

Gravity

* Annotated *

Reading Guide

What You'll Learn

- Describe the gravitational force.
- Distinguish between mass and weight.
- Explain why objects that are thrown will follow a curved path.
- Compare circular motion with motion in a straight line.

Why It's Important

There is a gravitational force between you and every other object in the universe.

Review Vocabulary

acceleration: the rate of change of velocity which occurs when an object changes speed or direction

New Vocabulary

- gravity
- weight
- centripetal acceleration
- centripetal force

What is gravity?

There's a lot about you that's attractive. At this moment, you are exerting an attractive force on everything around you—your desk, your classmates, even the planet Jupiter millions of kilometers away. It's the attractive force of gravity.

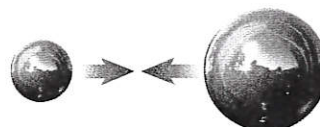
1.a. Anything that has mass is attracted by the force of gravity.

Gravity is an attractive force between any two objects that depends on the masses of the objects and the distance between them. This force increases as the mass of either object increases, or as the objects move closer, as shown in Figure 11.

You can't feel any gravitational attraction between you and this book because the force is weak. Only Earth is both close enough and has a large enough mass that you can feel its gravitational attraction. While the Sun has much more mass than Earth, the Sun is too far away to exert a noticeable gravitational attraction on you. And while this book is close, it doesn't have enough mass to exert an attraction you can feel.

1.c
Gravity—A Basic Force Gravity is one of the four basic forces. The other basic forces are the electromagnetic force, the strong nuclear force, and the weak nuclear force. The two nuclear forces only act on particles in the nuclei of atoms. Electricity and magnetism are caused by the electromagnetic force. Chemical interactions between atoms and molecules also are due to the electromagnetic force.

1.b
Figure 11 The gravitational force between two objects depends on their masses and the distance between them.



If the mass of either of the objects increases, the gravitational force between them increases.



If the objects are closer together, the gravitational force between them increases.

Topic: Gravity on Other Planets

Visit gpscience.com Web links to information about the gravitational acceleration near the surface of different planets in the solar system.

Activity Make a graph with the gravitational acceleration on the y -axis, and the planet's mass on the x -axis. Infer from your graph how the gravitational acceleration depends on a planet's mass.



Figure 12 The location of the planet Neptune in the night sky was correctly predicted using Newton's laws of motion and the law of universal gravitation.

The Law of Universal Gravitation

For thousands of years people everywhere have observed the stars and the planets in the night sky. Gradually, data were collected on the motions of the planets by a number of observers. Isaac Newton used some of these data to formulate the law of universal gravitation, which he published in 1687. This law can be written as the following equation.

The Law of Universal Gravitation

$$\text{gravitational force} = (\text{constant}) \times \frac{(\text{mass 1}) \times (\text{mass 2})}{(\text{distance})^2}$$

$$F = G \frac{m_1 m_2}{d^2}$$

2. a

In this equation G is a constant called the universal gravitational constant, and d is the distance between the two masses, m_1 and m_2 . The law of universal gravitation enables the force of gravity to be calculated between any two objects if their masses and the distance between them are known.

2. b

The Range of Gravity According to the law of universal gravitation, the gravitational force between two masses decreases rapidly as the distance between the masses increases. For example, if the distance between two objects increases from 1 m to 2 m, the gravitational force between them becomes one fourth as large. If the distance increases from 1 m to 10 m, the gravitational force between the objects is one hundredth as large.

However, no matter how far apart two objects are, the gravitational force between them never completely goes to zero. Because the gravitational force between two objects never disappears, gravity is called a long-range force.

2. c



Finding Other Planets Earth's motion around the Sun is affected by the gravitational pulls of the other planets in the solar system. In the same way, the motion of every planet in the solar system is affected by the gravitational pulls of all the other planets.

In the 1840s the most distant planet known was Uranus. The motion of Uranus calculated from the law of universal gravitation disagreed slightly with its observed motion. Some astronomers suggested that there must be an undiscovered planet affecting the motion of Uranus. Using the law of universal gravitation and Newton's laws of motion, two astronomers independently calculated the orbit of this planet. As a result of these calculations, the planet Neptune, shown in **Figure 12**, was found in 1846.

