

Gravity: A Force of Attraction

What You Will Learn

- Describe gravity and its effect on matter.
- Explain the law of universal gravitation.
- Describe the difference between mass and weight.

Vocabulary

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.

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

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?

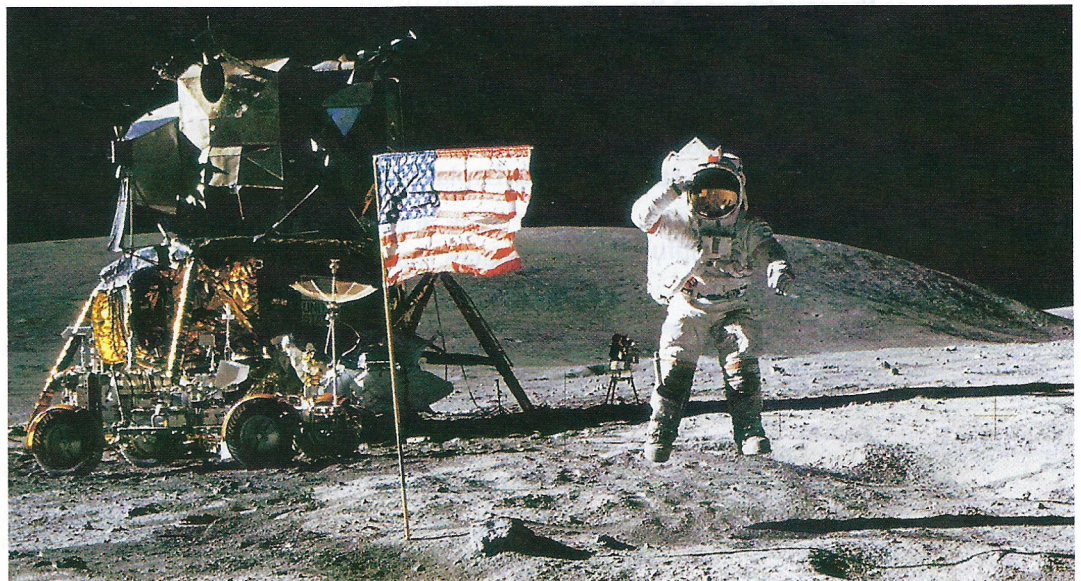
The answer is gravity. **Gravity** is a force of attraction between objects that is due to their masses. The force of gravity can change the motion of an object by changing its speed, direction, or both. In this section, you will learn about gravity and its effects on objects, such as the astronaut in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

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*.

The Birth of a Law

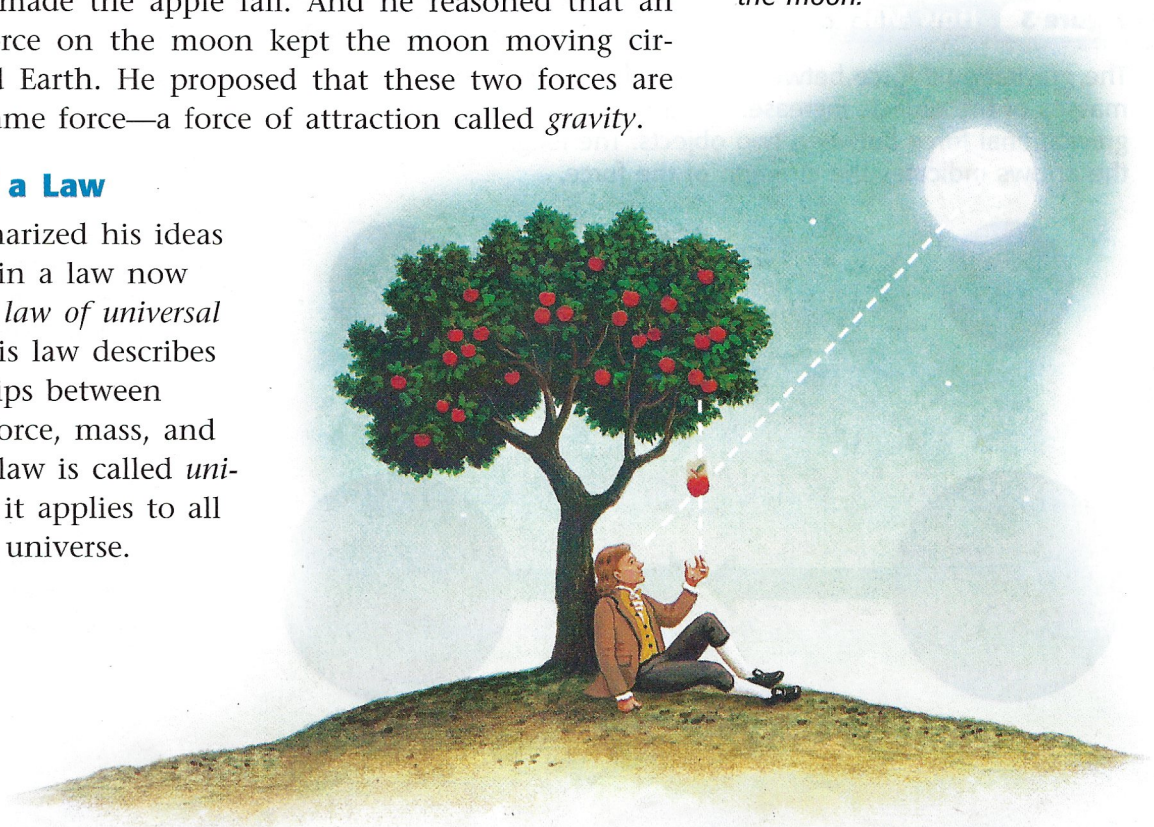
Newton summarized his ideas about gravity in a law now known as the *law of universal gravitation*. This law describes the relationships between gravitational force, mass, and distance. The law is called *universal* because it applies to all objects in the universe.

