Section 1

Reading Preview

Essential Questions

- How are force and motion related?
- How is the net force on an object determined?
- Why is there friction between objects?
- What is the difference between mass and weight?

Review Vocabulary

mass: amount of matter in an object

New Vocabulary

force
net force
friction
gravity
field
weight

Multilingual eGlossary

Forces

MAIN Idea **Unbalanced forces change motion.**

Real-World Reading Link Have you ridden a bike down a steep hill? You might have noticed that you went faster and faster or that you had to brake very hard to stop the bike. In both cases, you and your bike were accelerating. What caused that acceleration?

What is force?

Catching a basketball and hitting a baseball with a bat are examples of applying force to an object. A **force** is a push or a pull. In both examples, the applied force changes the movement of the ball. Sometimes, it is obvious that a force has been applied. But other forces are not as noticeable. For instance, are you conscious of the force that the floor exerts on your feet? Can you feel the force of the atmosphere pushing against your body or gravity pulling on your body? Think about all of the forces that you exert in a day. Every push, pull, stretch, or bend results in a force being applied to an object.

Changing motion What happens to the motion of an object when you exert a force on it? A force can cause the motion of an object to change. Think of kicking a soccer ball, as shown in **Figure 1.** The player's foot strikes the ball with a force that causes the ball to stop and then move in the opposite direction. If you have played billiards, you know that you can force a ball at rest to roll into a pocket by striking it with another ball. The force of the moving ball causes the ball at rest to move in the direction of the force. In each case, the velocity of the ball was changed by a force.

Figure 1 When the player kicks the soccer ball, she is exerting a force on the ball. This kick will cause the ball's motion to change.

Net force When two or more forces act on an object at the same time, the forces combine to form the net force. The **net force** is the sum of all of the forces acting on an object. Forces have a direction, so they follow the same addition rules as displacement, as listed in **Table 1**. Forces are measured in the SI unit of newtons (N). A force of about 3 N is needed to lift a full can of soda at a constant speed.

Unbalanced forces Look at **Figure 2A**. The students are each pushing on the box in the same direction. These forces are combined, or added together, because they are exerted on the box in the same direction. The students in **Figure 2B** are pushing in opposite directions. Here, the direction of the net force is the same as the direction of the larger force. In other words, the student who pushes harder causes the box to move in the direction of that push. The net force will be the difference between the two forces because they are in opposite directions. In **Figure 2A** and **Figure 2B**, the net force had a value that was not zero and the box moved. The forces that the students applied are considered unbalanced forces.

Balanced forces Now suppose that the students were pushing with the same size force but in opposite directions, as shown in **Figure 2C**. The net force on the box is zero because the two forces cancel each other. Forces on an object that are equal in size and opposite in direction are called balanced forces. Unbalanced forces cause changes in motion. Balanced forces do not cause a change in motion.

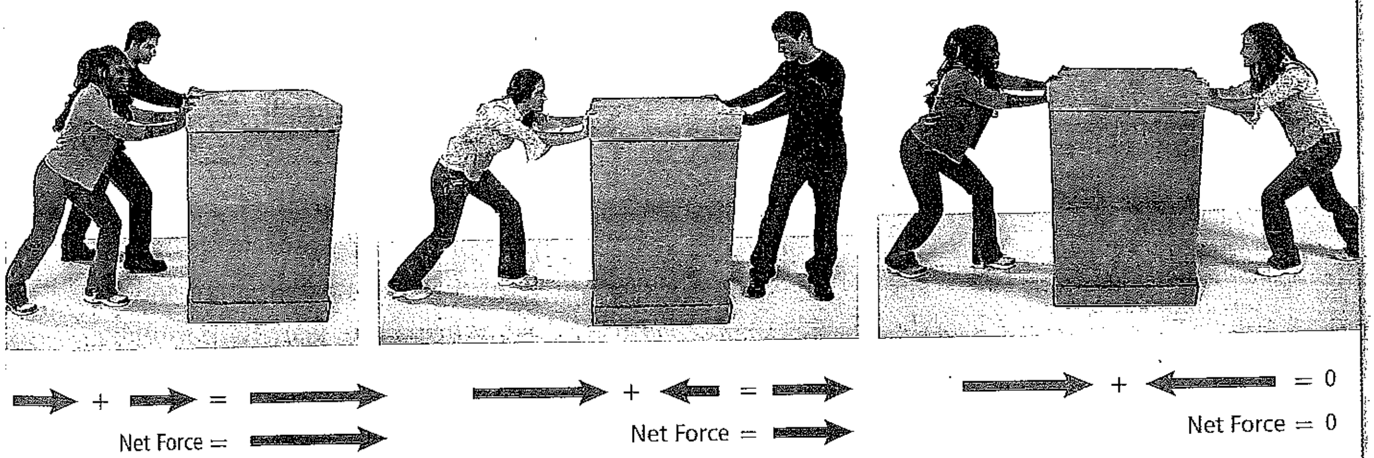
Table 1 Rules for Adding Forces

1. Add forces in the same direction.
2. Subtract forces in opposite directions.
3. Forces not in the same direction or in opposite directions cannot be directly added together.

