4•2 Projectile and Circular Motion

Science Words

projectile
centripetal acceleration
centripetal force

Objectives

- Explain why things that are thrown or shot follow a curved path.
- Compare motion in a straight line with circular motion.
- Define *weightlessness.*

Projectiles

Have you noticed that nearly all the moving objects described in this unit so far have been moving in straight lines? But that's not the only kind of motion you know about. Skateboarders wheel around in circles, cars go around hairpin curves, and rockets shoot upward and curve back to Earth. How do the laws of motion account for these kinds of motion?

If you've ever played darts, thrown a ball, or shot an arrow from a bow, you have probably noticed that these objects didn't travel in straight lines. They start off straight, but they curve downward. That's why dart players and archers learn to aim above their targets.

Anything that's thrown or shot through the air is called a **projectile.** Because of Earth's gravitational pull and their own inertia, projectiles follow a curved path. They have both horizontal and vertical velocities. The basketball in **Figure 4-7** is a projectile.

Horizontal Motion

When you throw a ball, like the pitcher in **Figure 4-8,** the force from your hand makes the ball move forward. It gives the ball *horizontal motion,* that is, motion parallel to Earth's surface. Once you let go of the ball, no other force accelerates it forward, so its horizontal velocity is constant if you ignore air resistance.

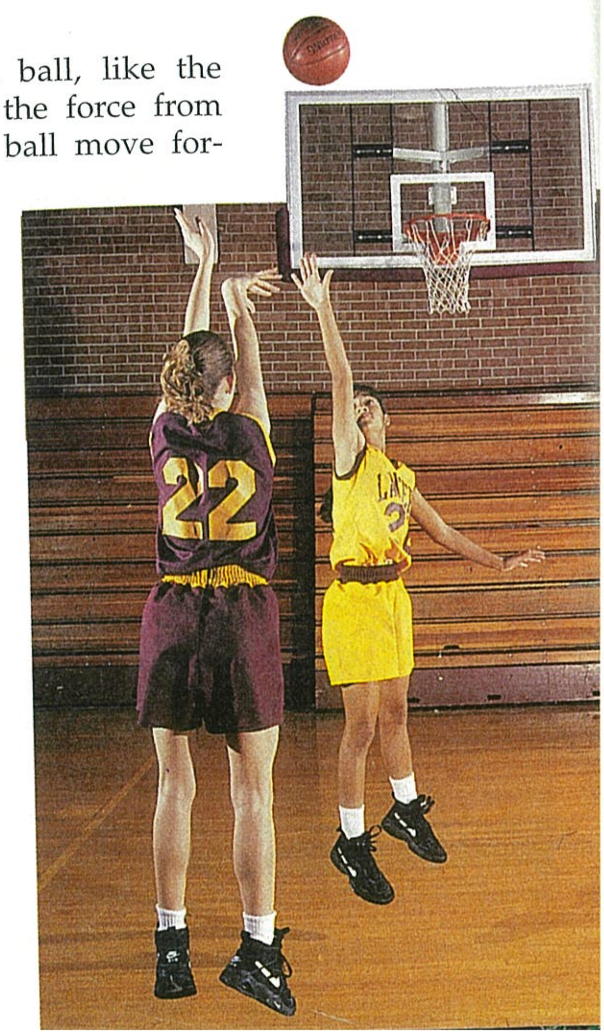


Figure 4-7

A basketball becomes a projectile when it is shot toward the basket. *Describe the path the ball takes after it leaves the shooter's hands.*

