Section 2
Gravity and Motion

Key Concept Gravity can be an unbalanced force that causes predictable changes in motion.

What You Will Learn
- The acceleration due to gravity is the same for all objects near Earth's surface.
- Air resistance is a force that opposes the motion of objects through air.
- Projectile motion has two components–horizontal motion and vertical motion.

Why It Matters
Gravity affects the motion of everything that you drop or throw.

Suppose that you dropped a baseball and a marble at the same time. Which do you think would land on the ground first?

In ancient Greece around 400 BCE, a philosopher named Aristotle (AR is TAHT'l) thought that the rate at which an object falls depends on the object's mass. If you asked Aristotle whether the baseball or the marble would land first, he would have said the baseball. But Aristotle never tried dropping objects that have different masses to test his idea about falling objects.

Gravity and Falling Objects
Late in the 16th century, Galileo Galilei (GAL uh LAY oh GAL uh LAY), an Italian scientist, questioned Aristotle's idea about falling objects. Galileo argued that the mass of an object does not affect the time the object takes to fall to the ground, as shown in **Figure 1.** According to one story, Galileo proved his argument by dropping two metal balls of very different masses from the top of the Leaning Tower of Pisa in Italy. The people watching from the ground below were amazed to see the two balls

land at the same time. Whether or not this story is true, Galileo's work changed people's understanding of gravity and falling objects.

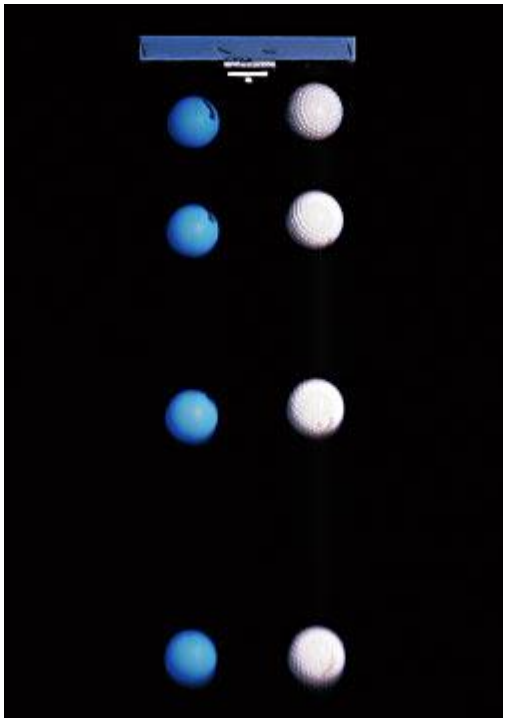


Figure 1 This stop-action photo shows that a table-tennis ball and a golf ball fall at the same rate even though they have different masses.

Gravity and Acceleration

Objects fall to the ground at the same rate because the acceleration due to gravity is the same for all objects near Earth's surface. Why is this true? Acceleration depends on both force and mass. A heavier object experiences a greater gravitational force than a lighter object does. But a heavier object is also harder to accelerate because it has more mass. The extra mass of the heavy object exactly makes up for the additional gravitational force.

Standards Check Why will a baseball and a marble fall at the same rate?

Acceleration and Changes in Velocity

Acceleration is the rate at which velocity changes over time. An object accelerates when the forces on it are unbalanced. Gravity exerts a downward, unbalanced force on falling objects. So, the objects accelerate. Falling objects accelerate toward Earth at a rate of 9.8 meters per second per second. This rate is written as 9.8 m/s^2. So, for every second that something falls, its downward velocity increases by 9.8 m/s, as shown in **Figure 2.** You can calculate the change in velocity (Δv) of a falling object by using the following equation:

$$\Delta v = g \times t$$

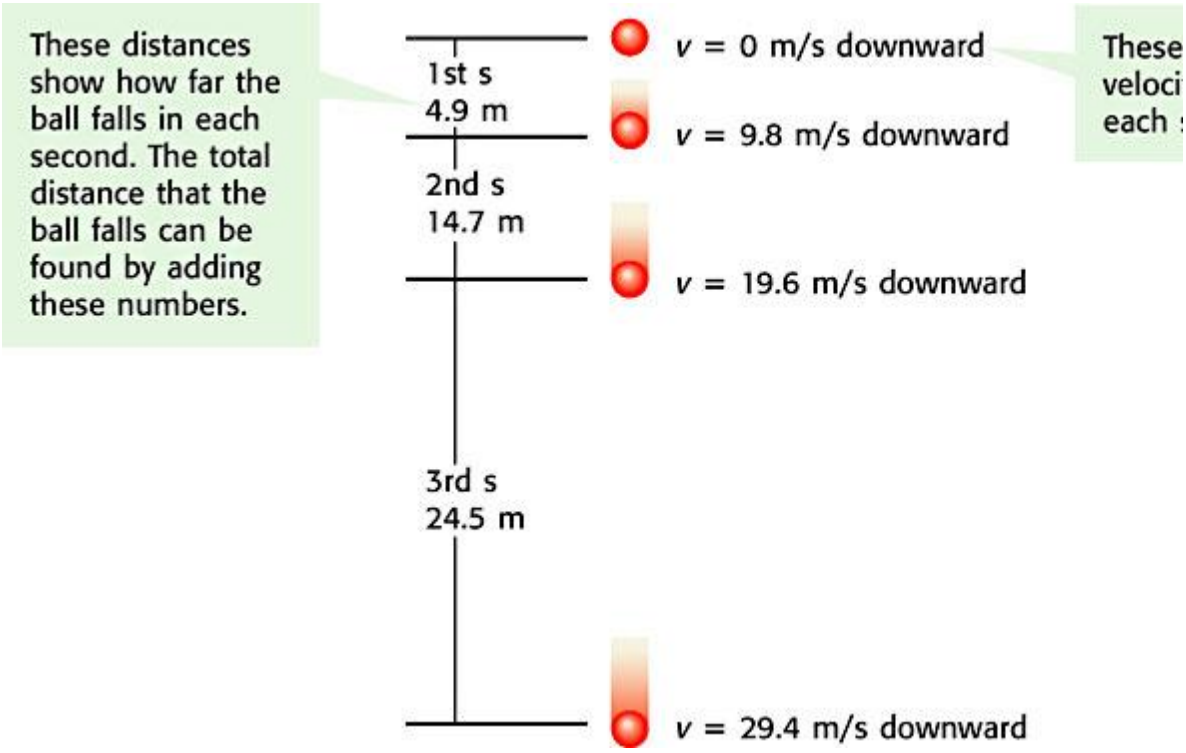


Figure 2 A falling object accelerates at a constant rate. The object falls faster and farther each second than it did the second before.