Inquiry Video Lab

Figure 2 Forces can be balanced or unbalanced.

Identify *another example of unbalanced forces and another example of balanced forces.*



[A] These students are pushing on the box in the same direction. These forces are unbalanced. The net force is the sum of the two forces, and the box will move in the direction that the students push.

[B] These students are pushing on the box with unequal forces in opposite directions. These forces are unbalanced. The net force is the difference of the two forces, and the box will move in the direction of the larger force.

[C] These students are pushing on the box with equal forces but in opposite directions. These forces are balanced. The net force is zero and the box does not move.

Friction

Suppose you give a skateboard a push with your hand. After you let go, the skateboard slows down and eventually stops. Because the skateboard's motion is changing as it slows down, there must be a force acting on it. The force that slows the skateboard is called friction. **Friction** is the force that opposes the sliding motion of two surfaces that are touching each other.

What causes friction? Would you believe that the surface of a highly polished piece of metal is rough? Surfaces that appear smooth actually have many bumps and dips. These bumps and dips can be seen when the surface is examined under a microscope, as shown in **Figure 3.** If two surfaces are in contact, welding or sticking occurs where the bumps touch each other. These microwelds are the source of friction. To move one surface over the other, a force must be applied to break the microwelds.

Reading Check **Describe** the source of friction.

The amount of friction between two surfaces depends on the kinds of surfaces and the force pressing the surfaces together. Rougher surfaces have more bumps and can form more microwelds, increasing the amount of friction. In addition, a larger force pushing the two surfaces together will cause more of the bumps to come into contact, as shown in **Figure 4.** The microwelds will be stronger, and a greater force must be applied to the object to break the microwelds.

Static friction Suppose you have a cardboard box filled with books, such as the one in **Figure 5,** and want to move that box. The box is resting on what seems to be a smooth floor, but when you push on the box, it does not budge. The box experiences no change in motion, so the net force on the box is zero. The force of friction cancels your push.

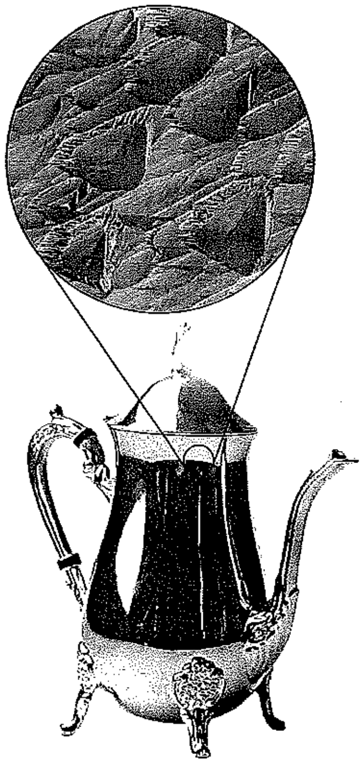


Figure 3 The surface of this teapot looks and feels smooth, but it is rough at the microscopic level.