Earth's Gravitational Acceleration

If you dropped a bowling ball and a marble at the same time, which would hit the ground first? Suppose the effects of air resistance are small enough to be ignored. When all forces except gravity acting on an a falling object can be ignored, the object is said to be in free fall. Then all objects near Earth's surface would fall with the same acceleration, just like the two balls in **Figure 13**.

Close to Earth's surface, the acceleration of a falling object in free fall is about 9.8 m/s^2 . This acceleration is given the symbol g and is sometimes called the acceleration of gravity. By Newton's second law of motion, the force of Earth's gravity on a falling object is the object's mass times the acceleration of gravity. This can be expressed by the equation:

Force of Earth's Gravity

$$\text{force of gravity (N)} = \text{mass (kg)} \times \text{acceleration of gravity (m/s}^2\text{)}$$

$$F = mg$$

For example, the gravitational force on a sky diver with a mass of 60 kg would be

$$F = mg = (60 \text{ kg}) (9.8 \text{ m/s}^2) = 588 \text{ N}$$

Weight Even if you are not falling, the force of Earth's gravity still is pulling you downward. If you are standing on a floor, the net force on you is zero. The force of Earth's gravity pulls you downward, but the floor exerts an upward force on you that balances gravity's downward pull.

Whether you are standing, jumping, or falling, Earth exerts a gravitational force on you. The gravitational force exerted on an object is called the object's **weight**. Because the weight of an object on Earth is equal to the force of Earth's gravity on the object, weight can be calculated from this equation:

Weight Equation

$$\text{weight (N)} = \text{mass (kg)} \times \text{acceleration of gravity (m/s}^2\text{)}$$

$$W = mg$$

On Earth where g equals 9.8 m/s^2 , a cassette tape weighs about 0.5 N, a backpack full of books could weigh 100 N, and a jumbo jet weighs about 3.4 million N. A sky diver with a mass of 60 kg has a weight of 588 N. Under what circumstances would the net force on the sky diver equal the sky diver's weight?

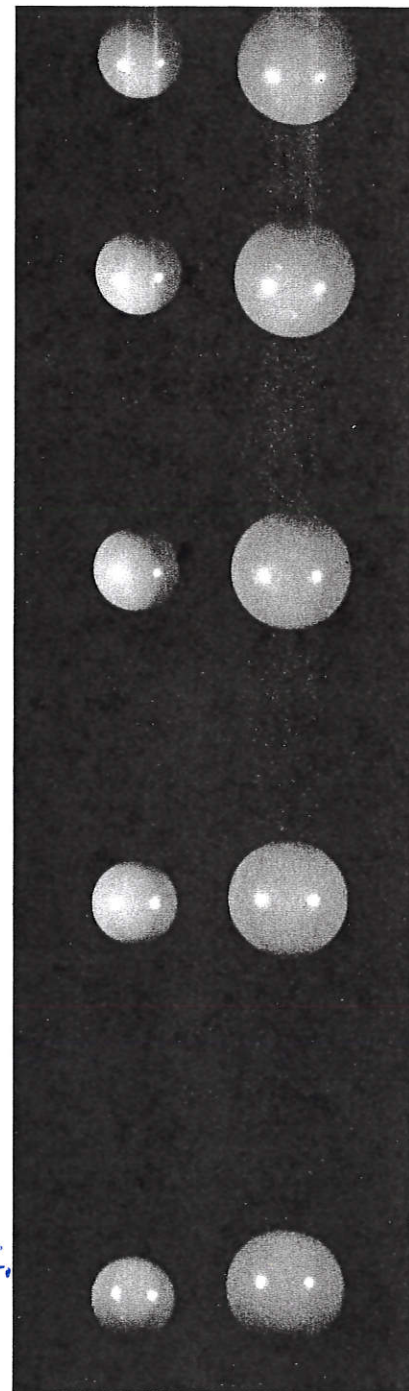


Figure 13 Time-lapse photography shows that two balls of different masses fall at the same rate.

