SECTION 4

Gravity: A Force of Attraction

READING WARM-UP

Objectives

- Describe gravity and its effect on matter.
- Explain the law of universal gravitation.
- Explain how an object's center of mass is used to determine gravitational force.
- Describe the difference between mass and weight.

Terms to Learn

gravity
weight
mass

READING STRATEGY

Paired Summarizing Read this section silently. In pairs, take turns summarizing the material. Stop to discuss ideas that seem confusing.

Have you ever seen a video of astronauts on the moon? They bounce around like beach balls even though they wear big, bulky spacesuits. Why is leaping on the moon easier than leaping on Earth?

The answer is gravity. **Gravity** is a force of attraction between objects that is due to their masses. The force of gravity can change the motion of an object by changing its speed, direction, or both. In this section, you will learn about gravity and its effects on objects, such as the astronaut in **Figure 1.**

gravity a force of attraction between objects that is due to their masses

The Effects of Gravity on Matter

All matter has mass. Gravity is a result of mass. Therefore, all matter is affected by gravity. That is, all objects experience an attraction toward all other objects. This gravitational force pulls objects toward each other. Right now, because of gravity, you are being pulled toward this book, your pencil, and every other object around you.

These objects are also being pulled toward you and toward each other because of gravity. So why don't you see the effects of this attraction? In other words, why don't you notice objects moving toward each other? The reason is that the mass of most objects is too small to cause a force large enough to move objects toward each other. However, you are familiar with one object that is massive enough to cause a noticeable attraction—the Earth.

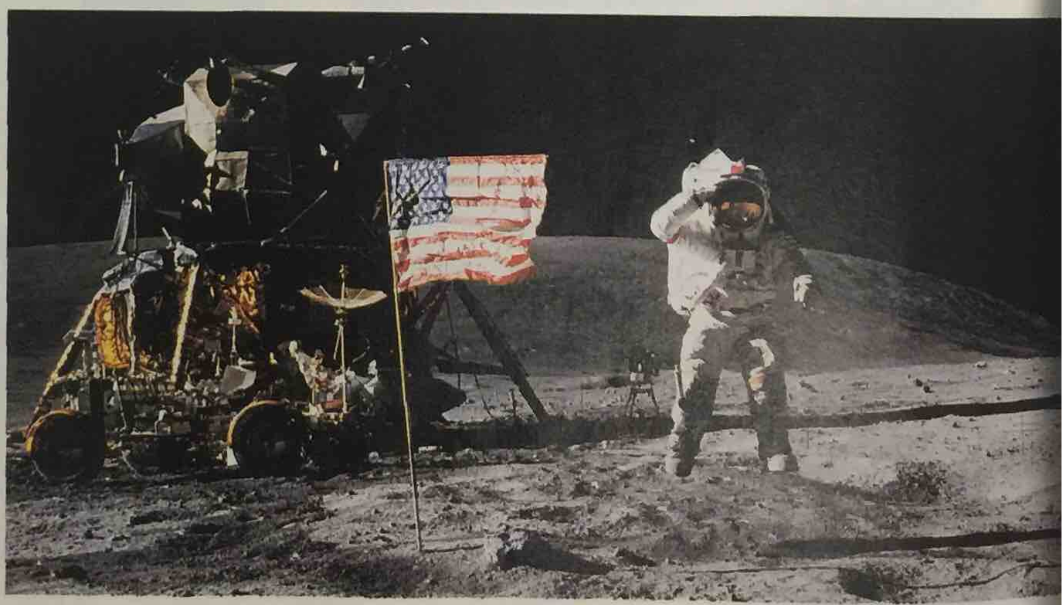


Figure 1 *Because the moon has less gravity than the Earth does, walking on the moon's surface was a very bouncy experience for the Apollo astronauts.*

The Size of Earth's Gravitational Force

Compared with all objects around you, Earth has a huge mass. Therefore, Earth's gravitational force is very large. You must apply forces to overcome Earth's gravitational force any time you lift objects or even parts of your body.

Earth's gravitational force pulls everything toward the center of Earth. Because of this force, the books, tables, and chairs in the room stay in place, and dropped objects fall to Earth rather than moving together or toward you.

