal force to orbital motion

Centripetal force

Centripetal force causes circular motion

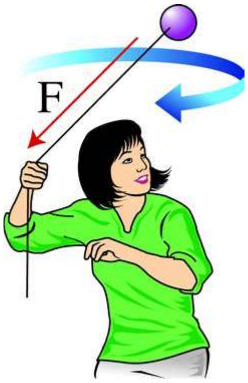
Any force that causes an object to move in a circle is called a **centripetal force**. Even though it is given its own name, centripetal force is not a new type of physical force. Any force can be a centripetal force if its action causes an object to move in a circle. For example, a car can move in a circle because friction provides the centripetal force. The lack of friction on an icy road is what makes it difficult for a car to turn.

The effect of a force depends on direction

Whether a force makes an object accelerate by changing its speed or by changing its direction depends on the direction of the force (Figure 6.15). A force in the same direction as the motion causes the object to speed up. A force exactly opposite the direction of motion makes the object slow down. A force *perpendicular* to the direction of motion causes the object to change its path from a line to a circle, without changing speed.

Centripetal force is toward the center

Centripetal force is always directed toward the center of the circle in which an object moves. Imagine tying a ball to the end of a string and twirling it in a circle over your head. The string exerts the centripetal force on the ball to move it in a circle. The direction of the pull is toward your hand at the center of the circle. Notice that the direction of the centripetal force changes as the object moves around you. If the ball is on your right, you pull to the left and vice versa. Centripetal forces change direction so they remain pointed toward the center of the circle.



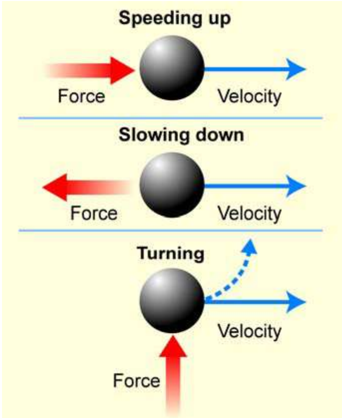


Figure 6.15: *The effect of a force depends on its direction.*

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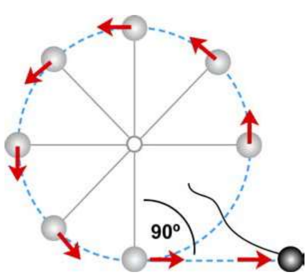
Centripetal force, inertia, and velocity

Inertia Why doesn't centripetal force pull a revolving object toward the center of its circle? Inertia is the key to answering this question. Suppose you want to move a ball tied to a string in a circle on the top of a smooth table. You place the ball on the table, straighten out the string, and give it a hard pull along its length. Will the ball move in a circle? No! The ball will simply move straight toward your hand. The ball has a tendency to remain at rest, but the force of the string accelerates it toward your hand in the direction of the roll.

Getting circular motion started Now suppose you hold the string with your right hand and use your left hand to toss the ball in a direction perpendicular to the string. As soon as the ball starts moving, you pull on the string. This time you can get the ball to move in a circle around your hand.

Centripetal force changes direction Let's examine exactly what is happening. If you give the ball an initial velocity to the left at point A, it will try to keep moving straight to the left (Figure 6.16). But the centripetal force pulls the ball to the side. A short time later, the ball is at point B and its velocity is 90 degrees from what it was. But now the centripetal force pulls to the right. The ball's inertia makes it want to keep moving straight, but the centripetal force always pulls it towards the center. This process continues, moving the ball in a circle as long as you keep supplying the centripetal force.

Velocity and force are perpendicular Notice that the velocity is always perpendicular to the string and therefore to the centripetal force. The centripetal force and velocity are perpendicular for any object moving in a circle. What happens if you release the string? Because there is nothing to provide the centripetal force, the ball stops moving in a circle. It moves in a straight line in the direction of the velocity the instant you let go. It flies away at a 90-degree angle from the string.



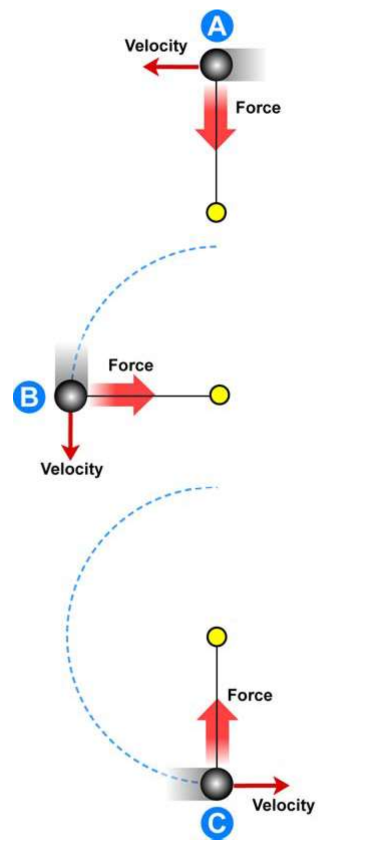


Figure 6.16: *The centripetal force changes direction so it is always perpendicular to the velocity.*

Newton's second law and circular motion

Acceleration An object moving in a circle at a constant speed accelerates because its direction changes. The faster its change in direction, the greater its acceleration. How quickly an object changes direction depends on its speed and the radius of the circle. If an object gets faster, and stays moving in the same circle, its direction changes more quickly and its acceleration is greater. If an object stays at the same speed but the circle of its motion expands, the change in direction becomes more gradual and the acceleration is reduced. *Centripetal acceleration* increases with speed and decreases with radius.