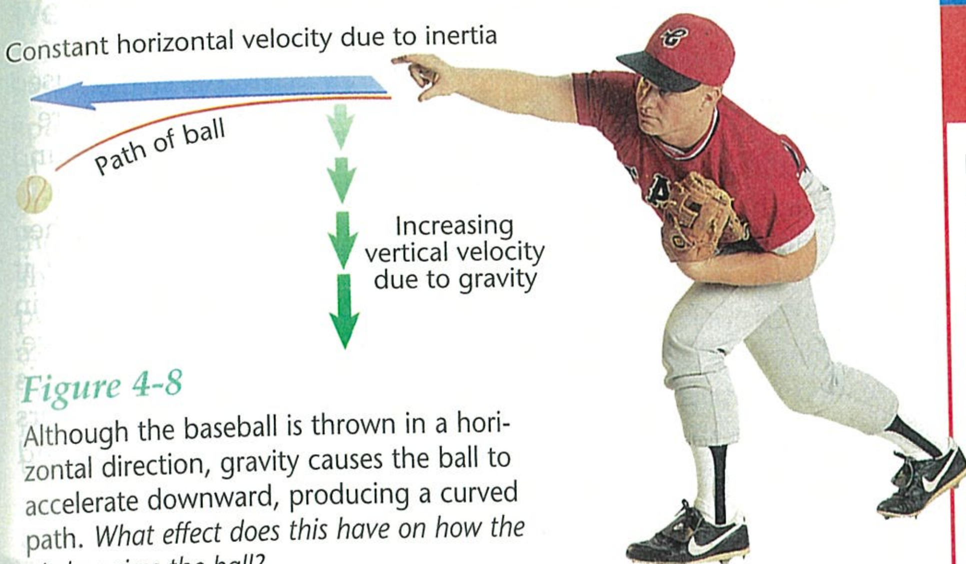


Figure 4-8

Although the baseball is thrown in a horizontal direction, gravity causes the ball to accelerate downward, producing a curved path. *What effect does this have on how the pitcher aims the ball?*

Vertical Motion

When you let go of the ball, something else happens, as well. Gravity starts pulling it downward, giving it *vertical motion*, or motion perpendicular to Earth's surface. Now the ball has constant horizontal velocity but increasing vertical velocity. Gravity exerts an unbalanced force on the ball, changing the direction of its path from forward only to forward and downward. The ball's horizontal and vertical motions are completely independent of each other.

If you throw a ball horizontally from shoulder height, will it take longer to hit the ground than a ball you simply drop from the same height? Surprisingly, both will hit the ground at the same time. If you have a hard time believing this, **Figure 4-9** may help. The two balls have the same acceleration due to gravity, $9.8\ m/s^2$ downward.

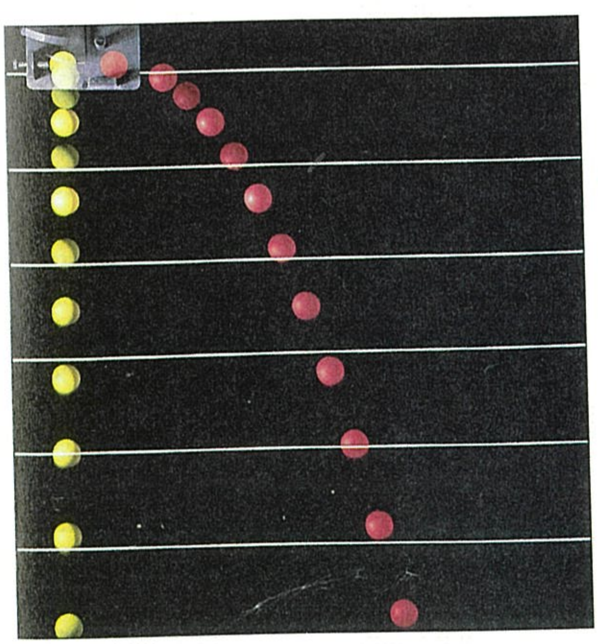


Figure 4-9

The two balls in the photograph were released at the same time. Although the red ball has horizontal velocity, gravity causes both balls to accelerate downward at the same rate.

MiniLAB

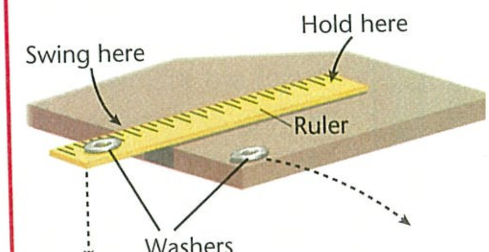
Do projectiles fall more slowly than dropped objects?