Reading Check **Why must you exert a force to pick up an object?** *(See the Appendix for answers to Reading Checks.)*

Newton and the Study of Gravity

For thousands of years, people asked two very puzzling questions: Why do objects fall toward Earth, and what keeps the planets moving in the sky? The two questions were treated separately until 1665 when a British scientist named Sir Isaac Newton realized that they were two parts of the same question.

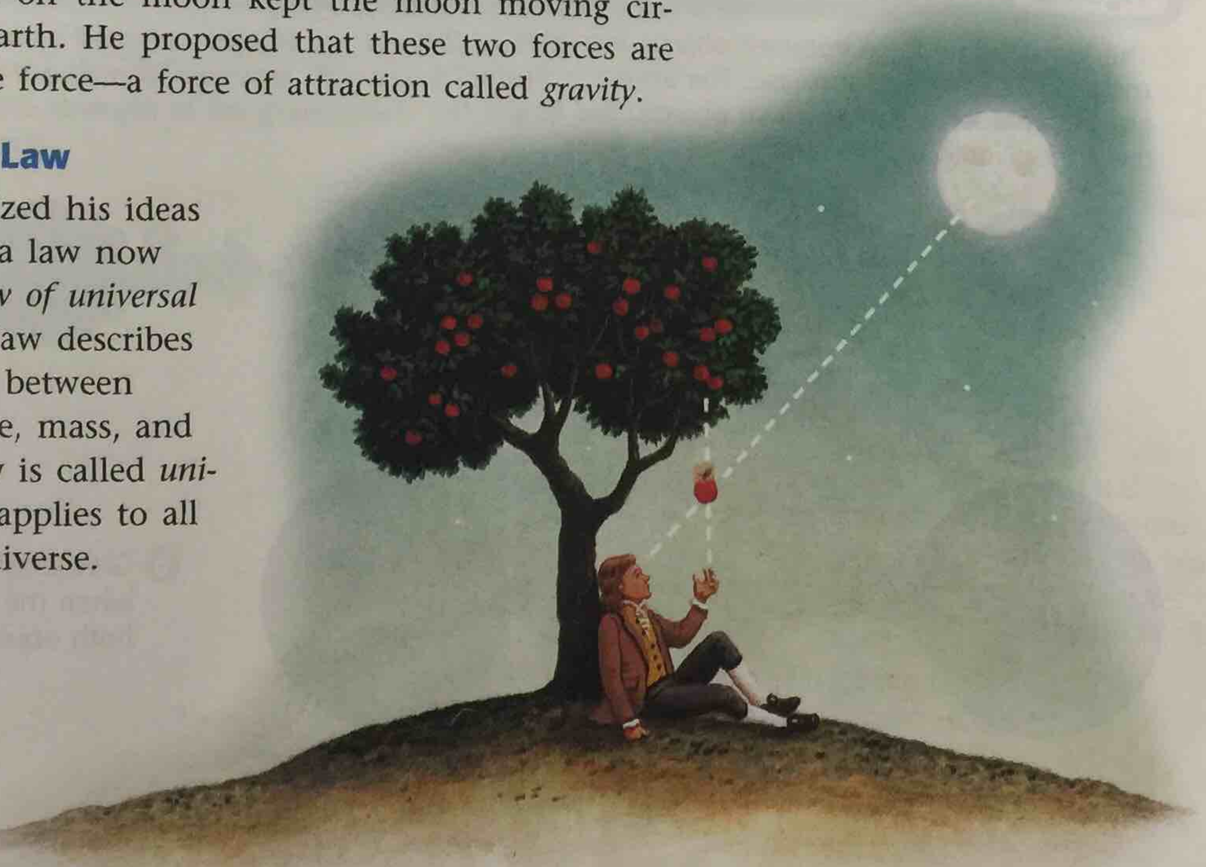
The Core of an Idea

The legend is that Newton made the connection between the two questions when he watched a falling apple, as shown in **Figure 2.** He knew that unbalanced forces are needed to change the motion of objects. He concluded that an unbalanced force on the apple made the apple fall. And he reasoned that an unbalanced force on the moon kept the moon moving circularly around Earth. He proposed that these two forces are actually the same force—a force of attraction called *gravity*.