Force, mass, and acceleration Newton's second law relates force, mass, and acceleration. According to the law, more force is needed to cause a greater acceleration. More force is also needed when changing the motion of an object with a larger mass. The strength of centripetal force needed to move an object in a circle therefore depends on its mass, speed, and the radius of the circle (Figure 6.17).

1. Centripetal force is directly proportional to the mass. A two-kilogram object needs twice the force to have the same circular motion as a one-kilogram object.
2. Centripetal force is inversely proportional to the radius of its circle. The smaller the circle, the greater the force. An object moving in a one-half-meter circle needs twice the force it does when it moves in a one-meter circle at the same linear speed.
3. Centripetal force is directly proportional to the *square* of the object's linear speed. *Doubling* the speed requires *four* times the centripetal force. *Tripling* the speed requires *nine* times the centripetal force.

Driving around bends The relationship between centripetal force and speed is especially important for automobile drivers to recognize. A car moves in a circle as it turns a corner. The friction between the tires and the road provides the centripetal force that keeps the car following the radius of the turn. This is why high-speed turns (on freeways) have a much larger radius than low-speed corners in town. You may have seen signs at highway ramps with sharp curves that warn drivers to reduce their speeds. Friction decreases when a road is wet or icy, and there may not be enough force to keep the car following the turn.

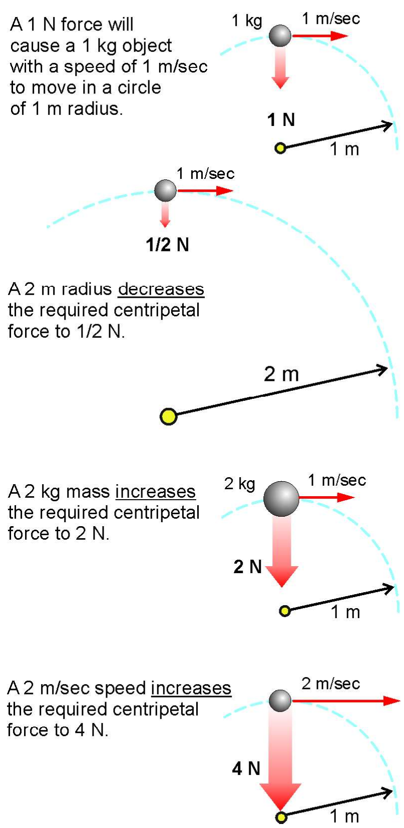


Figure 6.17: *The centripetal force needed to move an object in a circle depends on its mass, speed, and the radius of the circle.*

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Centrifugal force

A turning car Have you ever noticed that when a car makes a sharp turn, you are thrown toward the outside edge of the car? If the car turns to the right, you slide to the left. If the car turns to the left, you slide to the right. Although the centripetal force pushes the car toward the center of the circle, it seems as if there is a force pushing *you* to the *outside*. This apparent outward force is called **centrifugal force**. While it feels like there is a force acting on you, *centrifugal force is not a true force.*

Newton's first law According to Newton's first law, an object in motion tends to keep moving with the same speed and direction. Objects — including you — have inertia and the inertia resists any change in motion. When you are in a turning car, what seems like centrifugal force is actually your own inertia. Your body tries to keep moving in a straight line and therefore is flung toward the outer edge of the car. The car pushes back on you to force you into the turn, and that is the true *centripetal* force. This is one of many reasons why you should always wear a seatbelt!

An example Figure 6.18 shows a view from above of what happens when a car turns a bend. Suppose a box is in the center of a smooth back seat as the car travels along a straight road. The box and the car are both moving in a straight line. If the car suddenly turns to the left, the box tries to keep moving in that same straight line. While it seems like the box is being thrown to the right side of the car, the car is actually turning under the box.

The role of friction The car is able to turn because of the friction between the road and the tires. However, the box is not touching the road, so this force does not act it. There is friction acting on the box from the seat, but this force may be too small if the seat is smooth. The box slides to the right until it is stopped by the door of the car.

A useful example *Centrifugal* force is an effect of inertia that you feel whenever your body is forced to move in a circle. Although not a force, the centrifugal effect is quite useful and is the basis of the centrifuge. Centrifuges are used to separate mixtures by density. A centrifuge spins a liquid mixture at high speed. The rapid spinning causes all the heavier particles in the mixture to move to the farthest point away from the center of rotation.

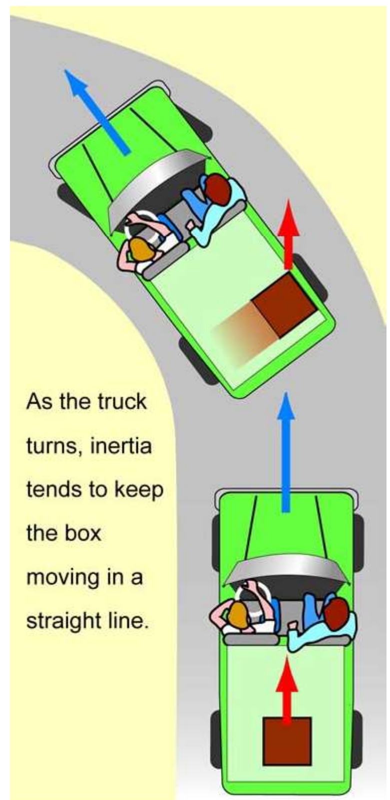

Figure 6.18: *As the car turns, the box keeps going straight ahead because of inertia.*

Gravitational force

Planets and moons A centripetal force is needed to move any object in a circle. What is the force that makes Earth orbit the sun and the moon orbit Earth? Newton first realized that this force is the same force that causes objects to fall toward the ground. The force of gravity between Earth and the sun provides the centripetal force to keep Earth moving in a circle. The force of gravity between Earth and the moon keeps the moon in orbit (Figure 6.19).