Procedure

1. Place a flat ruler near the edge of a table. Place a metal washer on the end of the ruler and extend that end of the ruler about 5 cm over the table's edge.
2. Place a second, identical washer on the corner of the table beside the ruler, as shown in the diagram below.
3. With a quick motion from the supported end of the ruler, slide the ruler out from under the first washer and knock the second washer forward so that it flies out from the table as a projectile.
4. Repeat the experiment several times, observing whether the washers hit the floor at the same time or different times by listening to the sound when they hit.

Analysis

1. Do the washers hit at the same time or at different times? Explain your answer, using your observations to support your conclusions.
2. Would the results be the same if you used two different masses, such as a washer and a small piece of tissue paper? Explain your prediction. Try it!

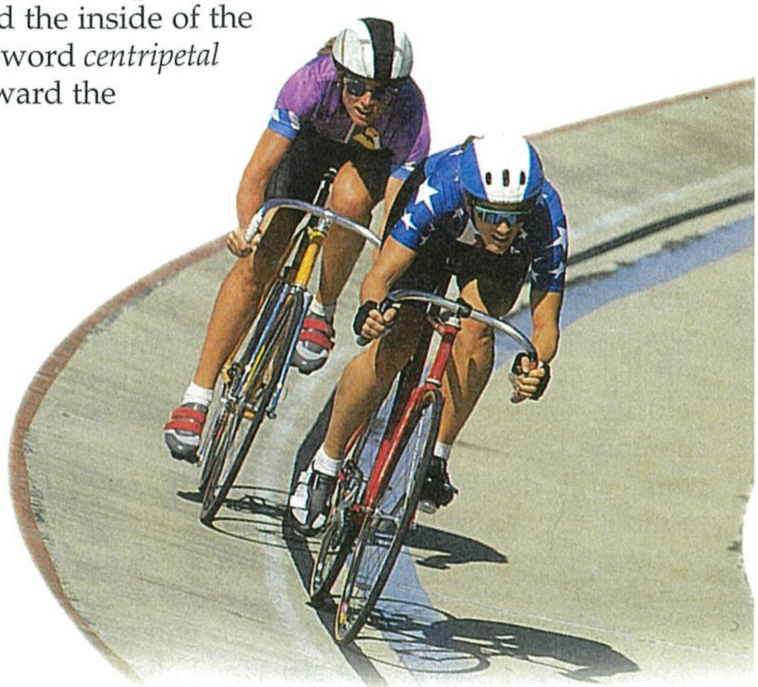


Motion Along Curves

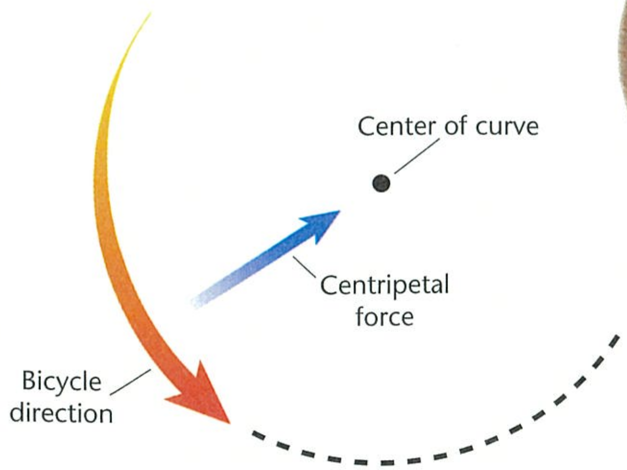
Recall that acceleration is a rate of change in velocity caused by a change in speed, in direction, or both. Now, picture a bicycle moving at a constant speed along the westbound straightaway of an oval track. Because its speed is constant in a straight line, the bicycle is not accelerating. However, when the bicycle enters a curve, even if its speed does not change, it is accelerating because its direction is changing. The change in the direction of the velocity is toward the center of the curve. Acceleration toward the center of a curved or circular path is called **centripetal acceleration.** The bicycles and their riders in **Figure 4-10** experience centripetal acceleration and lean toward the inside of the curve. The word *centripetal* means "toward the center."

