Section 1
Gravity: A Force of Attraction

Key Concept Gravity is a force of attraction between objects that is due to their masses.

What You Will Learn
- Gravity affects all matter, including the parts of the solar system.
- Because gravity is a force, it can change the velocity of objects.
- The law of universal gravitation explains how distance, mass, and gravitational force are related.
- The weight of an object depends on gravity, but the mass of the object does not.

Why It Matters
Gravity keeps you on Earth and holds the solar system together.

Have you ever seen a video of astronauts on the moon? The astronauts, such as the one in **Figure 1,** bounce around like beach balls even though they wear big, bulky spacesuits. Why is leaping on the moon easier than leaping on Earth? The reason is that there is less force pulling the astronauts to the ground when they leap on the moon than when they leap on Earth. **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 the object's velocity.

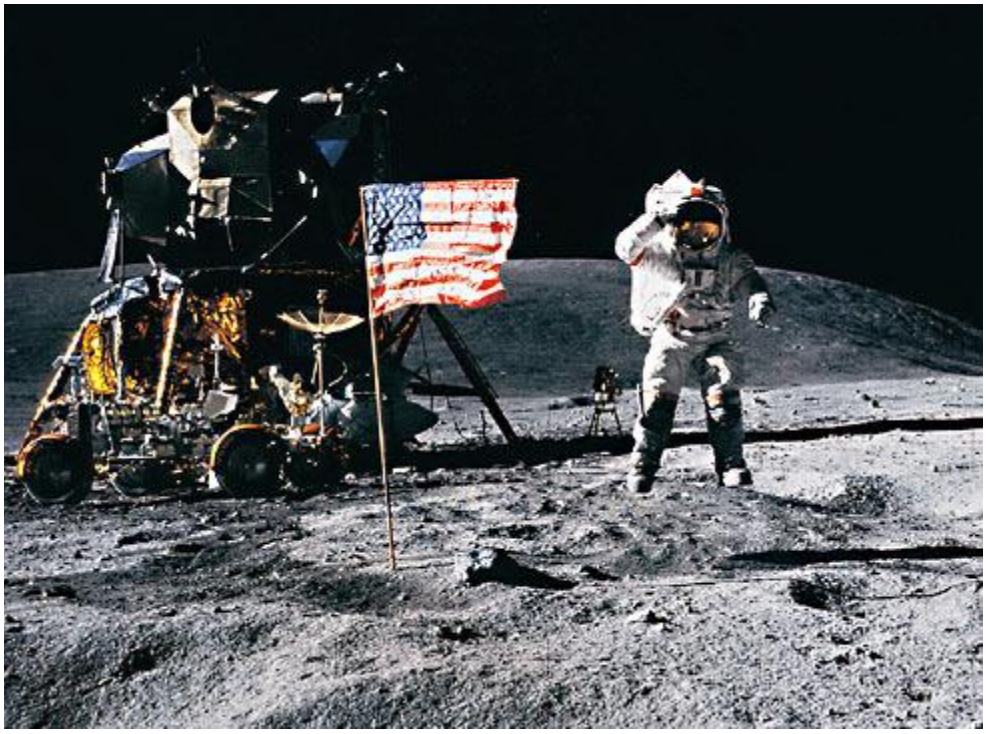


Figure 1 Because the moon has less gravity than Earth does, walking on the moon's surface was a very bouncy experience for the Apollo astronauts.

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. For example, gravity between the objects of the solar system holds the solar system together.

Gravity affects smaller objects, too. Right now, because of gravity, you are being pulled toward this book and every other object around you. These objects are also being pulled toward you and toward each other. So, 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 notice. However, you know one object that is massive enough to cause a noticeable attraction—Earth.

Earth's Gravitational Force

Compared with all objects around you, Earth has a huge mass. The gravitational attraction of Earth is thus an important force that you experience all the time. 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 move together or toward you. You must apply forces to overcome Earth's gravitational force any time that you lift objects or even parts of your body.

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. But in 1665, Sir Isaac Newton, a British scientist, 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 by changing the velocity of the 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. Newton said that these two forces are actually the same force—a force that he called *gravity.*

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

Standards Check How did Newton know that an unbalanced force was acting on the apple and on 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 is thought to apply to all objects in the universe.