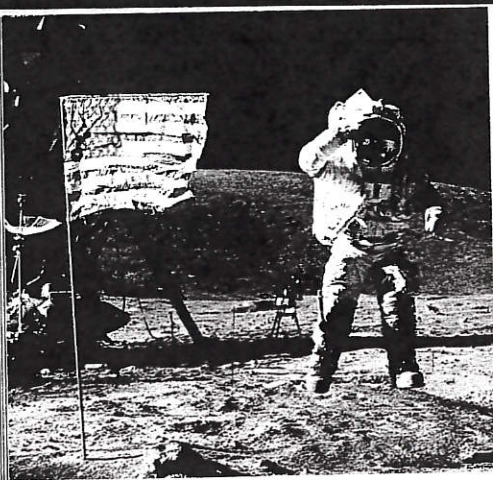


Figure 14 On the Moon, the gravitational force on the astronaut is less than it is on Earth. As a result, the astronaut can take longer steps and jump higher than on Earth.

3.d.

Weight and Mass Weight and mass are not the same. Weight is a force and mass is a measure of the amount of matter an object contains. However, according to the weight equation on the previous page, weight and mass are related. Weight increases as mass increases.

The weight of an object usually is the gravitational force between the object and Earth. But the weight of an object can change, depending on the gravitational force on the object. For example, the acceleration of gravity on the Moon is 1.6 m/s^2 , about one sixth as large as Earth's gravitational acceleration. As a result, a person, like the astronaut in **Figure 14**, would weigh only about one sixth as much on the Moon as on Earth. **Table 1** shows how various weights on Earth would be different on the Moon and some of the planets.

Reading Check *How are weight and mass related?*

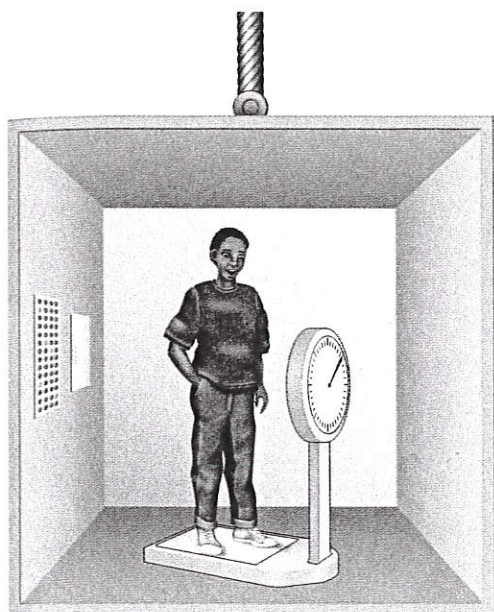
Weightlessness and Free Fall

You've probably seen pictures of astronauts and equipment floating inside the space shuttle. Any item that is not fastened down seems to float throughout the cabin. They are said to be experiencing the sensation of weightlessness.

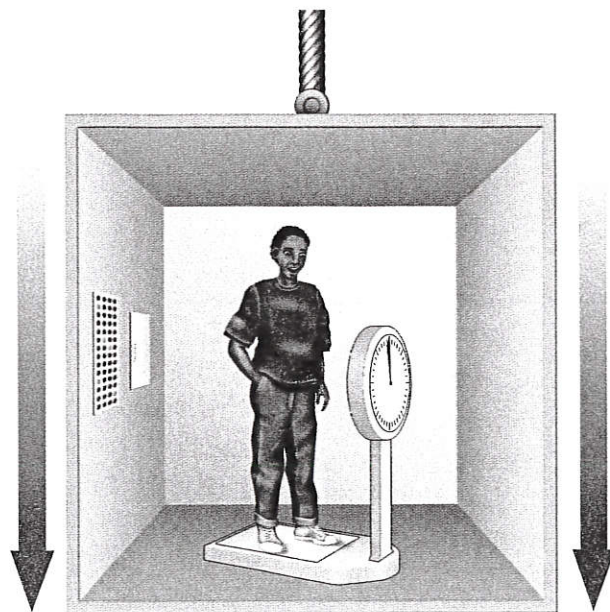
However, for a typical mission, the shuttle orbits Earth at an altitude of about 400 km. According the law of universal gravitation, at 400-km altitude the force of Earth's gravity is about 90 percent as strong as it is at Earth's surface. So an astronaut with a mass of 80 kg still would weigh about 700 N in orbit, compared with a weight of about 780 N at Earth's surface.