Figure 4-10

These bicycle riders are experiencing centripetal acceleration.



A *What is providing the centripetal force that helps these riders follow a circular path? In what direction are they accelerating?*



B The direction of the riders' velocity is constantly changing because of the influence of centripetal force.

Centripetal Force

In order for the bicycle to be accelerating, some unbalanced force must be acting on it in a direction toward the center of the curve. That force is a centripetal force. **Centripetal force** is a force acting toward the center of a curved or circular path.

When a car rounds a sharp curve on a highway, the centripetal force is the friction between the tires and the road surface. But if the road is icy or wet and the tires lose their grip, the centripetal force may not be enough to overcome the car's inertia. The car would then keep moving in a straight line in the direction it was traveling at the spot where it lost traction.

Weightlessness in Orbit

Maybe you've seen pictures of astronauts floating inside the space shuttle with various pieces of equipment suspended in midair beside them. Any item that is not fastened down in the shuttle will float around and pose a possible hazard for the astronauts and their equipment. The astronauts and their belongings are experiencing the sensation of weightlessness.

But to be truly weightless, the astronauts would have to be free from the effects of gravity. Orbiting 400 km above Earth, the shuttle and everything inside it still respond to those effects. In fact, gravity keeps the shuttle in orbit.

Free-Falling

So what does it really mean to say that something is weightless in orbit? Think about how the weight of an object is measured. When you place an object on a scale, gravity causes the object to

USING TECHNOLOGY

Roller Coaster Physics

A roller coaster designer applies the laws of motion so that it will be the most exciting ride in the park. A ride begins when a chain pulls the cars to the top of the first hill. Once the cars are released, acceleration increases until all of the cars are headed downward.

The debate on which seat is the scariest continues to rage, and the answer is, "that depends." As the cars descend, their speed increases. The rear car starts down the slope at a much greater speed than the front car, thus giving the passengers the sense of being hurled over the edge. At the bottom of the hill, it is a different story. When the change in direction from down to up occurs, the front car will be going fastest and its passengers will experience the greater forces. As the cars pop over the top of the hill, the passengers in the rear car may experience a considerable force, resulting in the sensation of being thrown free.

As ride technology improves, roller coasters get larger and faster. The Magnum XL 200 at Cedar Point in Sandusky, Ohio, has a first hill 61 m (201 feet) high, reaches a speed of 112 km/h, and covers 1.6 km (5106 feet) of track in 2½ minutes.

Riders experience rapid acceleration

Think Critically:

Describe the roller-coaster design that would result in the greatest sensations for the passengers.