Figure 2 *Sir Isaac Newton realized that the same unbalanced force affected the motions of the apple and the moon.*

The Birth of a Law

Newton summarized his ideas about gravity in a law now known as the *law of universal gravitation.* This law describes the relationships between gravitational force, mass, and distance. The law is called *universal* because it applies to all objects in the universe.



The Law of Universal Gravitation

The law of universal gravitation is the following: All objects in the universe attract each other through gravitational force. The size of the force depends on the masses of the objects and the distance between the objects. Understanding the law is easier if you consider it in two parts.

Part 1: Gravitational Force Increases as Mass Increases

Imagine an elephant and a cat. Because an elephant has a larger mass than a cat does, the amount of gravity between an elephant and Earth is greater than the amount of gravity between a cat and Earth. So, a cat is much easier to pick up than an elephant! There is also gravity between the cat and the elephant, but that force is very small because the cat's mass and the elephant's mass are so much smaller than Earth's mass. **Figure 3** shows the relationship between mass and gravitational force.

This part of the law of universal gravitation also explains why the astronauts on the moon bounce when they walk. The moon has less mass than Earth does. Therefore, the moon's gravitational force is less than Earth's. The astronauts bounced around on the moon because they were not being pulled down with as much force as they would have been on Earth.

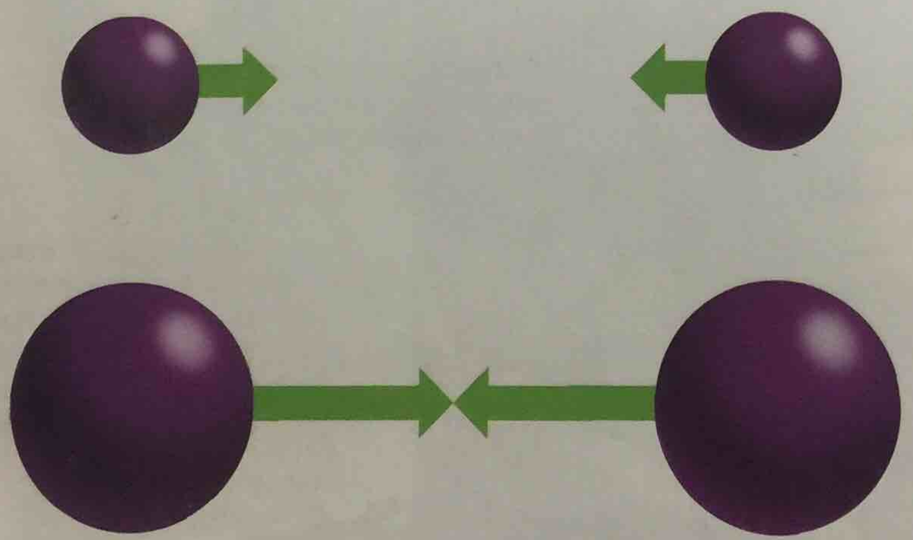
Reading Check How does mass affect gravitational force?

CONNECTION TO Astronomy

WRITING SKILL **Black Holes** Black holes are 4 times to 1 billion times as massive as our sun. So, the gravitational effects around a black hole are very large. The gravitational force of a black hole is so large that objects that enter a black hole can never get out. Even light cannot escape from a black hole. Because black holes do not emit light, they cannot be seen. Research how astronomers can detect black holes without seeing them. Write a one-page paper that details the results of your research.

Figure 3 **How Mass Affects Gravitational Force**

The gravitational force between objects increases as the masses of the objects increase. The arrows indicate the gravitational force between two objects. The length of the arrows indicates the strength of the force.



a Gravitational force is small between objects that have small masses.

b Gravitational force is large when the mass of one or both objects is large.

Part 2: Gravitational Force Decreases as Distance Increases

The gravitational force between you and Earth is large. Whenever you jump up, you are pulled back down by Earth's gravitational force. On the other hand, the sun is more than 300,000 times more massive than Earth. So why doesn't the sun's gravitational force affect you more than Earth's does? The reason is that the sun is so far away.