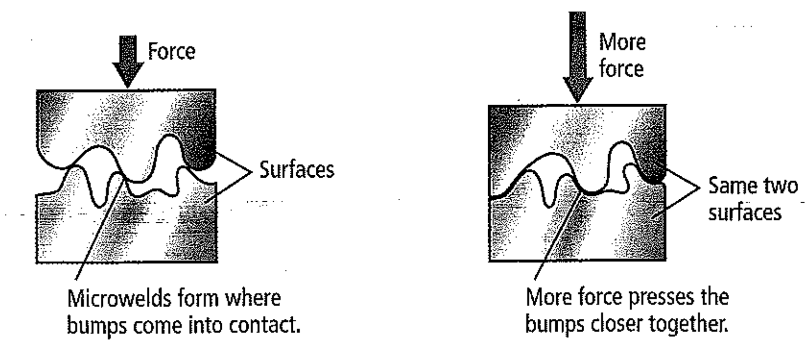
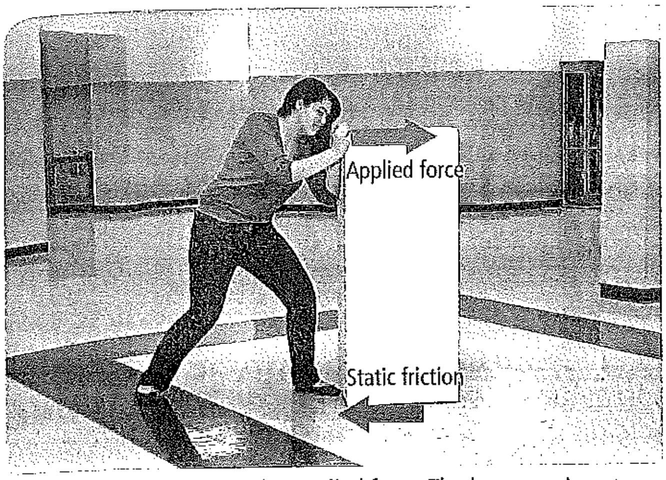
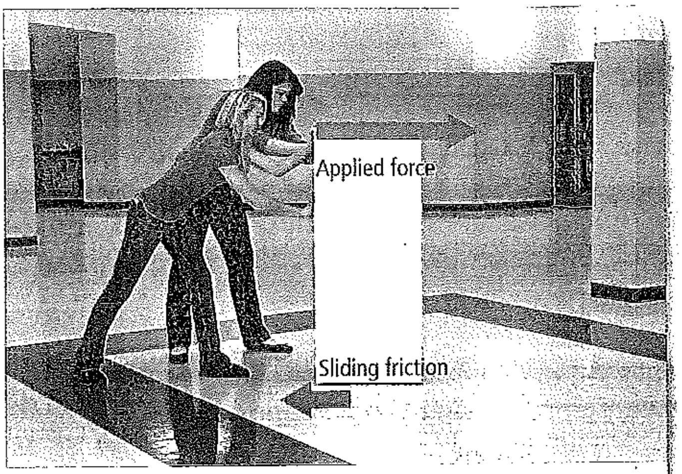


Figure 4 Friction is caused by microwelds that form between two surfaces. Microwelds are stronger when the two surfaces are pushed together with a larger force.

Explain ***how the area of contact between the surfaces changes when they are pushed together.***



Static friction balances the applied force. The box remains at rest and does not accelerate.



Sliding friction and the applied force are unbalanced. The box accelerates to the right.

Figure 5 Friction opposes the sliding motion of two surfaces that are touching each other.

Describe *the net force on each box.*

This type of friction is called static friction. Static friction prevents two surfaces from sliding past each other and is due to the microwelds that have formed between the bottom of the box and the floor. Your push is not large enough to break the microwelds, and the box does not move, as shown in **Figure 5.**

Sliding friction If you and a friend push together, as shown on the right in **Figure 5,** the box moves. Together, you and your friend have exerted enough force to break the microwelds between the floor and the bottom of the box. But if you stop pushing, the box quickly comes to a stop. To keep the box moving, you must continually apply a force. This is because sliding friction opposes the motion of the box as the box slides across the floor. Sliding friction opposes the motion of two surfaces sliding past each other and is caused by microwelds constantly breaking and forming as the objects slide past each other. The force of sliding friction is usually smaller than the force of static friction.

Rolling friction You may think of friction as a disadvantage. But wheels, like the ones shown in **Figure 6,** would not work without friction. As a wheel rolls, static friction acts over the area where the wheel and surface are in contact. This special case of static friction is sometimes called rolling friction.

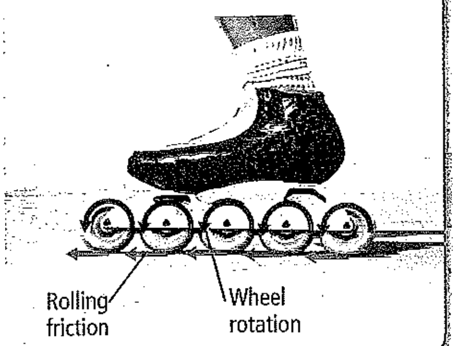
You may have seen a car that was stuck in snow, ice, or mud. The driver steps on the gas, but the wheels just spin without the car moving. The force used to rotate the tires is larger than the force of static friction between the wheels and the ground, so the tires slide instead of gripping the ground. Spreading sand or gravel on the surface increases the friction until the wheels stop slipping and begin rolling. When referring to tires on vehicles, people often use the term *traction* instead of friction.

VOCABULARY

WORD ORIGIN

Friction
from the Latin *fricare* meaning "to rub"
Oil can be used to reduce friction.