The Law of Universal Gravitation

The law of universal gravitation states that all objects in the universe attract each other through gravitational force. The magnitude of the force depends on the masses

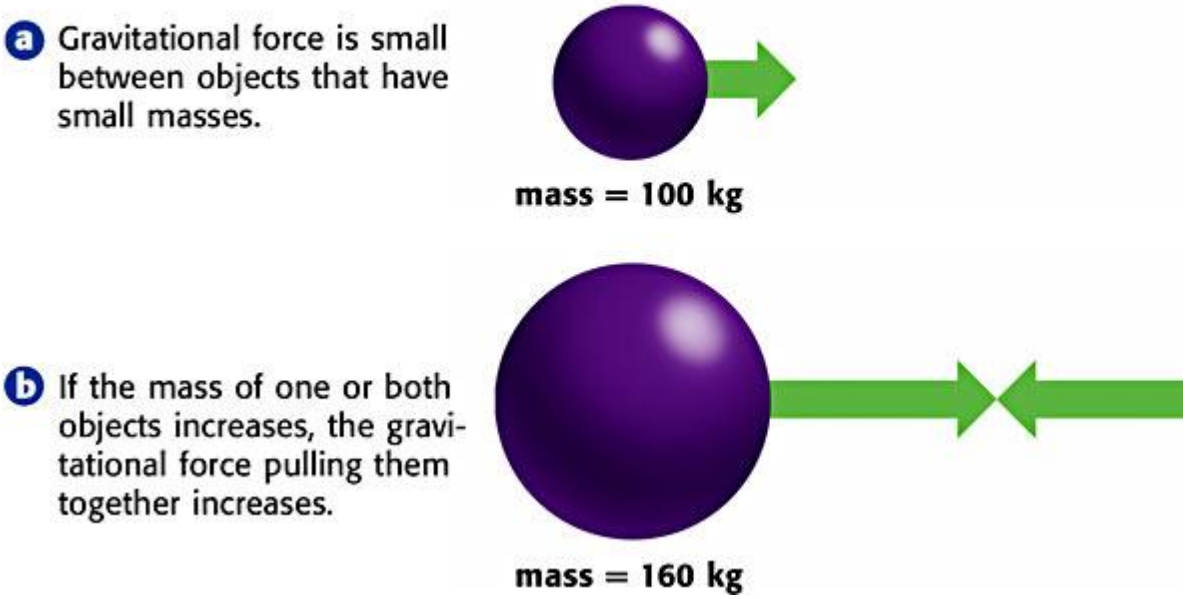
of the objects and the distance between the objects. Understanding the law is easier if you consider it in two parts.

Part 1: Gravitational Force and Mass

The gravitational force between objects depends on the product of the masses of the objects. So, the gravity between objects increases as the masses of the objects increase, as shown in **Figure 3.** For example, an elephant has a larger mass than a cat does. Thus, gravitational force between an elephant and Earth is greater than the gravitational force 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 seems very small because the cat's mass and the elephant's mass are so much smaller than Earth's mass.

Figure 3 How Mass Affects Gravitational Force

The arrows indicate the gravitational force between two objects. The length of the arrows indicates the magnitude of the force.



This part of the law of universal gravitation also explains why the astronauts on the moon bounce so easily. 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.

Standards Check How does mass affect the magnitude of gravitational force?

Part 2: Gravitational Force and Distance

The force of gravity depends on the distance between two objects. If you jump up, you are pulled back down by Earth's gravitational force. But the sun is more than 300,000 times more massive than Earth. Why doesn't the sun's gravitational force affect you more than Earth's does when you jump up? The reason is that the sun is about 150 million kilometers (93 million miles) away.

The force of gravity changes as distance changes, as shown in **Figure 4.** As the distance between two objects gets larger, the force of gravity gets much smaller. For example, if the distance between two things is doubled, the force of gravity becomes one-fourth as large. **Figure 5** shows how the force of gravity gets smaller as the distance between objects gets larger.

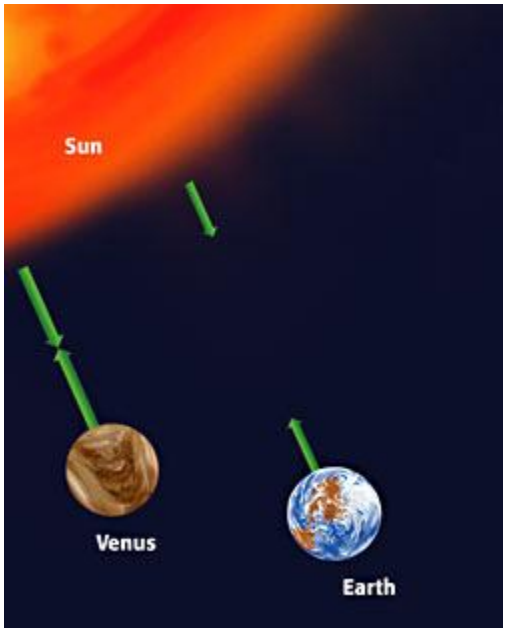


Figure 4 Venus and Earth have approximately the same mass. But because Venus is closer to the sun, the gravitational force between Venus and the sun is greater than the gravitational force between Earth and the sun.

Figure 5 How Distance Affects Gravitational Force

The length of the arrows indicates the magnitude of the gravitational force between two objects.