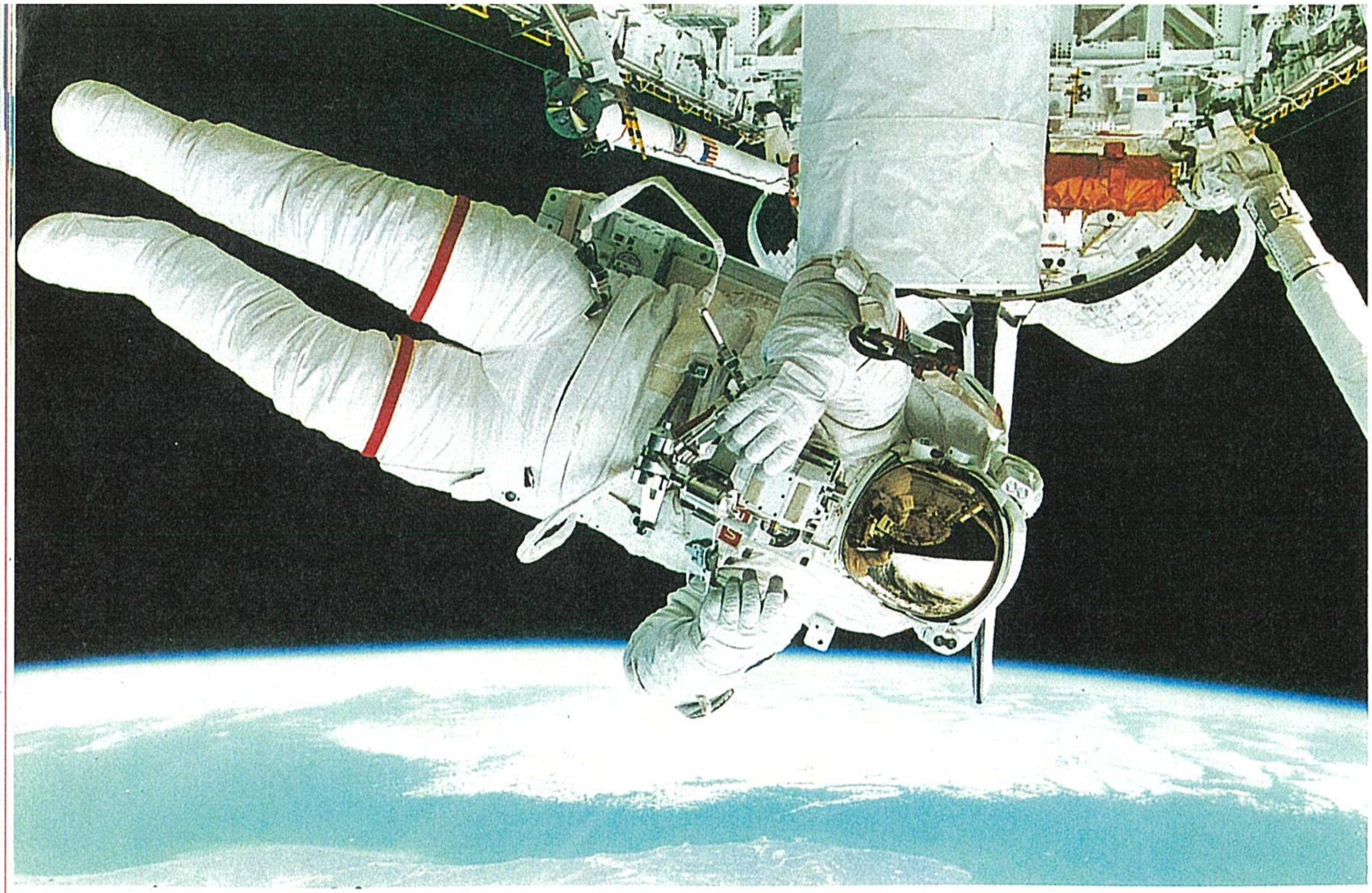


Figure 4-11

The space shuttle and everything in it are in free-fall around Earth, thus producing apparent weightlessness. *Are objects in orbit around Earth really weightless? Explain.*

push down on the scale. In turn, the scale pushes back on the object with the same force. The dial on the scale measures the amount of upward force needed to offset gravity.

Now suppose that the scale is falling, being pulled downward by gravity at the same rate as the object being weighed. The scale couldn't push back on the object, so its dial would read zero. The object would seem to be weightless. This is what is happening in a space shuttle orbiting Earth. The shuttle and everything in it, including the astronaut working in **Figure 4-11,** are all "falling" toward Earth at exactly the same rate of acceleration. When an object is influenced only by gravity, it is said to be in free-fall. An orbiting space shuttle and all its contents are in free-fall around Earth.

INTEGRATION
Life Science

Effects of Weightlessness

As you move about in your daily routines, the resistance provided by gravity helps you exercise your body. What happens to the physical condition of astronauts who experience the sensation of weightlessness for extended periods of time? When Russian cosmonauts experienced weightlessness for more than 200 consecutive days, they developed health problems. Health tests performed on American astronauts have also shown that some bone and muscle deterioration occurs during long periods of weightlessness.

Exercising in Space

Flight doctors have developed special exercise programs for astronauts to reduce the health problems related to weightlessness. Several activities, such as the one in **Figure 4-12,** are helpful. They include isometric exercises, in which muscles push against other muscles in the body. For example, you can feel some resistance if you place your left palm against your right palm and push your palms together for 10 seconds.

Aboard the space shuttle, astronauts also walk on a unique treadmill for 15 to 30 minutes each day. Special attachments to their arms and legs make their muscles work even harder. An air duct circulates air to help dry off their sweat. They can even listen to music or gaze out the window into space while they exercise.