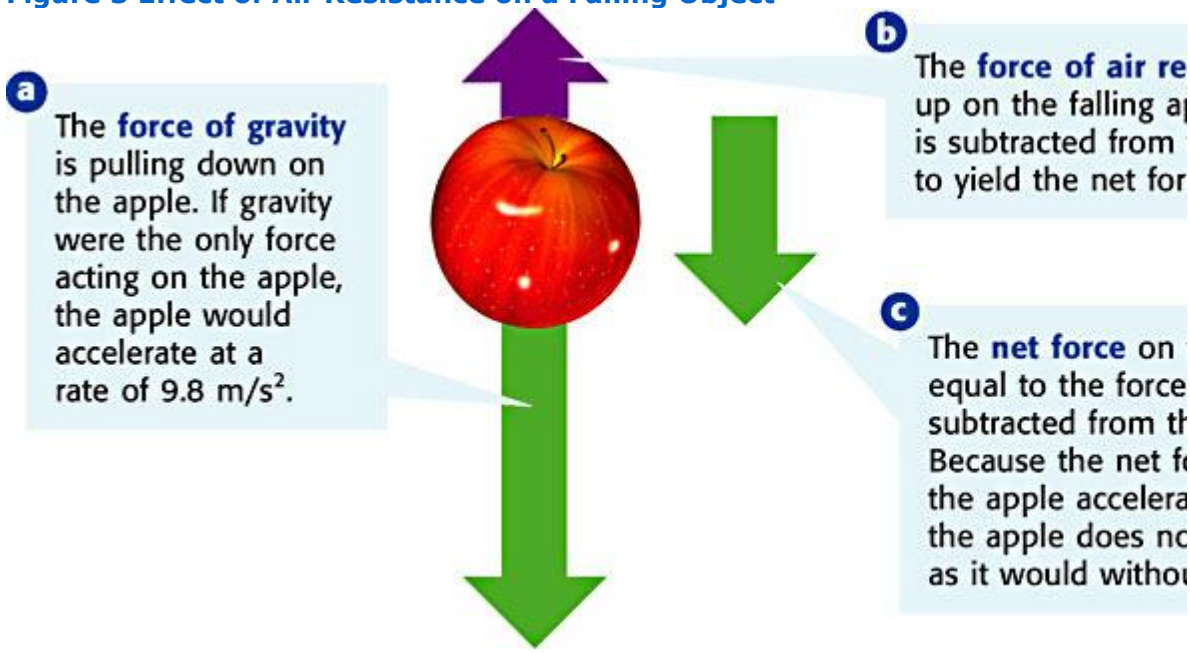
In this equation, g is the acceleration due to gravity. And t is the time the object falls (in seconds). The change in velocity is the difference between the final velocity and the starting velocity. If the object starts at rest, this equation gives you the object's velocity after falling for a certain amount of time.

Air Resistance and Falling Objects

Try dropping two sheets of paper—one crumpled in a tight ball and the other kept flat. What happened? Does this simple experiment seem to contradict what you just learned about falling objects? The flat paper falls more slowly than the crumpled paper because of air resistance. *Air resistance* is the force that opposes the motion of objects through air.

The magnitude of air resistance acting on an object depends on the size, shape, and speed of the object. Air resistance affects the flat sheet of paper more than the crumpled one. The larger surface area of the flat sheet causes the flat sheet to encounter more air as it falls. Thus there is more air resistance. **Figure 3** shows the effect of air resistance on a falling object.

Figure 3 Effect of Air Resistance on a Falling Object



Standards Check Which two forces combine to determine the net force on a falling object? In which directions do these two forces act?

Acceleration and Terminal Velocity

As the speed of a falling object increases, air resistance increases. The upward force of air resistance continues to increase until it is equal to the downward force of gravity. At this point, the net force is 0 N, and the object stops accelerating. The object then falls at a constant velocity called the **terminal velocity.**

Terminal velocity can be a good thing. Every year, cars, buildings, and vegetation are severely damaged in hailstorms. The terminal velocity of hailstones is between 5 and 40 m/s, depending on their size. If there were no air resistance, hail-stones would hit the ground at velocities near 350 m/s!

Free Fall and Air Resistance

Sky divers are often described as being in free fall before they open their parachutes. But this description is not correct. A sky diver is falling through air. As a result, air resistance is always acting on the sky diver.

Something is in **free fall** only if gravity is pulling it down and no other forces are acting on it. Because air resistance is a force, free fall can happen only where there is no air. For example, there is no air in outer space or in a vacuum. The term *vacuum* is used to describe a place in which there is no matter. Vacuum chambers are special containers from which air can be removed to make a vacuum. **Figure 4** shows two objects falling in a vacuum chamber. Because there is no air resistance in a vacuum, the two objects are in free fall.