The force of gravity between Earth and the sun keeps Earth in orbit.

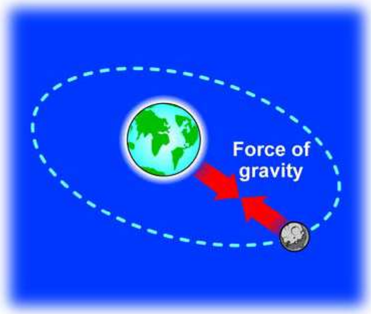

Figure 6.19: *Gravitational force keeps the moon in orbit around Earth.*

Weight Gravitational force exists between *all* objects that have mass. The strength of the force depends on the mass of the objects and the distance between them. Your *weight* is the force of gravity between you and Earth. It depends on your mass, the planet's mass, and your distance from the center of the planet. Until now you have used the equation $F_g = mg$ to calculate weight. Your mass is represented by m. The value of g depends on Earth's mass and the distance between its center and surface. If you travel to a planet with a different mass and/or radius, the value of g and your weight would change.

Gravitational force exists between all objects You do not notice the attractive force between ordinary objects because gravity is a relatively weak force. It takes a great deal of mass to create gravitational forces that can be felt. For example, a gravitational force exists between you and your textbook, but you cannot feel it because both masses are small. You notice the force of gravity between you and Earth because the planet's mass is huge. Gravitational forces tend to be important only when one of the objects has an extremely large mass, such as a moon, star, or planet.

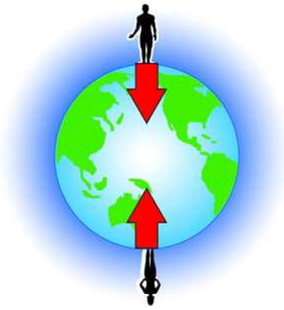

Figure 6.20: *The direction "down" is opposite on the north and south poles.*

Direction of the gravitational force The force of gravity between two objects always lies along the line connecting their centers. As objects move, the direction of the force changes to stay pointed along the line between their centers. For example, the force between Earth and your body points from your center to the center of Earth. The direction of the planet's gravitational force is what we use to define "down." If you tell a person on the north pole and one on the south pole to point down, they will be pointing in opposite directions (Figure 6.20).

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The gravitational force between objects

Mass and gravity The force of gravity between two objects is proportional to the mass of each object. If one object doubles in mass, then the gravitational force doubles. If both objects double in mass, then the force doubles twice, becoming four times as strong (Figure 6.21).

Distance and gravity The distance between objects, measured from center to center, is also important when calculating gravitational force. The closer objects are to each other, the greater the force between them. The farther apart, the weaker the force. The decrease in gravitational force is related to the square of the distance. Doubling the distance divides the force by four (2^2). If you are twice as far from an object, you feel one-fourth the gravitational force. Tripling the distance divides the force by nine ($9 = 3^2$). If you are three times as far away, the force is one-ninth as strong.

Changing elevation If you climb a hill or fly in an airplane, your distance from the center of Earth increases. The gravitational force on you, and therefore your weight, decreases. However, this change in distance is so small when compared with Earth's radius that the difference in your weight is not noticeable.

Measuring distance When calculating the force of Earth's gravity, distance is measured from the center of the object to the center of Earth. This is *not* because gravity "comes from" the center of the planet. Every part of Earth's mass contributes to the gravitational force. You measure the distance to the center because your distance from all the particles making up the planet varies. You are close to the mass under your feet but far from the mass on the other side of Earth. The distance used to calculate the force of gravity is the average distance between you and all the particles making up Earth's mass. This average distance is the distance to the planet's center.

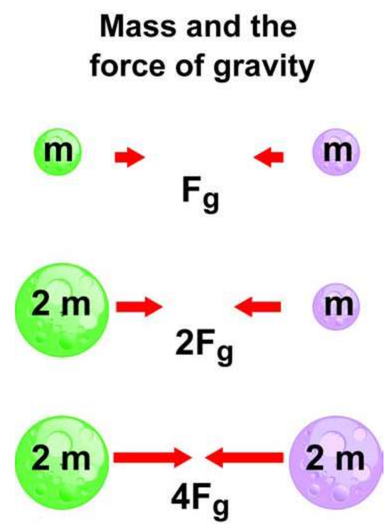

Figure 6.21: *Doubling one mass doubles the force of gravity. Doubling both quadruples the force of gravity.*

Newton's law of universal gravitation

The law of universal gravitation

Newton's **law of universal gravitation** gives the relationship between gravitational force, mass, and distance. The **gravitational constant** (G) is the same everywhere in the universe ($6.67 \times 10^{-11}\ N{\cdot}m^2/kg^2$). Its small value shows why gravity is weak unless at least one mass is huge.

LAW OF UNIVERSAL GRAVITATION

$$F_g = G\frac{m_1 m_2}{r^2}$$

- Force: F_g
- *Gravitational constant* ($6.67 \times 10^{-11}\ N{\cdot}m^2/kg^2$): G
- *Mass 1, Mass 2* (kg): m_1, m_2
- *Distance between masses squared* (m): r^2

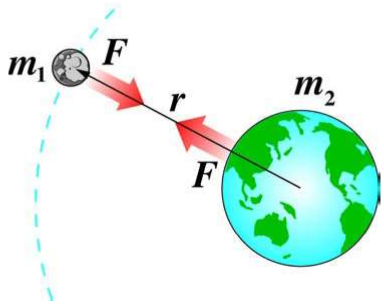

Figure 6.22: *The force on the moon is equal in strength to the force on Earth.*

The force on each object

The force calculated using the law of universal gravitation is the force felt by *each* object (Figure 6.22). The gravitational force of Earth on the moon is the same strength as the gravitational force of the moon on Earth.