Figure 4-12

Astronauts don't have much room to exercise inside the shuttle. Here astronaut Ellen Baker exercises aboard Columbia while in orbit.

Section Wrap-up

Review

1. Use a diagram similar to **Figure 4-8** to show why a dart player has to aim above the target to hit the bull's-eye. In your diagram, show the forces acting on the dart, the dart's path, and the two kinds of motion involved.
2. A child is swinging a yo-yo in a circle. What provides the force to keep the yo-yo going in a circle? What is the force called? What happens if the string breaks?
3. **Think Critically:** Does the mass of an astronaut change when he or she is in orbit around Earth? Does an astronaut's weight change?

Skill Builder

Making and Using Tables

Make a table showing important characteristics of projectile motion, circular motion, and free-fall. Table headings should include: *Kind of Motion, Shape of Path,* and *Laws or Forces Involved.* You may add other headings. If you need help, refer to Making and Using Tables in the **Skill Handbook.**

Science Journal

Write a paragraph describing a situation in which you experienced something close to free-fall or a feeling of weightlessness. Think about amusement park rides, elevators, athletic events, or even movie scenes.

SCIENCE & SOCIETY

4•3 TECHNOLOGY:

Sending up Satellites

Science Words

artificial satellite

Objectives

- Explain how satellites are placed into orbit around Earth.
- Give examples of how satellites can be used.

What is an Earth satellite?

When watching a sports program, newscast, or weather report, have you heard the announcer state that a report was received "via satellite"? You may know that Earth's moon is a natural satellite, but the moon was not the source of these reports. What other satellites are orbiting Earth? **Artificial satellites** are human-made devices that orbit Earth for a specific purpose. Once in orbit, their motion and behavior are like those of natural satellites such as Earth's moon.

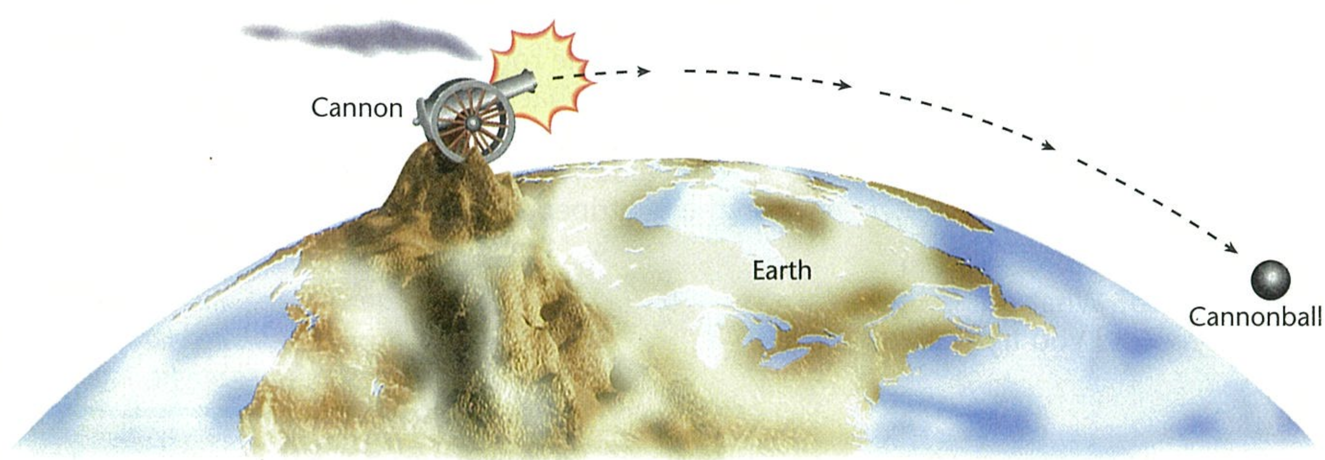
Launching Artificial Satellites

Newton's original idea of launching a satellite by blasting it horizontally from a mountaintop, illustrated in **Figure 4-13,** did not turn out to be practical, but in the 1950s, the developing field of rocketry did make launching satellites possible. A multistage rocket system typically boosts the satellite to the desired height of the orbit and then fires again to accelerate the satellite to the speed required to stay in orbit. This speed for circular orbits is around 8 km/s, or about 29 000 km/h.