Figure 6 Rolling friction between the in-line skate's wheels and the pavement keeps the wheels from slipping.



MiniLab

Inquiry MiniLab

Compare Friction and Gravity

Procedure

1. Read the procedure and safety information, and complete the lab form.
2. Place an **ice cube,** a **rock,** an **eraser,** a **wood block,** and a **square of aluminum foil** at one end of a **metal or plastic tray.**
3. Slowly lift the end of the tray with the items.
4. Have a partner use a **metric ruler** to measure the height of the raised end of the tray at which each object begins to slide. Record the measurements.

Analysis

1. **Create** a table and include the height at which each object began to slide.
2. **Infer** Which item experienced the greatest frictional force? How do you know?
3. **Identify** the force that caused the objects to slide.

Gravity

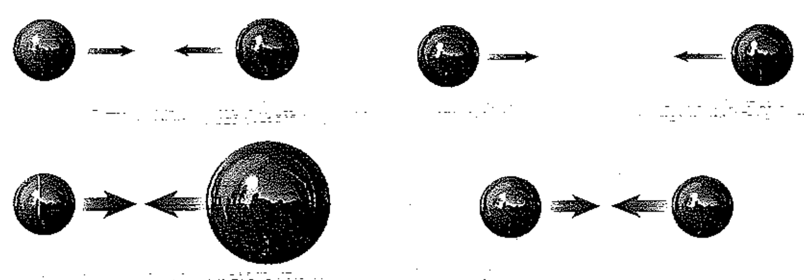
At this moment, you are exerting an attractive force on everything around you—your desk, your classmates, and even the planet Jupiter, millions of kilometers away. This attractive force acts on all objects with mass and is called gravity. **Gravity** is an attractive force between any two objects that depends on the masses of the objects and the distance between them.

Gravity is one of the four basic forces. These forces are called the fundamental forces. The other basic forces are the electromagnetic force, the strong nuclear force, and the weak nuclear force. Gravity acts on all objects with mass, and the electromagnetic force acts on all charged particles. Both gravity and the electromagnetic force have an infinite range. The nuclear forces only affect particles in the nuclei of atoms.

The law of universal gravitation In the 1660s, British scientist Isaac Newton used data on the motions of the planets to find the relationship between the gravitational force between two objects, the objects' masses, and the distance between them. This relationship is called the law of universal gravitation and can be written as the following equation.

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

In this equation, G is the universal gravitational constant, and d is the distance between the centers of the two masses, m_1 and m_2. The law of universal gravitation states that the gravitational force increases as the mass of either object increases and as the objects move closer, as shown in **Figure 7.** The force of gravity between any two objects can be calculated if their masses and the distance between them are known.



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.

Figure 7 The law of universal gravitation states that the gravitational force between two objects depends on their masses and the distance between them.

Gravity and you The law of universal gravitation explains why you feel Earth's gravity but not the Sun's gravity or this book's gravity. 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 does not have enough mass to exert an attraction that you can feel. Only Earth is both close enough and has a large enough mass that you can feel its gravitational attraction.

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.

Reading Check **Explain** why gravity is called a long-range force.

The gravitational field Because contact between objects is not required, gravity is sometimes discussed as a field. A **field** is a region of space that has a physical quantity (such as a force) at every point. All objects are surrounded by a gravitational field. **Figure 8** shows that Earth's gravitational field is strongest near Earth and becomes weaker as the distance from Earth increases. The strength of the gravitational field, represented by the letter *g*, is measured in newtons per kilogram (N/kg).