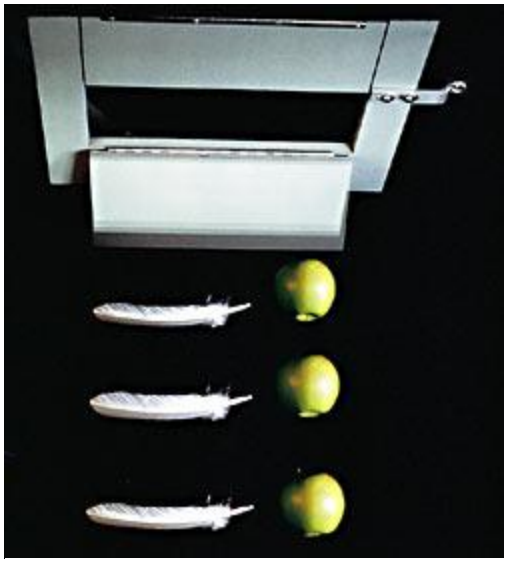


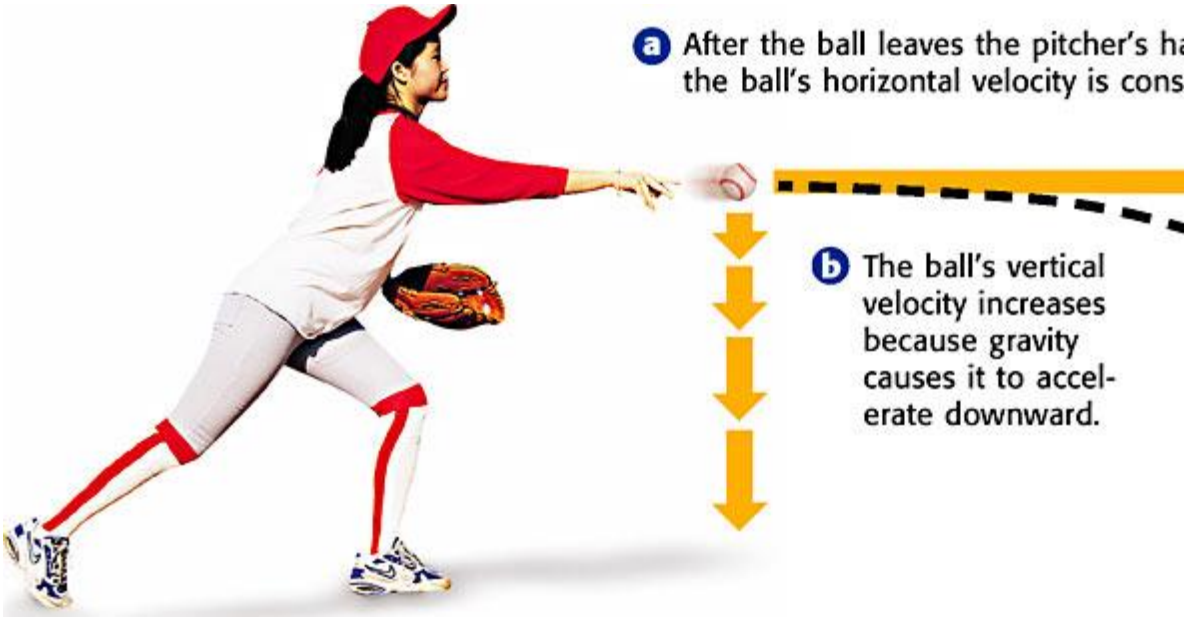
Figure 4 Air resistance usually causes a feather to fall more slowly than an apple falls. But in a vacuum chamber, a feather and an apple fall with the same acceleration because both are in free fall.

Standards Check Why can an object falling in a vacuum never reach terminal velocity?

Projectile Motion and Gravity

The movement of a hopping grasshopper is an example of projectile motion. **Projectile motion** is the curved path an object follows when it is thrown or propelled near the surface of Earth. Projectile motion is made of two different motions, or movements—horizontal movement and vertical movement. These two movements are separate. So, they have no effect on each other. But when these two movements are put together, they form a curved path, as shown in **Figure 5.** Projectile motion can be seen in the following situations:

Figure 5 Projectile Motion



- a frog leaping
- water spraying from a hose
- a swimmer diving into water
- balls being juggled

Horizontal Movement

When you throw a ball to a friend, your hand applies a force to the ball that makes the ball begin to move forward. This force gives the ball its horizontal movement, which is movement parallel to the ground. After the ball leaves your hand, no horizontal forces are acting on the ball (ignoring air resistance). Even gravity does not affect the horizontal movement of projectile motion. So, there are no forces to change the ball's horizontal velocity. Thus, the horizontal velocity of the ball remains the same after the ball leaves your hand, as shown in **Figure 5.**

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Vertical Movement

Gravity pulls everything on Earth down toward the center of Earth. A ball in your hand doesn't fall down because your hand is holding the ball. After you throw the ball, gravity pulls the ball down. Gravity gives the ball vertical movement, which is

movement perpendicular to the ground. Gravity pulls the ball in projectile motion down at an acceleration of 9.8 m/s^2 (if air resistance is ignored). This rate is the same for all falling objects on Earth. **Figure 6** shows that the downward acceleration of a thrown ball and a falling ball are the same.