CONNECTION TO Biology

Seeds and Gravity Seeds respond to gravity. The ability to respond to gravity causes seeds to send roots down and the green shoot up. But scientists do not understand how seeds can sense gravity. Plan an experiment to study how seedlings respond to gravity. After getting your teacher's approval, do your experiment and report your observations in a poster.

ACTIVITY

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



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.

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

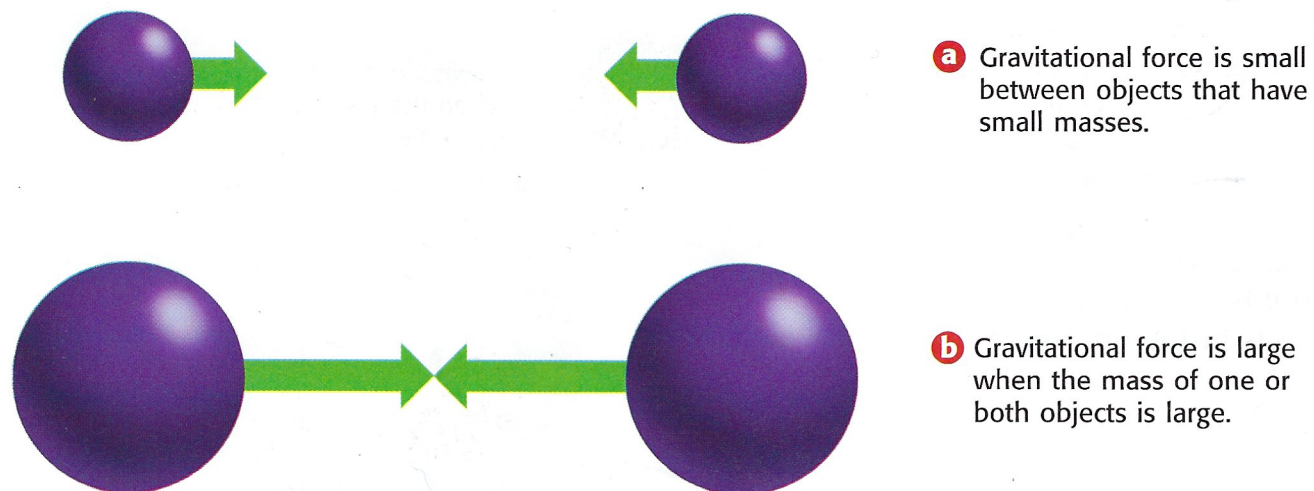
Imagine an elephant and a cat. Because an elephant has a larger mass than a cat does, the amount of gravity between an elephant and Earth is greater than the amount of gravity between a cat and Earth. So, a cat is much easier to pick up than an elephant! There is also gravity between the cat and the 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?

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.



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.

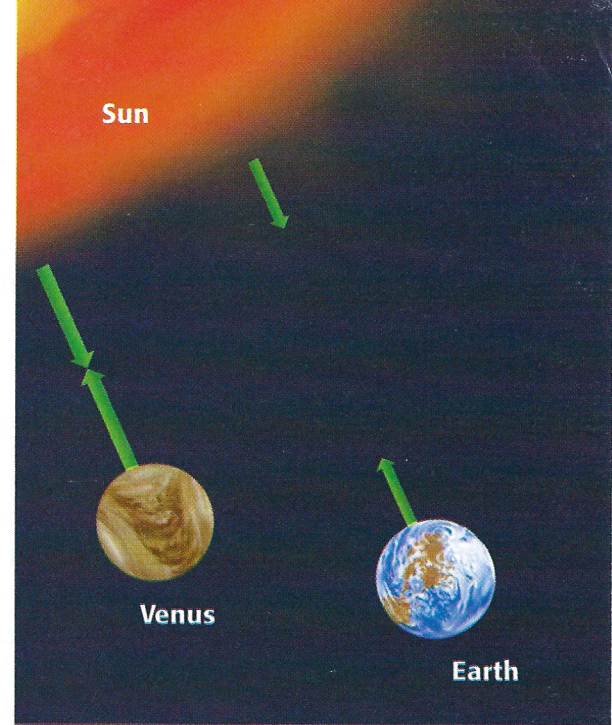
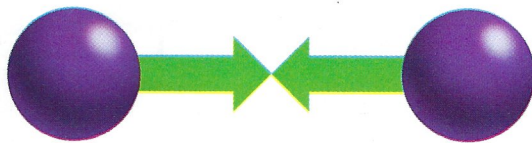