Table 1 Weight Comparison Table

Weight on Earth (N)	Weight on Other Bodies in the Solar System (N)				
	Moon	Venus	Mars	Jupiter	Saturn
75	12	68	28	190	87
100	17	90	38	254	116
150	25	135	57	381	174
500	84	450	190	1,270	580
700	119	630	266	1,778	812
2,000	333	1,800	760	5,080	2,320



A When the elevator is stationary, the scale shows the boy's weight.



B If the elevator were in free fall, the scale would show a zero weight.

4.a.
Floating in Space So what does it mean to say that something is weightless in orbit? Think about how you measure your weight. When you stand on a scale, as in **Figure 15A**, you are at rest and the net force on you is zero. The scale supports you and balances your weight by exerting an upward force. The dial on a scale shows the upward force exerted by the scale, which is your weight. Now suppose you stand on a scale in an elevator that is falling, as in **Figure 15B**. If you and the scale were in free fall, then you no longer would push down on the scale at all. The scale dial would say you have zero weight, even though the force of gravity on you hasn't changed.

4.a.
A space shuttle in orbit is in free fall, but it is falling around Earth, rather than straight downward. Everything in the orbiting space shuttle is falling around Earth at the same rate, in the same way you and the scale were falling in the elevator. Objects in the shuttle seem to be floating because they are all falling with the same acceleration.

Projectile Motion

If you've tossed a ball to someone, you've probably noticed that thrown objects don't always travel in straight lines. They curve downward. That's why quarterbacks, dart players, and archers aim above their targets. Anything that's thrown or shot through the air is called a projectile. Earth's gravity causes projectiles to follow a curved path. 5.a.

Figure 15 The boy pushes down on the scale with less force when he and the scale are falling at the same rate.



Gravity and Earth's Atmosphere

Apart from simply keeping your feet on the ground, gravity is important for life on Earth for other reasons, too. Because Earth has a sufficient gravitational pull, it can hold around it the oxygen/nitrogen atmosphere necessary for sustaining life. Research other ways in which gravity has played a role in the formation of Earth.

Figure 16 The pitcher gives the ball a horizontal motion. Gravity, however, is pulling the ball down. The combination of these two motions causes the ball to move in a curved path.

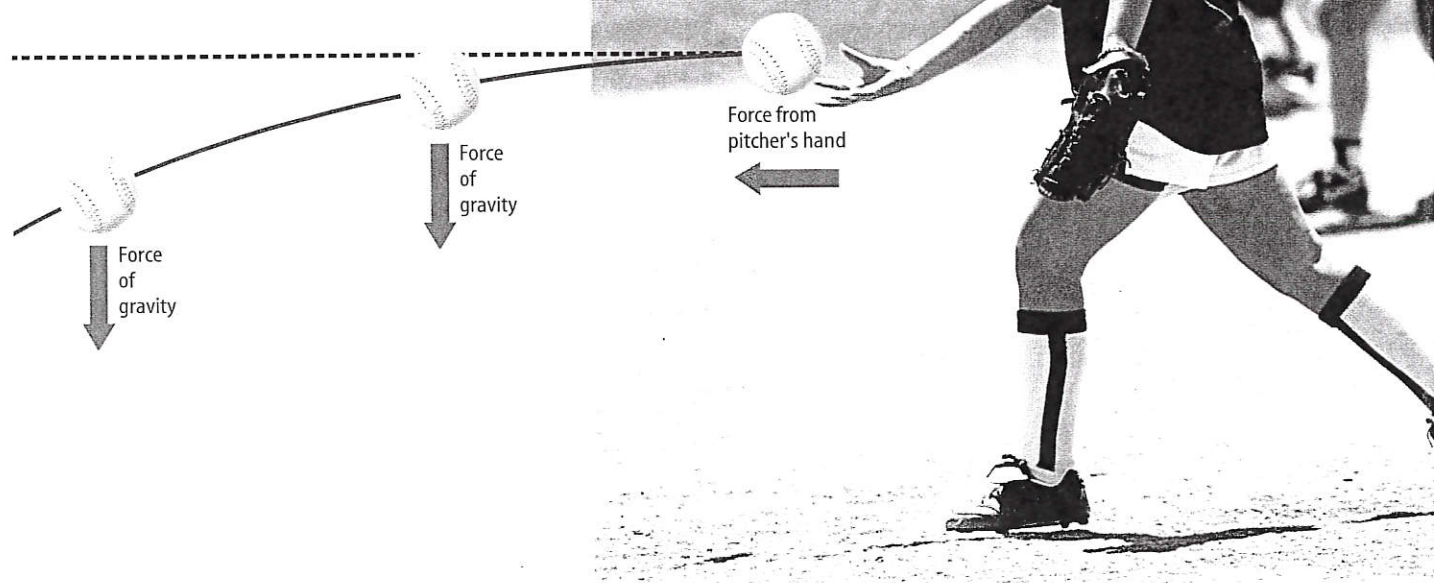
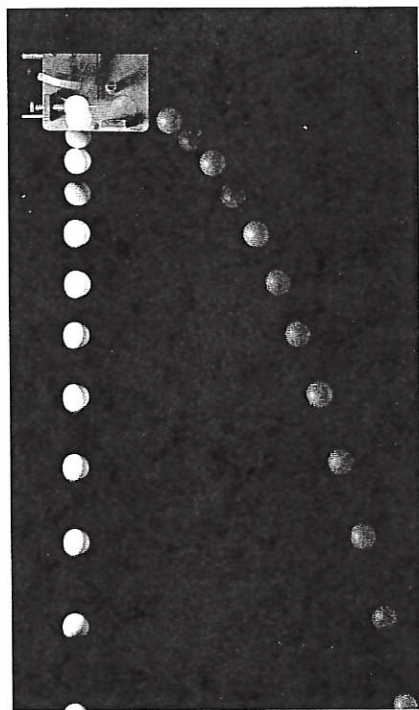