Calculating gravitational forces

Use the following information to calculate the force of gravity between Earth and the moon.
Mass of Earth: 5.97×10^{24} m Mass of moon: 7.34×10^{22} kg Distance between centers of Earth and moon: 3.84×10^{8} m

1. Looking for: You are asked for the force of gravity between Earth and the moon.

2. Given: You are given their two masses in kilograms and the distance between their centers in meters.

3. Relationships:

$$F_g = G\frac{m_1 m_2}{r^2}$$

3. Relationships:

$$F_g = (6.67\times10^{-11}\ \frac{N\cdot m^2}{kg^2})\frac{(5.97\times10^{24}\ kg)(7.34\times10^{22}\ kg)}{(3.84\times10^{8}\ m)^2}$$

$$F_g = (6.67\times10^{-11}\ \frac{N\cdot m^2}{kg^2})\frac{(4.38\times10^{47}\ kg^2)}{(1.47\times10^{17}\ m^2)} = 1.99\times10^{20}\ N$$

Your turn...

a. Calculate the force of gravity on a 50-kilogram person on Earth (6.38×10^6 m from its center). **Answer:** 489 N

b. Calculate the force of gravity on a 50-kilogram person on the moon (1.74×10^6 m from its center). **Answer:** 81 N

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Orbital motion

Satellites A **satellite** is an object that circles around another object with gravity providing the centripetal force. Earth, its moon, and the other planets are examples of natural satellites. Artificial satellites that **orbit**, or move around Earth include the Hubble Space Telescope, the International Space Station, and satellites used for communications.

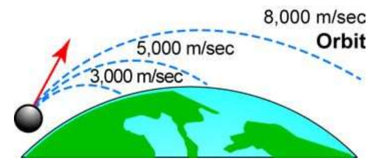


Figure 6.23: *A projectile launched fast enough from Earth becomes a satellite.*

Launching a satellite The motion of a satellite is closely related to projectile motion. If an object is launched above Earth's surface at a slow speed, it follows a parabolic path and falls back to the planet (Figure 6.23). The faster it is launched, the farther it travels before reaching the ground. At a launch speed of about 8 kilometers per second, the curve of a projectile's path matches the curvature of Earth. The object goes into orbit instead of falling back to Earth. A satellite in orbit *falls around Earth.* But as it falls, Earth curves away beneath it.

Elliptical orbits An orbit can be a circle or an oval shape called an **ellipse**. Any satellite launched above Earth at more than 8 kilometers per second will have an elliptical orbit. An object in an elliptical orbit does not move at a constant speed. It moves fastest when it is closest to the object it is orbiting because the force of gravity is strongest there.

Planets and comets All the planets' orbits are almost circular. Comets, however, orbit the sun in very long elliptical paths (Figure 6.24). Their paths bring them close to the sun and then out into space, often beyond Pluto. Some comets take only a few years to orbit the sun once, while others travel so far out that a solar orbit takes thousands of years.

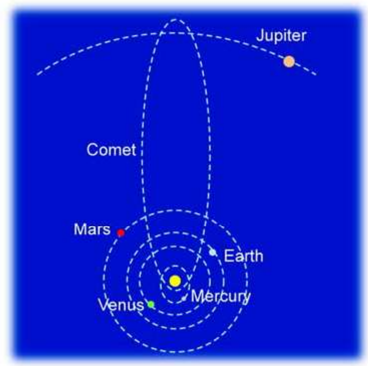


Figure 6.24: *The planets move in nearly circular orbits. Comets travel in elliptical orbits around the sun.*

6.3 Section Review

1. Draw a diagram of a ball at the end of a string moving in a clockwise circle. Draw vectors to show the direction of the centripetal force and velocity at three different locations on the circle.
2. Explain the difference between centrifugal force and centripetal force.
3. What factors affect the force of gravity between two objects?
4. What is the force that keeps Earth in orbit around the sun?

6.4 Center of Mass

The shape of an object and the way its mass is distributed affect the way it moves and balances. For example, a tall stool tips over much more easily than a low, wide chair. Wheels and other objects that spin are designed to rotate with as little effort as possible. In this section you will learn about the factors that affect an object's rotation.

Vocabulary

center of mass, center of gravity

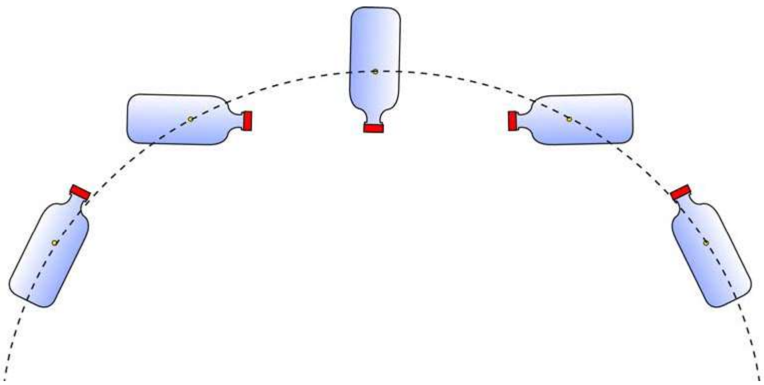
Objectives

- ✓ Define center of mass and center of gravity
- ✓ Explain how to locate an object's center of mass and center of gravity
- ✓ Use the concept of center of gravity to explain toppling

Finding the center of mass

The motion of a tossed object

Earlier in this unit you learned that a ball thrown into the air at an angle moves in a parabola. But what if you hold the top of an empty soda bottle and toss it across a field? You will notice that the bottle rotates as it moves through the air. The rotation comes from the torque you exerted when throwing it. If you filmed the bottle and carefully looked at the film you would see that one point on the bottle moves in a perfect parabola. The bottle spins around this point as it moves.