Review
Additional Practice Problems

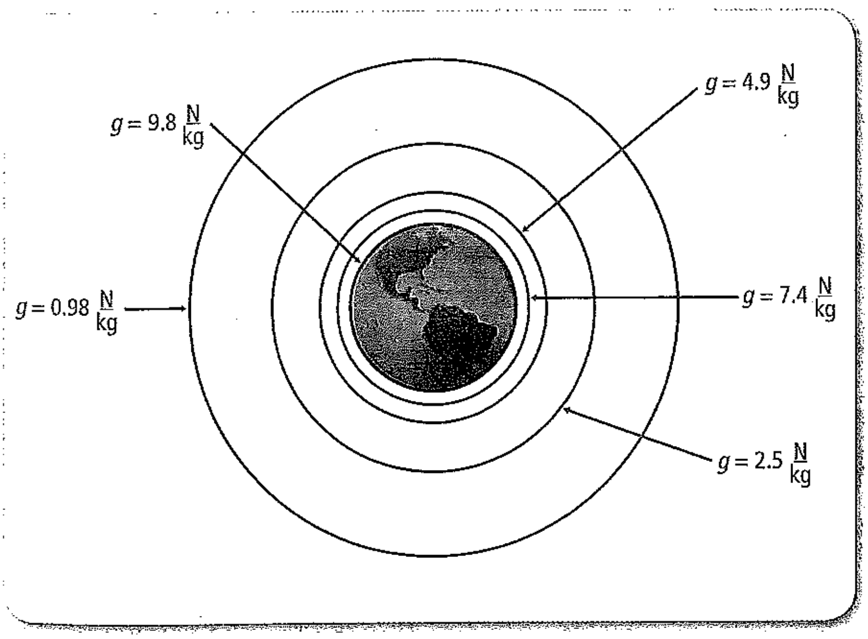


Figure 8 Earth's gravitational field exists at all points in space. It is strongest near the surface and decreases in strength as one moves away from Earth.

Table 2	Weight of Common Objects on Earth
Object	**Weight**
Cell phone	1 N
Backpack full of books	100 N
Jumbo jet	3.4 million N

Weight The gravitational force exerted on an object is the object's **weight.** The universal law of gravitation can be used to calculate weight, but scientists use a simplified version of this equation that combines m_1, d^2, and G into a single number called the gravitational strength, g.

Weight Equation

weight (N) = **mass** (kg) × **gravitational strength** (N/kg)

$$F_g = mg$$

We use F_g for weight because weight is the force due to gravity. Weight has units of newtons (N) because it is a force. The g in the subscript stands for *gravity.* The gravitational strength, g, has the units N/kg. Recall that 1 N = 1 kg · m/s^2. So, g can also be written with units of m/s^2.

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. But, according to the weight equation, weight and mass are related. Weight increases as mass increases.

Weight on Earth We often need to know an object's weight on Earth. Near Earth's surface, m_1, from the law of universal gravitation, is Earth's mass and d is Earth's radius. As a result, $g = 9.8$ N/kg. **Table 2** lists the weights of some objects on Earth.

EXAMPLE Problem 1

Solve for Weight An elephant has a mass of 5,000 kg. What is the elephant's weight?

Identify the Unknown: weight: F_g

List the Knowns: mass: m = **5,000 kg**
gravitational strength: g = **9.8 N/kg**

Set Up the Problem: $F_g = mg$

Solve the Problem: F_g = **(5,000 kg)(9.8 N/kg)** = **49,000 N**

Check the Answer: The gravitational strength is about 10 N/kg, so we would expect the elephant's weight to be about 50,000 kg. Our answer (F_g = 49,000 N) makes sense.

PRACTICE Problems

Find **Additional Practice Problems** in the back of your book.

1. A squirrel has a mass of 0.5 kg. What is its weight?
2. A boy weighs 400 N. What is his mass?
3. **Challenge** An astronaut has a mass of 100 kg and has a weight of 370 N on Mars. What is the gravitational strength on Mars?

Review
Additional Practice Problems

Weight away from Earth An object's weight usually refers to 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 gravitational strength on the Moon is 1.6 N/kg, about one-sixth as large as Earth's gravitational strength. As a result, a person, such as the astronaut in **Figure 9,** would weigh only about one-sixth as much on the Moon as on Earth.

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 of 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 the laws of motion, two astronomers independently calculated the orbit of this planet. As a result of these calculations, the planet Neptune was found in 1846.

Figure 9 Although the astronaut has the same mass on the Moon, he weighs less than he does on Earth. He can take longer steps and jump higher than on Earth.

Section 1 Review

Section Summary

- A force is a push or a pull on an object.
- The net force on an object is the combination of all of the forces acting on the object.
- Unbalanced forces cause the motion of objects to change.
- Friction is the force that opposes the sliding motion of two surfaces that are in contact.
- Gravity is an attractive force between all objects that have mass.

4. MAIN Idea **Describe** two forces that would change the motion of a bicycle traveling along a road.
5. **Explain** Can there be forces acting on an object if the object is at rest? Must there be an unbalanced force acting on a moving object? Explain your answers.
6. **Explain** Why does coating surfaces with oil reduce friction between the surfaces?
7. **Distinguish** between the mass of an object and the object's weight.
8. **Think Critically** Suppose Earth's mass increased but Earth's diameter did not change. How would the gravitational strength near Earth's surface change?

Apply Math

9. **Calculate Weight** On Earth, what is the weight of a large-screen TV that has a mass of 75 kg?
10. **Calculate Net Force** Two students push on a box in the same direction, and one student pushes in the opposite direction. What is the net force on the box if each student pushes with a force of 50 N?

Assessment **Online Quiz**