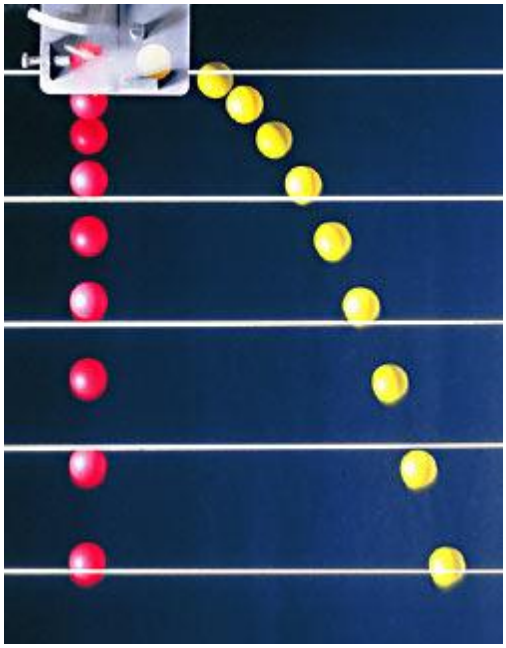


Figure 6 The two balls have the same acceleration due to gravity even though the yellow ball is in projectile motion and the red ball is not.

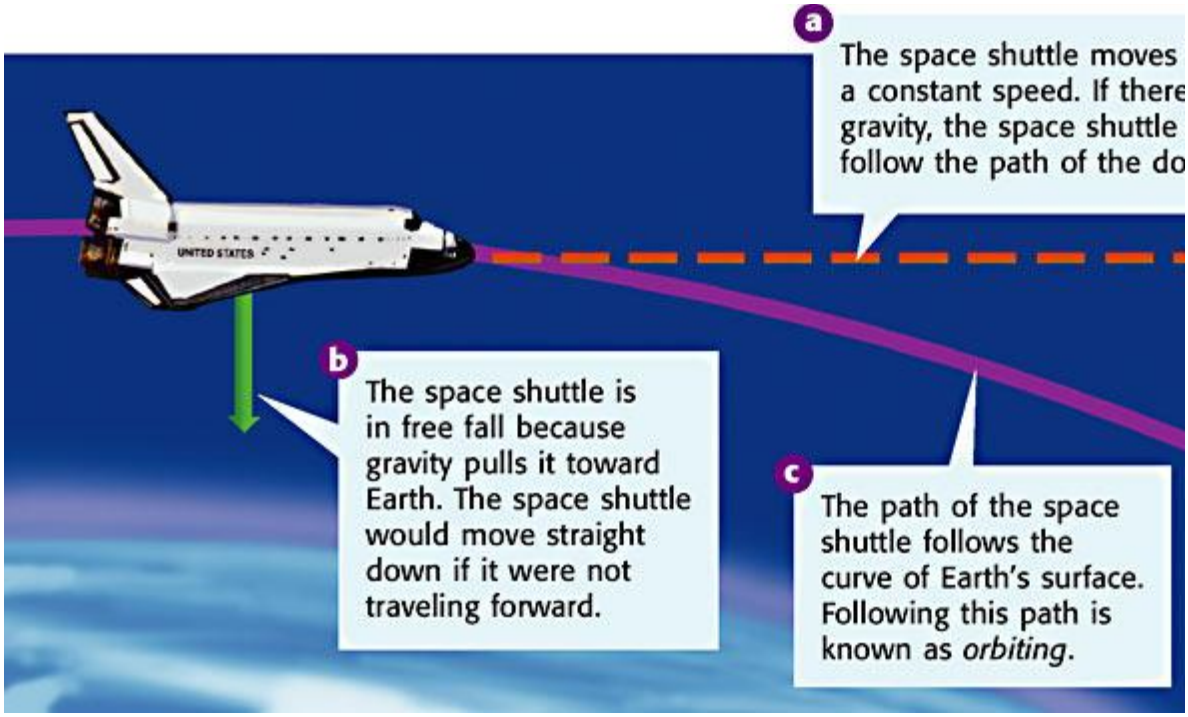
Because objects in projectile motion accelerate down, you always have to aim above a target if you want to hit it with a thrown or propelled object. For this reason, when you aim an arrow directly at a round bull's-eye, your arrow hits the bottom of the circle rather than the middle of the circle.