Defining center of mass

The point at which an object naturally spins is its **center of mass**. Since a solid object has length, width, and height, there are three different axes about which an object tends to spin. These three axes intersect at the center of mass (Figure 6.25). The center of mass is important because it is the average position of all the particles that make up the object's mass.

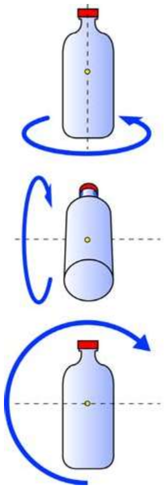


Figure 6.25: *An object naturally spins about three different axes.*

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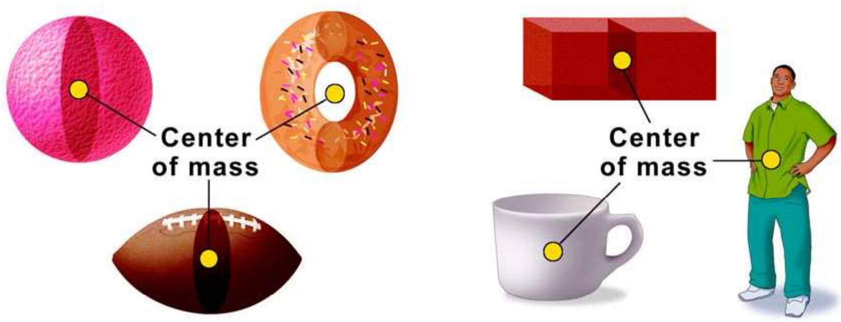
Finding the center of mass

The center of mass may not be "in" an object It is easy to find the center of mass for a symmetric object made of a single material such as a solid rubber ball or a wooden cube. The center of mass is located at the geometric center of the object. If an object is irregularly shaped, it can be found by spinning the object, as with the soda bottle on the previous page. The center of mass of some objects may not be inside the object. The center of mass of a doughnut is at its very center — where there is only space.



The center of gravity Closely related to the center of mass is the **center of gravity**, or the average position of an object's weight. If the acceleration due to gravity is the same at every point in an object, its centers of gravity and of mass are at the same point. This is the case for most objects, so the two terms are often used interchangeably. However, gravity toward the bottom of a skyscraper is slightly stronger than it is toward the top. The top half therefore weighs less than the bottom half, even when both halves have the same mass. The center of mass is halfway up the building, but the center of gravity is slightly lower.

Finding the center of gravity An object's center of mass can easily be found experimentally. When an object hangs from a point at its edge, the center of mass falls in the line directly below the point of suspension. If the object is hung from two or more points, the center of mass can be found by tracing the line below each point and finding the intersection of the lines (Figure 6.26).

Finding the center of mass

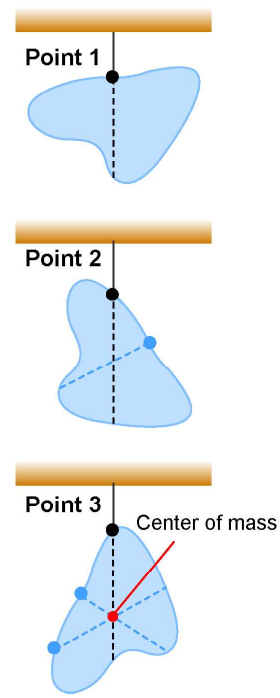
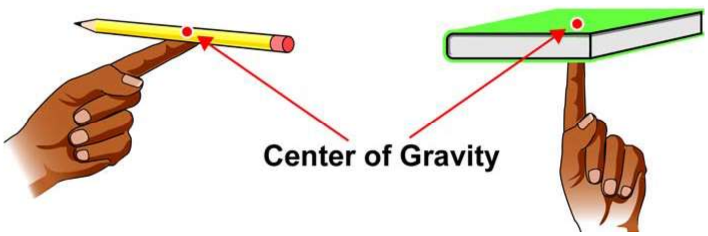


Figure 6.26: *The center of mass of an irregularly shaped object can be found by suspending it from two or more points.*

Mass and the center of gravity

Balancing an object To balance an object such as a book or a pencil on your finger, you must place your finger directly under the object's center of mass. The object balances because the torque caused by the force of the object's weight is equal on each side.



The area of support For an object to stay upright, its center of mass must be above its area of support. The area of support includes the entire region surrounded by the actual supports. For example, a stool's area of support is the entire rectangular area surrounded by its four legs. Your body's support area is not only where your feet touch the ground, but also the region between your feet. The larger the area of support, the less likely an object is to topple over.

When an object will topple over An object will topple over if its center of mass is not above its area of support. A stool's center of mass is slightly below the center of the seat. A vector showing the force of gravity or the stool's weight points from the center of mass toward the center of Earth (Figure 6.27). If this vector passes through the area of support, the object will not topple over; if it passes outside that area, the object will topple. Tall stools topple over more easily than low ones for this reason.

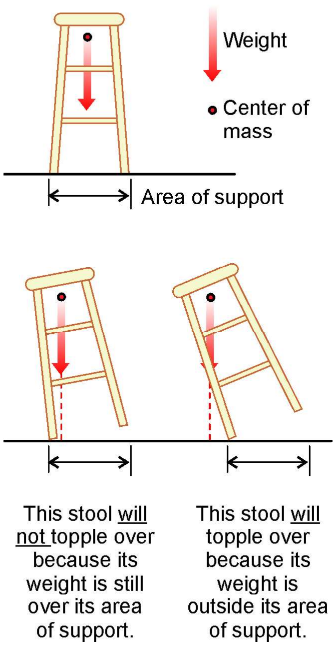


Figure 6.27: *.A stool will topple if its weight vector is outside the area of support.*

6.4 Section Review

1. What is the difference between center of mass and center of gravity?
2. Explain how you can find an object's center of mass.
3. Is a pencil easier to balance on its sharp tip or on its eraser? Why?