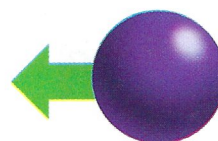
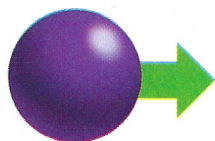
Figure 4 Venus and Earth have approximately the same mass. But because Venus is closer to the sun, the gravitational force between Venus and the sun is greater than the gravitational force between Earth and the sun.

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.

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

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.

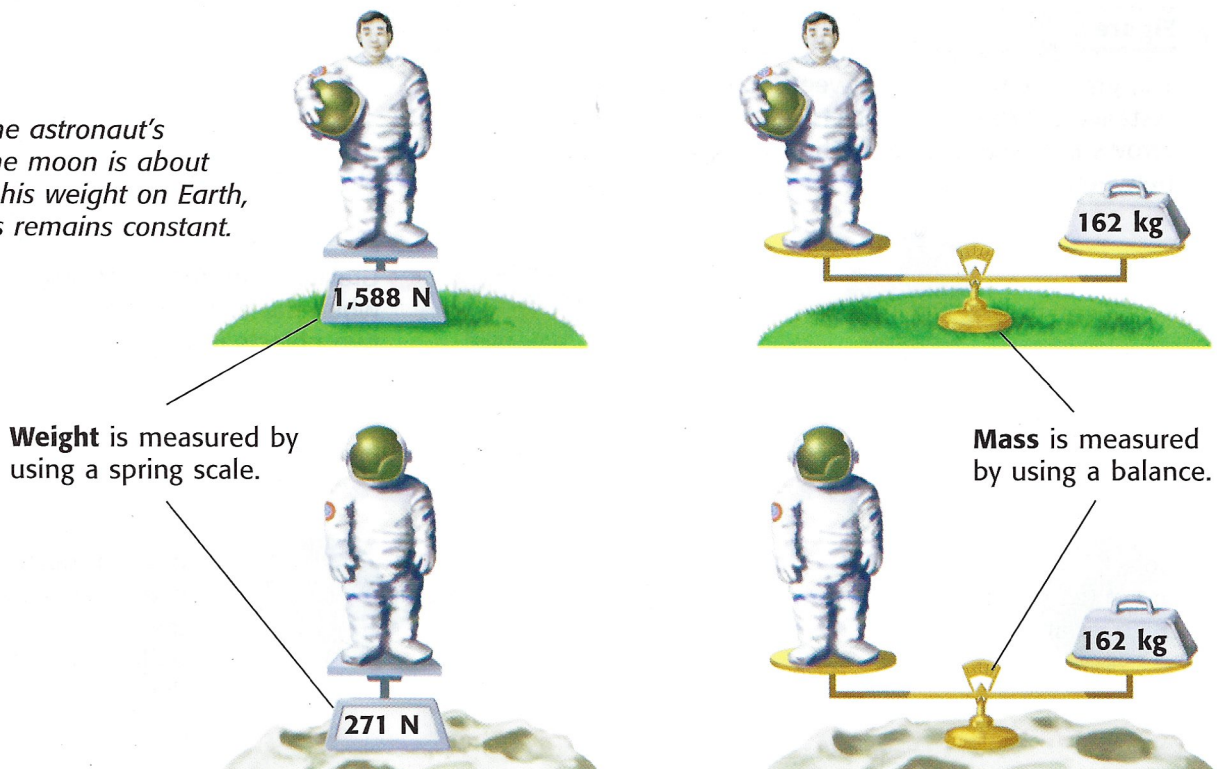
The Differences Between Weight and Mass

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 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. 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?

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



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 7**, 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.



Figure 7 A small apple weighs approximately 1 N.

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.
- Weight and mass are not the same. 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?

Math Skills

8. The gravitational force on Jupiter is approximately 2.3 times the gravitational force on Earth. If an object has a mass of 70 kg and a weight of 686 N on Earth, what would the object's mass and weight on Jupiter be?

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.