Standards Check What force affects the vertical movement of an object in projectile motion?

Orbiting and Gravity

An object is orbiting when it is moving around another object in space. A spacecraft orbiting Earth is moving forward. But the spacecraft is also in free fall toward Earth. **Figure 7** shows how these two movements come together to form an orbit.

Figure 7 How an Orbit Is Formed



The two movements that come together to form an orbit are similar to the horizontal and vertical movements in projectile motion. In fact, you can think of something in orbit as being in projectile motion but never reaching the ground.

Orbiting and Centripetal Force

Besides spacecraft, many other things in the universe are in orbit. The moon orbits Earth. Earth and the other planets orbit the sun. Also, many stars orbit large masses in the center of galaxies. The path of an orbiting object is not quite a circle. Instead, the path is an ellipse.

Anything in orbit is always changing direction. An unbalanced force is needed to change the movement of an object. So, there must be an unbalanced force acting on anything in orbit. This

unbalanced force that makes things move in an elliptical path (or in a circular path) is called a *centripetal force* (sen TRIP uht'l FOHRS). The word *centripetal* means "toward the center." Gravity provides the centripetal force that keeps things in orbit, as shown in **Figure 8.**

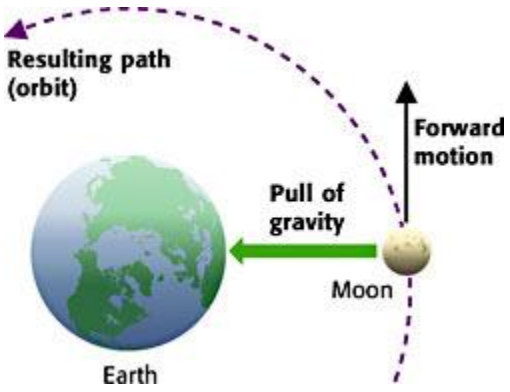


Figure 8 Gravity changes the straight-line path of the moon into a curved orbit. **What kind of force provided by gravity keeps the moon in orbit around Earth?**

Gravity and the Solar System

Gravity plays an important role in maintaining the shape of the solar system. Gravity between the sun and the planets keeps the planets in orbit around the sun. Gravity provides a centripetal force on the planets. Also, gravity between a planet and its moons keeps the moons in orbit around the planet. Gravity also keeps asteroids in orbit around the sun. And gravity between comets and the sun makes the comets orbit the sun in very long ellipses.

Gravity can also change the movement of very small things in the solar system. For example, the rings of Saturn are made of tiny pieces of ice and dust. These pieces of ice and dust stay around the planet in a ring because of gravity.

Standards Check What helps keep the planets orbiting the sun?

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Section Summary

- Gravity is the force that causes all objects on Earth to accelerate downward at a rate of 9.8 m/s^2.
- Air resistance slows the acceleration of falling objects. An object falls at its terminal velocity when the upward force of air resistance equals the downward force of gravity.
- An object is in free fall if gravity is the only force acting on it.
- Projectile motion is the curved path that an object follows when thrown or propelled near the surface of Earth.
- Projectile motion has two components: horizontal motion and vertical motion. Gravity affects only the vertical motion of projectile motion.
- Gravity provides the centripetal force that keeps objects in orbit.
- Gravity is the force that keeps the solar system together.