You are about 150 million kilometers (93 million miles) away from the sun. At this distance, the gravitational force between you and the sun is very small. If there were some way you could stand on the sun, you would find it impossible to move. The gravitational force acting on you would be so great that you could not move any part of your body!

Although the sun's gravitational force on your body is very small, the force is very large on Earth and the other planets, as shown in **Figure 4.** The gravity between the sun and the planets is large because the objects have large masses. If the sun's gravitational force did not have such an effect on the planets, the planets would not stay in orbit around the sun. **Figure 5** will help you understand the relationship between gravitational force and distance.

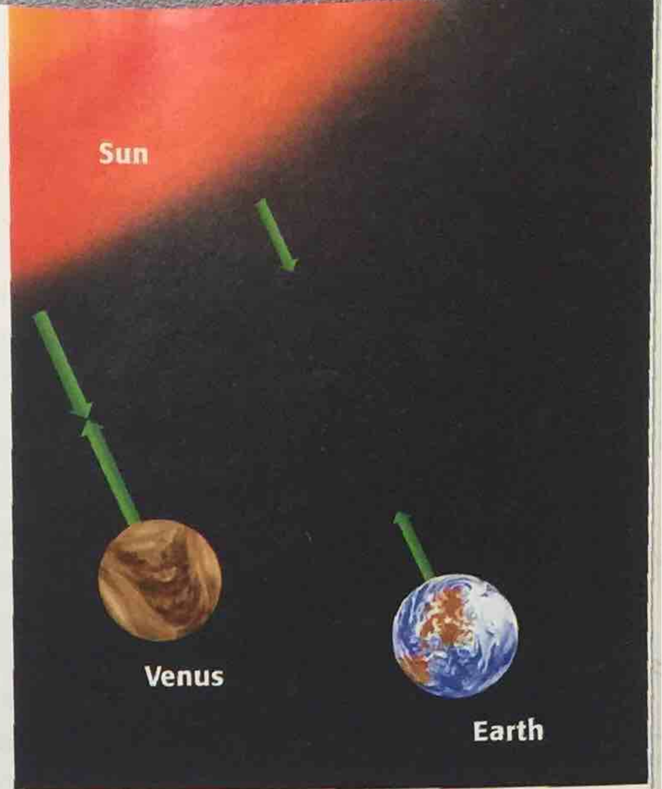
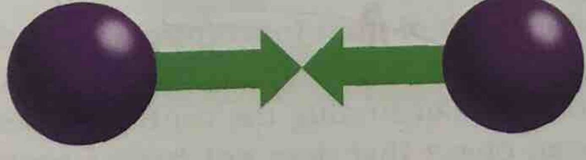


Figure 4 *Venus and Earth have approximately the same mass. But because Venus is closer to the sun, the gravitational force between Venus and the sun is greater than the gravitational force between Earth and the sun.*

Figure 5 How Distance Affects Gravitational Force

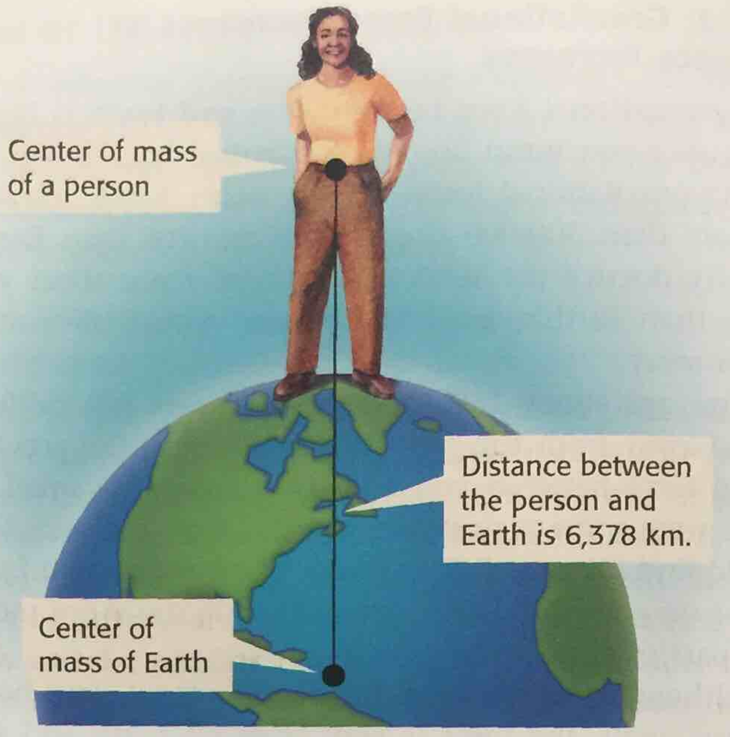
The gravitational force between objects decreases as the distance between the objects increases. The length of the arrows indicates the strength of the gravitational force between two objects.