History of the Helicopter

When we think of flying, we often imagine fixed-wing aircraft like airplanes. These flying machines are prominent in aviation history. However, helicopters were probably the first flight pondered by man. For example, the ancient Chinese played with a simple toy—feathers on a stick—that they would spin and release into flight.

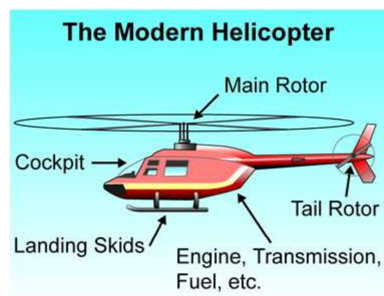
In the 1400s, Leonardo Da Vinci (1452-I5I9) had a plan for a vertically flying machine that could lift a person. Da Vinci planned to use muscle power to revolve the rotor, but this was insufficient to lift his helicopter into the air. In the 1900s, the invention of the internal combustion engine provided adequate power, but not stability to the design.

In 1940, Igor Sikorsky (1889 - 1972) developed the first stable helicopter, named the VS-300. His design allowed stability at any speed, including a hover, and he could accelerate it in any direction!

Rotors and action-reaction forces

Today's helicopters retain much of Sikorsky's original design. The *main rotor*, is the large propeller on top that makes the "chop-chop" sound that gave helicopters the nickname "chopper." The main rotor is used to lift the helicopter straight up. However it can tilt in any direction to stabilize the helicopter in a hover.

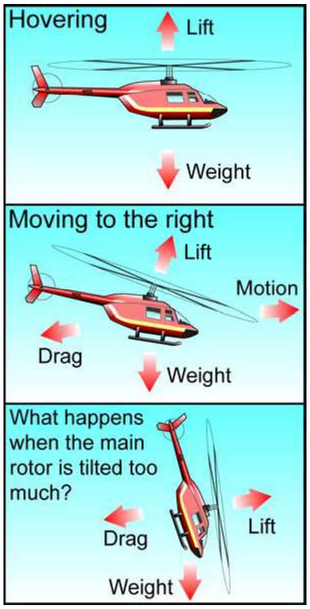
Helicopters must be lightweight in order for them to be lifted. However, with such low inertia, a small net force can easily cause a helicopter to get out of control. A *tail rotor*, the propeller on the tail of the helicopter, provides a force that counteracts the tendency of the main rotor to spin the helicopter counterclockwise. In addition, the tail rotor is used to rotate the helicopter right or left in a hover. This tail rotor from Sikorsky's VS-300 is now considered to be part of the conventional design because it works so well.



The helicopter tends to turn counterclockwise (a reaction force) because the helicopter engine turns the main rotor clockwise (an action force). The force provided by the tail rotor is a reaction force that counteracts the action force of the main rotor causing the helicopter to spin counterclockwise. This mechanism for how the helicopter works is an example of Newton's third law of motion.

Helicopter motion

Airplanes have propellers or jet engines to accelerate forward. In contrast, helicopters use the main rotor to accelerate.



Once the helicopter is moving forward, wind resistance (drag) increases until equilibrium is reached. Then, the helicopter moves at constant speed.

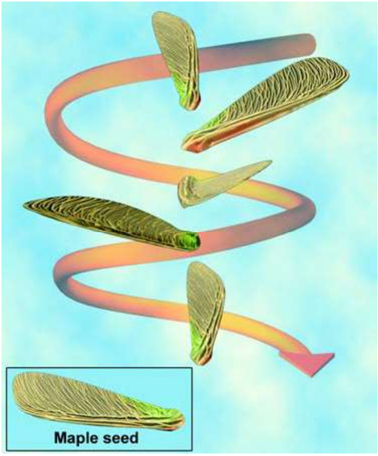
A lift force provided by the main rotor balances the weight of the helicopter so that it stays in the air. Also, the forward directing force of the lift (produced by the main rotor) balances the drag.

By tilting the main rotor, a helicopter pilot can increase the speed of the helicopter. The world's fastest helicopter can travel at 249 miles per hour, but most helicopters fly at 120 miles per hour. There are several limits to the maximum speed of a helicopter, but an obvious one is that if you tilt the main rotor of the helicopter too much, the lift force is large and occurs nearly parallel to the ground. Such a flying configuration causes the passengers and pilot of a helicopter to slide out of their seats!

As the speed of a helicopter increases, more lift is needed. Another role of the tail rotor is that it acts to balance the lift forces of the helicopter.

A helicopter mimics nature

If the engine of a helicopter failed, you might think that it would drop out of the sky like a rock. Fortunately, this does not happen. Instead, a helicopter with engine failure gently spins to the ground. This motion is similar to how a maple tree seed twirls to the ground when it falls from a tree. Helicopter pilots must practice and be able to perform this emergency landing maneuver in order to obtain a license.



Questions:

1. What is the purpose of the main rotor?
2. Why is the tail rotor an important part of helicopter design?
3. Name two pairs of action-reaction forces that are involved in how a helicopter works.
4. In which directions can a helicopter move?
5. Helicopters are often used to transport seriously ill patients from one hospital to another. Given your answer to question (4), why are helicopters used instead of airplanes which can travel at faster speeds?