Figure 17 Multiflash photography shows that each ball has the same acceleration downward, whether it's thrown or dropped.



Horizontal and Vertical Motions When you throw a ball, like the pitcher in **Figure 16**, the force exerted by your hand pushes the ball forward. This force gives the ball horizontal motion. After you let go of the ball, no force accelerates it forward, so its horizontal velocity is constant, if you ignore air resistance.

However, when you let go of the ball, gravity can pull it downward, giving it vertical motion. 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 only forward to forward and downward. The result of these two motions is that the ball appears to travel in a curve, even though its horizontal and vertical motions are completely independent of each other.

Horizontal and Vertical Distance If you were to throw a ball as hard as you could from shoulder height in a perfectly horizontal direction, would it take longer to reach the ground than if you dropped a ball from the same height? Surprisingly, it won't. A thrown ball and one dropped will hit the ground at the same time. Both balls in **Figure 17** travel the same vertical distance in the same amount of time. However, the ball thrown horizontally travels a greater horizontal distance than the ball that is dropped.

Centripetal Force

Look at the path the ball follows as it travels through the curved tube in **Figure 18**. The ball may accelerate in the straight sections of the pipe maze if it speeds up or slows down. However, when the ball enters a curve, even if its speed does not change, it is accelerating because its direction is changing. When the ball goes around a curve, 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**.

According to the second law of motion, when the ball has centripetal acceleration, the direction of the net force on the ball also must be toward the center of the curved path. The net force exerted toward the center of a curved path is called a **centripetal force**. For the ball moving through the tube, the centripetal force is the force exerted by the walls of the tube on the ball.

Centripetal Force and Traction When a car rounds a curve on a highway, a centripetal force must be acting on the car to keep it moving in a curved path. This centripetal force is the frictional force, or the traction, between the tires and the road surface. If the road is slippery and the frictional force is small, the centripetal force might not be large enough to keep the car moving around the curve. Then the car will slide in a straight line. Anything that moves in a circle, such as the people on the amusement park ride in **Figure 19**, is doing so because a centripetal force is accelerating it toward the center.



Figure 19 Centripetal force keeps these riders moving in a circle.