a Gravitational force is strong when the distance between two objects is small.

b If the distance between two objects increases, the gravitational force pulling them together decreases rapidly.

Figure 6 *The distance between a person standing on the ground and Earth is not 0 m! When finding distance to determine gravitational force, you always measure from the center of mass of each object.*



Gravitational Force and Center of Mass

You know that gravitational force depends on the distance between objects. But, how do you find the distance between objects? For example, if you need to know the distance between you and your friend, where would you measure? Would you measure from your nose to your friend's nose or from your foot to your friend's foot? When finding the distance between objects to determine gravitational force, scientists always measure from the center of mass of each object. The *center of mass* is the point at which all the mass of an object can be considered to be concentrated. **Figure 6** shows how the distance between a person and Earth is measured by using centers of mass.

Finding the Center of Mass

Finding the center of mass for regularly shaped objects, such as spheres and cubes, is easy. The center of mass is in the center of such objects. But finding the center of mass of an irregular object or an object that does not have a uniform density can be more difficult. However, one simple way to find the center of mass of an object is to spin the object. The point around which the object spins is its center of mass.

Scientists usually measure the motion of an object by the motion of its center of mass. Look at **Figure 7.** The hammer is spinning around its center of mass as it moves through the air. The line drawn on the photo shows how the center of mass moves. So, if you wanted to measure how far the hammer moved, you would measure from one end of the red line to the other end.

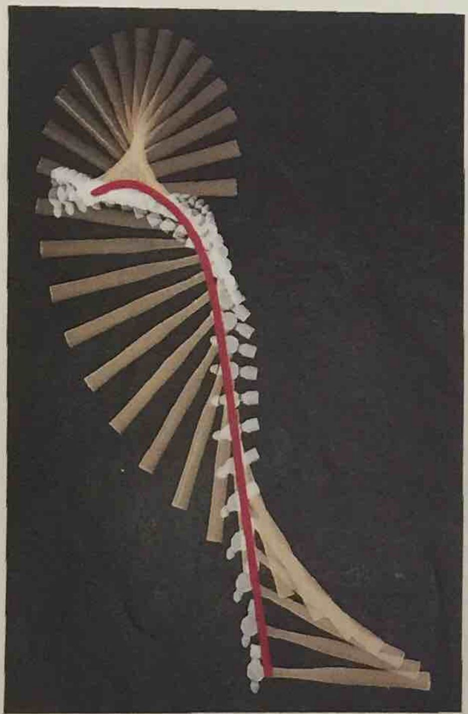


Figure 7 *Objects always spin around their center of mass. The motion of an object is usually described as the motion of its center of mass.*

Weight as a Measure of Gravitational Force

Gravity is a force of attraction between objects. **Weight** is a measure of the gravitational force on an object. When you see or hear the word *weight,* it usually refers to Earth's gravitational force on an object. But weight can also be a measure of the gravitational force exerted on objects by the moon or other planets.

The Differences Between Weight and Mass

Weight is related to mass, but they are not the same. Weight changes when gravitational force changes. **Mass** is the amount of matter in an object. An object's mass does not change. Imagine that an object is moved to a place that has a greater gravitational force—such as the planet Jupiter. The object's weight will increase, but its mass will remain the same. **Figure 8** shows the weight and mass of an astronaut on Earth and on the moon. The moon's gravitational force is about one-sixth of Earth's gravitational force.