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Chapter 6 Review

Understanding Vocabulary

Select the correct term to complete the sentences.

centripetal force	parabola	trajectory
range	revolves	center of mass
center of gravity	satellite	angular speed
rotates	projectile	law of universal gravitation
displacement		

Section 6.1

1. A _____ vector shows an object's change in position.
2. The path of a projectile is its _____.
3. A _____ is an object that moves through the air only affected by the force of gravity.
4. The mathematical shape of a projectile's trajectory is a _____.
5. The horizontal distance a projectile travels is its _____.

Section 6.2

6. An object _____ when it moves in a circle around an external axis.
7. A wheel ____ about an axis in its center.
8. _____ is the measure of how fast an object rotates or revolves.

Section 6.3

9. An inward _____ is needed to move an object in a circle.
10. The _____ describes the relationship between mass, distance, and gravitational force.
11. An object that orbits the earth is a _____.

Section 6.4

12. An object's _____ is the average position of all the particles that make up its mass.
13. You can balance an object on your finger if you support it at its _____.

Reviewing Concepts

Section 6.1

1. List the three ways to describe a displacement vector.
2. The directions north, south, east and west can be described using angles. List the angle for each of the four directions.
3. Explain how a vector diagram can be used to find an object's displacement.
4. A velocity vector tells you the object's _____ and _____ of motion.
5. State whether each of the following is a projectile.
   a. a diver who has jumped off a diving board
   b. a soccer ball flying toward the net
   c. a bird flying up toward its nest
6. What does it mean to say that the horizontal and vertical components of a projectile's velocity are independent of each other?
7. Is the horizontal velocity of a projectile constant? Is the vertical velocity of a projectile constant? Explain your answers.
8. Why does a projectile move in a curved path?
9. You kick a ball off the ground with a horizontal speed of 15 m/sec and a vertical speed of 19.6 m/sec. As it moves upward, its vertical speed _____ by _____ each second. It gets to its highest point _____ seconds after it is kicked. At the highest point, its vertical speed is ____ and its horizontal speed is _____. As it falls, its vertical speed _____ by _____ each second. It reaches the ground _____ seconds after it is kicked. Its horizontal speed is always _____.
10. At which angle should you kick a soccer ball if you want it to have the greatest range?
11. A ball kicked off the ground at an angle of 20 degrees and a ball kicked at an angle of _____ degrees have the same range.

Section 6.2

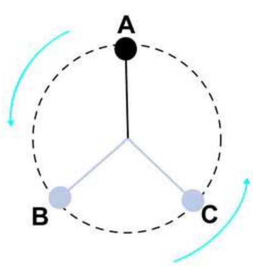
12. State whether each object is rotating or revolving.
    a. a satellite orbiting Earth
    b. a toy train moving on a circular track
    c. a fan blade

13. Which of the following units is appropriate for angular speed: rotations per second, meters per second, revolutions per minute.
14. How many degrees are in one revolution or rotation?
15. Two ants are sitting on a spinning record. One sits near the center and the other near the edge.
    a. How do their angular speeds compare?
    b. How do their linear speeds compare?

16. Rolling is a combination of _____ motion and _____ motion.
17. How far does the center of a wheel move in a line as the wheel rolls through one rotation?

Section 6.3

18. A force acts on a moving object. The force makes the object _____ if it acts in the same direction as the velocity. The force makes it _____ if it acts opposite the velocity. The force makes it _____ if it is perpendicular to the velocity.
19. A sports car moves around a sharp curve (small radius) at a speed of 50 mph. A four door family car moves around a wider curve (large radius) at the same speed. The cars have equal masses.
    a. Which car changes its direction more quickly?
    b. Which car has the greater acceleration?
    c. Which car has the greater centripetal force acting on it?
    d. What provides the centripetal force on each car?
20. A ball tied to a string is twirled around in a circle as shown. Copy the diagram and draw a vector showing the direction of the ball's velocity and the direction of the centripetal force on the ball at each of the three points.



21. Explain how the centripetal force needed to move an object in a circle is related to its mass, speed, and the radius of the circle.
22. What is centrifugal force? Is it a real force?
23. What keeps the moon in orbit around the Earth?
24. Is there a gravitational force between you and your pencil? Do you notice this force? Explain.
25. You experience a gravitational force that attracts you to Earth. Does Earth also experience a force? Explain.
26. What is a satellite?
27. Do all satellites move in perfect circles?

Section 6.4

28. Explain how you can find the location of an object's center of mass.
29. What is the difference between the center of mass and the center of gravity?
30. Explain how you can find the location of an object's center of gravity.
31. Why is a tall SUV more likely than a car to roll over in an accident?
32. A force is needed to change an object's linear motion. What is needed to change its rotational motion?
33. Tightrope walkers often use long poles to help them balance. Explain why this makes sense.
34. Explain the relationship between velocity and centripetal force in creating circular motion.

Solving Problems

Section 6.1

1. Use a scaled drawing to find the displacement for each of the following. Then check your work with the Pythagorean theorem.
    a. an ant that walks 3 meters north and 3 meters east
    b. a cat who runs 6 meters west and 2 meters north
    c. a car that drives 8 km south and 6 km west
    d. a plane that flies 200 miles north, turns, and flies 200 miles south
2. Draw a vector to scale to represent each velocity. Specify your scale.°
    a. (20 m/sec, 60°)
    b. (40 mph, 150°)
    c. (500 km/h, 180°)