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

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

The sun is very far away from you. So, the sun's gravitational force on your body is very small. However, the gravitational force between the sun and the planets is large because they all have such large masses. The large gravitational force of the sun affects the movement of all the planets. This force helps them stay in orbit around the sun. So, the force of gravity has an important role in maintaining the shape of the solar system.

Standards Check Why do the planets in the solar system stay in orbit around the sun?

Weight and Gravitational Force

Gravity is a force of attraction between objects. **Weight** is a measure of the gravitational force on an object. Therefore, weight is expressed in the SI unit of force, the newton (N). When you see or hear the word *weight,* it usually refers to Earth's gravitational force on something. But weight can also be a measure of the gravitational force exerted on things by other planets or even by the moon.

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 a measure of the amount of matter in an object. Mass is usually expressed in kilograms (kg) or grams (g). An object's mass does not change when gravitational force changes. Imagine that an object is moved to a place where it would experience a greater gravitational force than on Earth—such as the planet Jupiter. The object's weight will increase, but its mass will remain the same.

Figure 6 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. Because the weight of an object is constant as long as the object remains on Earth, we often get confused about the difference between weight and mass. Be sure you understand the difference!

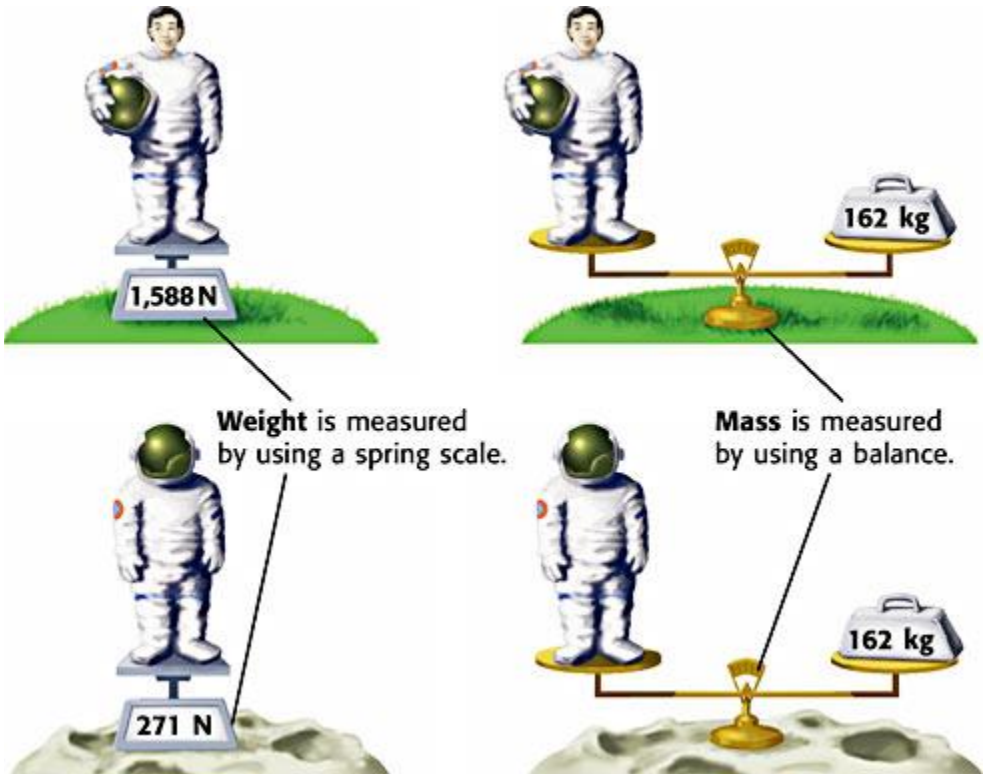


Figure 6 The astronaut's weight on the moon is about one-sixth of his weight on Earth, but his mass remains constant.

Gravity and Static Objects

Like all forces, gravity can cause objects to move. But gravity also acts on nonmoving, or *static,* objects. Earth's gravity pulls static objects downward. But they do not move downward, because gravity is balanced by an upward force. For example, imagine a framed picture hanging from a nail. The gravity on the picture is balanced by elastic forces due to tension in the nail. What if you place the same picture on a shelf? Then, the gravity on the picture is balanced by elastic forces due to compression in the shelf. In both cases, the picture is static.

Standards Check Why won't a book resting on a table fall to the ground? What forces are acting on the book?

Section Summary

- Gravity is a force of attraction between objects that is due to their masses. Gravity can be an unbalanced force that causes changes in velocity.
- Gravity holds the solar system together.
- The law of universal gravitation states that all objects attract each other through gravitational force and that the magnitude of this force depends on the objects' masses and the distance between them.
- Mass is the amount of matter in an object. Weight is a measure of the gravitational force on an object.
- Gravity is often balanced by elastic forces due to tension or compression.