Gravitational force is about the same everywhere on Earth. So, the weight of any object is about the same everywhere. Because mass and weight are constant on Earth, the terms *weight* and *mass* are often used to mean the same thing. This can be confusing. Be sure you understand the difference!

Reading Check **How is gravitational force related to the weight of an object?**

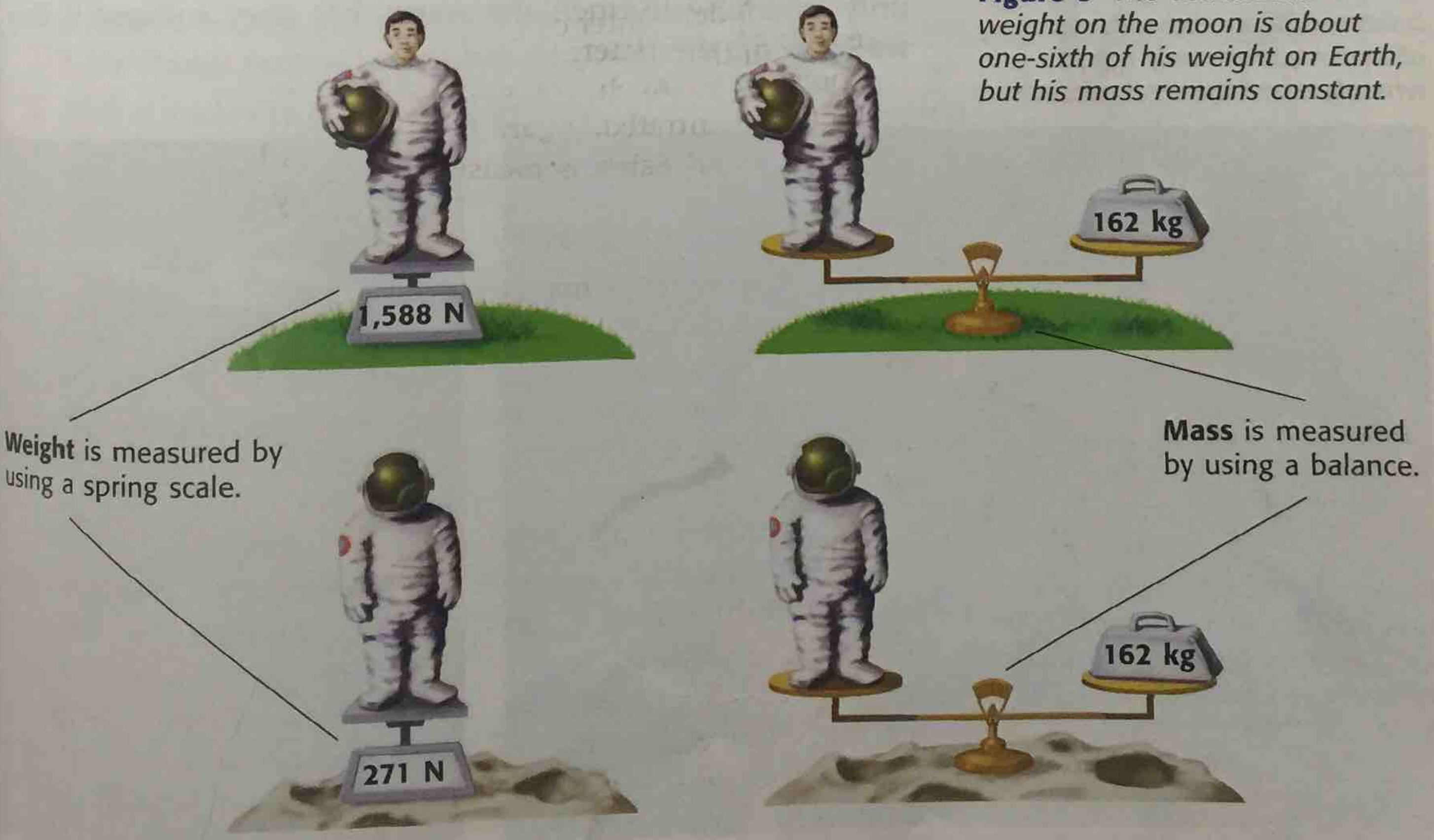
CONNECTION TO Language Arts

WRITING SKILL **Gravity Story** Suppose you had a device that could increase or decrease the gravitational force of Earth. In your **science journal,** write a short story describing what you might do with the device, what you would expect to see, and what effect the device would have on the weight of objects.