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Topic: **Matter and Gravity**
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Chapter Review

USING KEY TERMS

Complete each of the following sentences by choosing the correct term from the word bank.

| | |
|-----------|----------|
| mass | gravity |
| friction | weight |
| speed | velocity |
| net force | newton |

- 1 ___ opposes motion between surfaces that are touching.
- 2 The ___ is the unit of force.
- 3 ___ is determined by combining forces.
- 4 Acceleration is the rate at which ___ changes.
- 5 ___ is a measure of the gravitational force on an object.

UNDERSTANDING KEY IDEAS

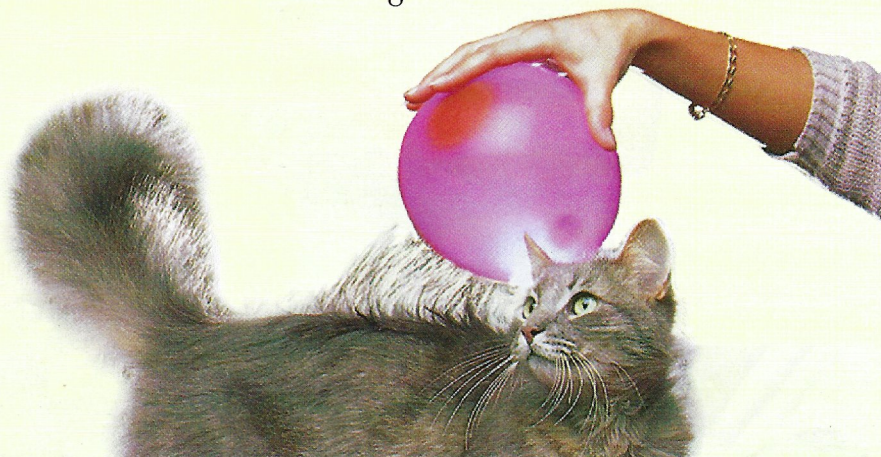
Multiple Choice

- 6 If a student rides her bicycle on a straight road and does not speed up or slow down, she is traveling with a
 - a. constant acceleration.
 - b. constant velocity.
 - c. positive acceleration.
 - d. negative acceleration.
- 7 A force
 - a. is expressed in newtons.
 - b. can cause an object to speed up, slow down, or change direction.
 - c. is a push or a pull.
 - d. All of the above

- 8 If you are in a spacecraft that has been launched into space, your weight would
 - a. increase because gravitational force is increasing.
 - b. increase because gravitational force is decreasing.
 - c. decrease because gravitational force is decreasing.
 - d. decrease because gravitational force is increasing.
- 9 The gravitational force between 1 kg of lead and Earth is ___ the gravitational force between 1 kg of marshmallows and Earth.
 - a. greater than
 - b. less than
 - c. the same as
 - d. None of the above
- 10 Which of the following is a measurement of velocity?
 - a. 16 m east
 - b. 25 m/s²
 - c. 55 m/h south
 - d. 60 km/h

Short Answer

- 11 Describe the relationship between motion and a reference point.
- 12 How is it possible to be accelerating and traveling at a constant speed?
- 13 Explain the difference between mass and weight.



Math Skills

- 14 A kangaroo hops 60 m to the east in 5 s. Use this information to answer the following questions.
- What is the kangaroo's average speed?
 - What is the kangaroo's average velocity?
 - The kangaroo stops at a lake for a drink of water and then starts hopping again to the south. Each second, the kangaroo's velocity increases 2.5 m/s. What is the kangaroo's acceleration after 5 s?

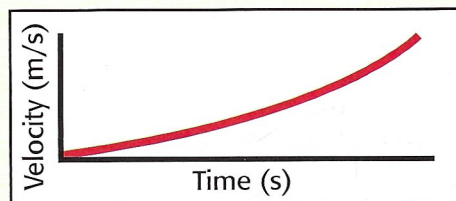
CRITICAL THINKING

- 15 **Concept Mapping** Use the following terms to create a concept map: *speed*, *velocity*, *acceleration*, *force*, *direction*, and *motion*.
- 16 **Applying Concepts** Your family is moving, and you are asked to help move some boxes. One box is so heavy that you must push it across the room rather than lift it. What are some ways you could reduce friction to make moving the box easier?
- 17 **Analyzing Ideas** Considering the scientific meaning of the word *acceleration*, how could using the term *accelerator* when talking about a car's gas pedal lead to confusion?
- 18 **Identifying Relationships** Explain why it is important for airplane pilots to know wind velocity and not just wind speed during a flight.

INTERPRETING GRAPHICS

Use the figures below to answer the questions that follow.

- 19 Is the graph below showing positive acceleration or negative acceleration? How can you tell?



- 20 You know how to combine two forces that act in one or two directions. The same method can be used to combine several forces acting in several directions. Look at the diagrams, and calculate the net force in each diagram. Predict the direction each object will move.