In 1957, the former Soviet Union launched the first artificial Earth satellite. The satellite, called Sputnik, was a metallic instrument module having a mass of only 84 kg and a diameter of 60 cm. It orbited Earth about once every 90 minutes. Literally thousands of satellites have now been placed into orbit, including some that have orbited Mars, Venus, and Earth's moon.

Figure 4-13

Newton's idea of using cannons to launch satellites was based on the technology of the time. He proposed that if a cannonball were launched with large enough speed, the curve of its trajectory would match Earth's curve and the ball would orbit Earth at a constant height. *How is his idea similar to the way satellites are put into orbit today?*



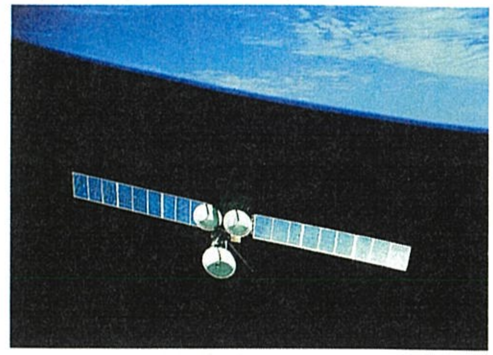
How We Use Satellites

Artificial satellites, such as the one in **Figure 4-14,** serve a variety of different purposes. Communications and weather satellites are most familiar. These are usually geostationary satellites, which are put into orbit with a speed that matches the movement of Earth as it spins on its axis. Thus, as **Figure 4-15** shows, they appear to be stationary high above a given location on Earth. Communication satellites serve as receivers and transmitters to relay TV and radio signals around the world. Weather satellites use different photographic techniques to monitor weather patterns and ground temperatures.

Many satellites are used by the military to monitor actions in other countries—tiny details can be photographed from hundreds of kilometers above Earth.

Figure 4-14

Satellites can remain in orbit performing their tasks for many years.



Falling Satellites

Artificial satellites cannot orbit forever. Even in high orbits, small amounts of air resistance gradually cause a satellite to lose energy, allowing Earth's gravity to pull it lower. As a satellite is pulled downward into the denser part of Earth's atmosphere, it usually burns up in the extreme heat generated by atmospheric friction.

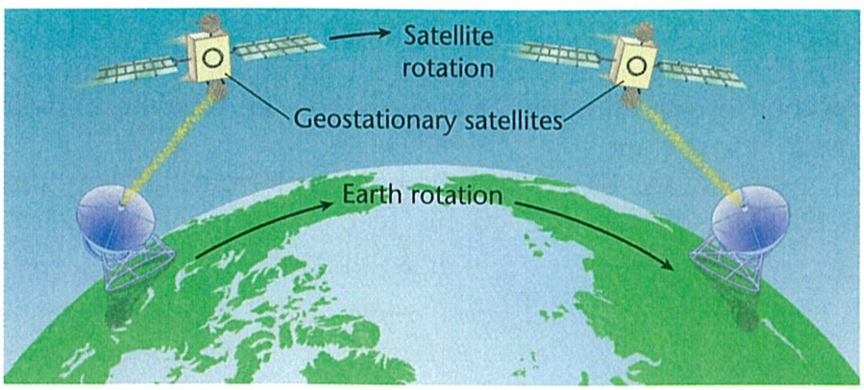


Figure 4-15

If you look up at a geostationary satellite, it appears to be hovering motionless overhead. *Why are communication satellites placed in geostationary orbits?*

Section Wrap-up

Review

1. For what purposes are artificial satellites used?
2. Why are geostationary satellites often useful for communications and monitoring weather?

Explore the Technology

Rockets are used to launch satellites. Why do you think Newton's original idea has not been practical for launching satellites? Try to cite several problems.

SCIENCE & SOCIETY