weight a measure of the gravitational force exerted on an object; its value can change with the location of the object in the universe

mass a measure of the amount of matter in an object

Figure 8 *The astronaut's weight on the moon is about one-sixth of his weight on Earth, but his mass remains constant.*



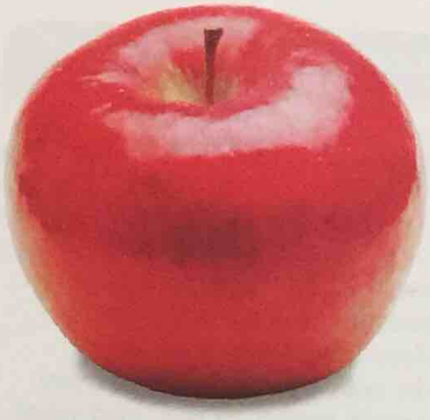


Figure 9 *A small apple weighs 1 N. The newton is the SI unit of weight.*

Units of Weight and Mass

You have learned that the SI unit of force is a newton (N). Gravity is a force, and weight is a measure of gravity. So, weight is also measured in newtons. The SI unit of mass is the kilogram (kg). Mass is often measured in grams (g) and milligrams (mg) as well. On Earth, a 100 g object, such as the apple shown in **Figure 9,** weighs about 1 N.

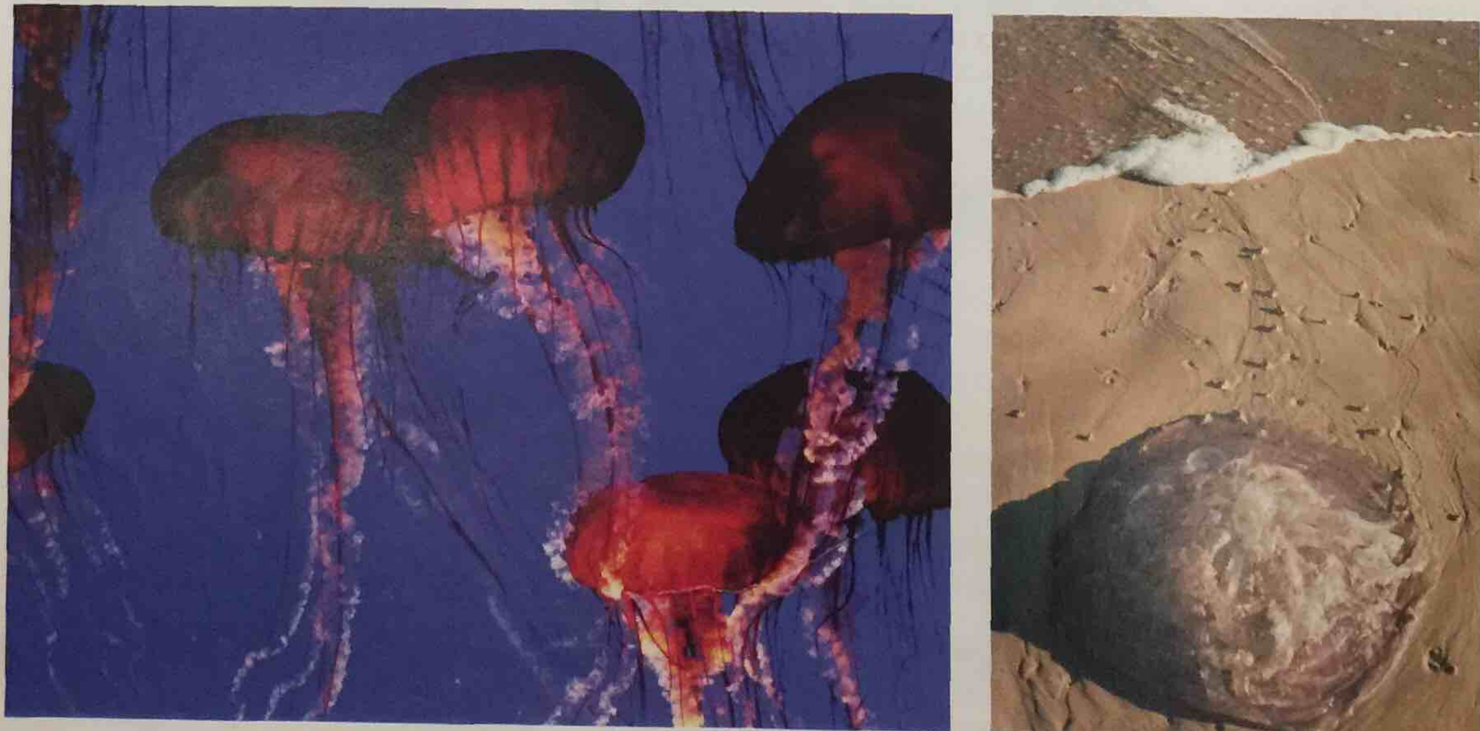
When you use a bathroom scale, you are measuring the gravitational force between your body and Earth. So, you are measuring your weight, which should be given in newtons. However, many bathroom scales have units of pounds and kilograms instead of newtons. Thus, people sometimes mistakenly think that the kilogram (like the pound) is a unit of weight.