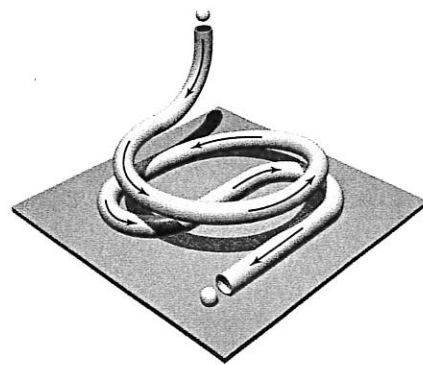


Figure 18 When the ball moves through the curved portions of the tube, it is accelerating because its velocity is changing. **Identify** the forces acting on the ball as it falls through the tube.



Observing Centripetal Force

Procedure

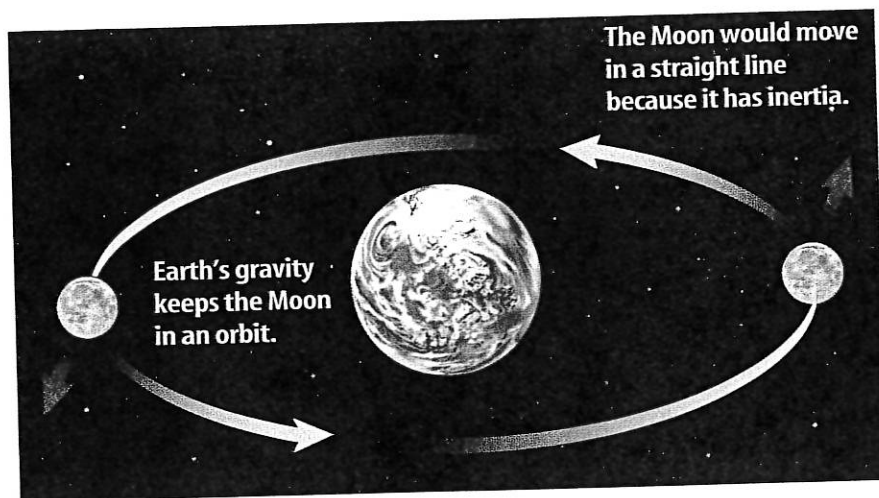
1. Thread a **string** about 1 m long through the holes of a **plastic, slotted golf ball**.
2. Swing the ball in a vertical circle.
3. Swing the ball at different speeds and observe the motion of the ball and the tension in the string.

Analysis

1. What force does the string exert on the ball when the ball is at the top, sides, and bottom of the swing?
2. How does the tension in the string depend on the speed of the ball?



Figure 20 The Moon would move in a straight line except that Earth's gravity keeps pulling it toward Earth. This gives the Moon a nearly circular orbit.



Gravity Can Be a Centripetal Force Imagine whirling an object tied to a string above your head. The string exerts a centripetal force on the object that keeps it moving in a circular path. In the same way, Earth's gravity exerts a centripetal force on the Moon that keeps it moving in a nearly circular orbit, as shown in **Figure 20**.

section 2 review

Summary

Gravity

- According to the law of universal gravitation, the gravitational force between two objects depends on the masses of the objects and the distance between them.
- The acceleration due to gravity near Earth's surface has the value 9.8 m/s^2 .
- Near Earth's surface, the gravitational force on an object with mass, m , is given by:

$$F = mg$$

Weight

- The weight of an object is related to its mass according to the equation:

$$W = mg$$

- An object in orbit seems to be weightless because it is falling around Earth.

Projectile Motion and Centripetal Force

- Projectiles follow a curved path because their horizontal motion is constant, but gravity causes the vertical motion to be changing.
- The net force on an object moving in a circular path is called the centripetal force.

Self Check

1. **Describe** how the gravitational force between two objects depends on the mass of the objects and the distance between them.
2. **Distinguish** between the mass of an object and the object's weight.
3. **Explain** what causes the path of a projectile to be curved.
4. **Describe** the force that causes the planets to stay in orbit around the Sun.
5. **Think Critically** Suppose Earth's mass increased, but Earth's diameter didn't change. How would the acceleration of gravity near Earth's surface change?

Applying Math

6. **Calculate Weight** On Earth, what is the weight of a large-screen TV that has a mass of 75 kg?
7. **Calculate Gravity on Mars** Find the acceleration of gravity on Mars if a person with a mass of 60.0 kg weighs 222 N on Mars.
8. **Calculate Force** Find the force exerted by a rope on a 10-kg mass that is hanging from the rope.