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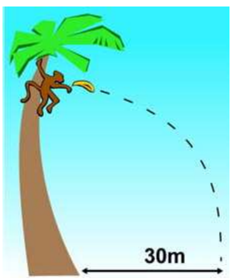
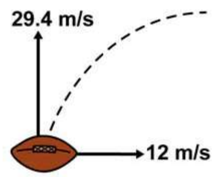
3. Calculate the speed of each velocity given in component form. Then draw the velocity vector to scale. State the scale you use.
   a. (5, 8) m/sec
   b. (60, 20) m/sec
4. You run straight off a high diving board at a speed of 6 m/sec. You hit the water 2 seconds later.
   a. How far did you travel horizontally during the 2 seconds?
   b. How far did you travel vertically during the 2 seconds?
   c. How fast were you moving horizontally when you hit the water?
   d. How fast were you moving vertically when you hit the water?
5. A monkey throws a banana horizontally from the top of a tree. The banana hits the ground 3 seconds later and lands 30 meters from the base of the tree.



   a. How fast did the monkey throw the banana?
   b. How high is the tree?
   c. How fast was the banana moving horizontally as it hit the ground?
   d. How fast was the banana moving vertically as it hit the ground?
   e. What was the resultant velocity of the banana as it hit the ground?
6. A bowling ball rolls off a high cliff at 5 m/sec. Complete the chart that describes its motion during each second it is in the air.

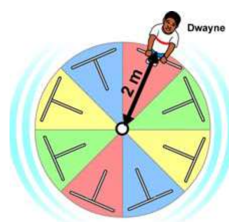
Time (sec)	Horizontal velocity (m/s)	Vertical velocity (m/s)	Horizontal distance (m)	Vertical distance (m)
0	5	0	0	0
1				
2				
3				
4				

7. You kick a football off the ground with a horizontal velocity of 12 m/sec to the right and a vertical velocity of 29.4 m/sec upward. Draw a diagram showing the football's trajectory. Draw vectors showing its horizontal and vertical velocity at each second until it returns to the ground.



Section 6.2

8. Find the angular speed of a ferris wheel that makes 12 rotations during 3 minute ride. Express your answer in rotations per minute.
9. A wheel makes 10 rotations in 5 seconds.
   a. Find its angular speed in rotations per second.
   b. How many degrees does it turn during the 5 seconds?
   c. Find its angular speed in degrees per second.
10. You are sitting on a merry-go-round at a distance of 2 meters from its center. It spins 15 times in 3 minutes.

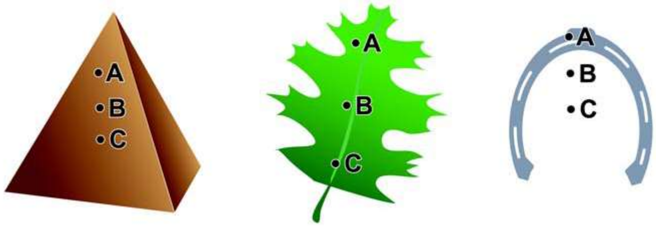


    a. What distance do you move as you make one revolution?
    b. What is your angular speed in RPM?
    c. What is your angular speed in degrees per minute?
    d. What is your linear speed in meters per minute?
    e. What is your linear speed in meters per second?
11. A car requires a centripetal force of 5,000 N to drive around a bend at 20 mph. What centripetal force is needed for it to drive around the bend at 40 mph? At 60 mph?
12. A 1000-kg car drives around a bend at 30 mph. A 2000-kg truck drives around the same bend at the same speed. How does the centripetal force on the car compare to the force on the truck?
13. What would happen to the force of gravity on you if you doubled your distance from the center of the Earth?
14. What would happen to the force of gravity on you if the Earth's mass suddenly doubled but the radius stayed the same?

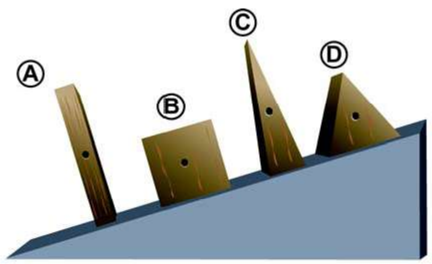
15. Use Newton's law of universal gravitation to find the force of gravity between the Earth and a 60-kilogram person.
16. Use Newton's law of universal gravitation to find the force of gravity between the Earth and the Sun. Use the data inside the back cover of your book.

Section 6.3

17. Choose the point that is at the center of mass of each object.



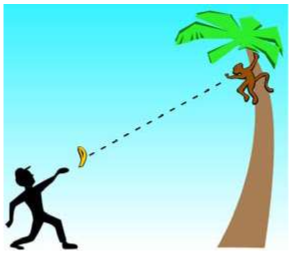
18. Which object(s) will topple? The center of gravity of each is marked.



Applying Your Knowledge

Section 6.1

1. What is the mathematical equation for a parabola shaped like a projectile's trajectory? How is the equation for a parabola similar to the equations for projectile motion?
2. You want to throw a banana up to a monkey sitting in a tree. The banana is directed straight toward the monkey as you release it. While throwing it you make a sound that scares the monkey. He jumps down from the tree at the instant you let go of the banana. Will the monkey catch it as he falls through the air?



Section 6.2

3. Research to find out how the angular speeds of a music CDs and DVDs compare.
4. How are projectile motion and circular motion similar? How are they different?

Section 6.3

5. There are many satellites orbiting earth for communications, weather monitoring, navigation, and other purposes. Research one of the uses of satellites and prepare a poster summarizing your results.
6. A *geosynchronous* satellite makes one revolution around the Earth each day. If positioned above the equator, it is always over the same point on Earth. Geosynchronous satellites must be a distance of approximately 42,000 km from the center of the Earth (36,000 km above Earth's surface). Calculate the linear speed of a geosynchronous satellite in km/h.
7. The International Space Station is an Earth satellite. Research the history and purpose of this space station.

Section 6.4

8. The toy bird shown to the right can be easily balanced on a fingertip, and it sways side-to-side without falling if it is tapped. How do you think the bird balances this way?