Reading Check **What is the SI unit for force? What is the SI unit for mass?**

The Influences of Weight on Shape

Gravitational force influences the shapes of living things. On land, large animals must have strong skeletons to support their mass against the force of gravity. For example, you would never see an elephant that has legs as thin as a person's legs! And the trunks of trees support the mass of the tree. For organisms that live in water, however, the downward force of gravity is balanced by the upward force of the water. For many of these creatures, strong skeletons are unnecessary. Jellyfish, such as the ones shown in **Figure 10,** have no skeleton. So, jellyfish drift gracefully through the water, but they collapse if they wash up on the beach.

Figure 10 *Jellyfish look like flying saucers when gravity is balanced by the upward force of water but are only lumps when washed up on the beach.*



SECTION Review

Summary

- Gravity is a force of attraction between objects that is due to their masses.
- The law of universal gravitation states that all objects in the universe attract each other through gravitational force.
- Gravitational force increases as mass increases.
- Gravitational force decreases as distance increases.
- The distance between objects is measured between the centers of mass.
- Mass is the amount of matter in an object. Weight is a measure of the gravitational force on an object.

Using Key Terms

1. In your own words, write a definition for the term *gravity*.
2. Use each of the following terms in a separate sentence: *mass* and *weight*.

Understanding Key Ideas

3. If Earth's mass doubled without changing its size, your weight would
   a. increase because gravitational force increases.
   b. decrease because gravitational force increases.
   c. increase because gravitational force decreases.
   d. not change because you are still on Earth.
4. What is the law of universal gravitation?
5. How does the mass of an object relate to the gravitational force that the object exerts on other objects?
6. How does the distance between objects affect the gravitational force between them?
7. Why are mass and weight often confused?
8. How is an object's center of mass used to determine gravitational force?

Critical Thinking

9. **Applying Concepts** Your friend thinks that there is no gravity in space. How could you explain to your friend that there must be gravity in space?
10. **Making Comparisons** Explain why it is your weight and not your mass that would change if you landed on Mars.

Interpreting Graphics

A teacher placed four sets of objects around the classroom. A student measured the mass of each object and the distance between the two objects in each set. The data the student collected are shown in the table below. Use the table below to answer the questions that follow.

Data Collected

Set	Mass A (g)	Mass B (g)	Distance (cm)
1	100	50	40
2	100	100	20
3	50	50	40
4	100	50	20

11. For which set of objects is the gravitational force between the two objects the greatest? Explain your answer.
12. Compare sets 1 and 4. For which set is the gravitational force smaller? Explain your answer.