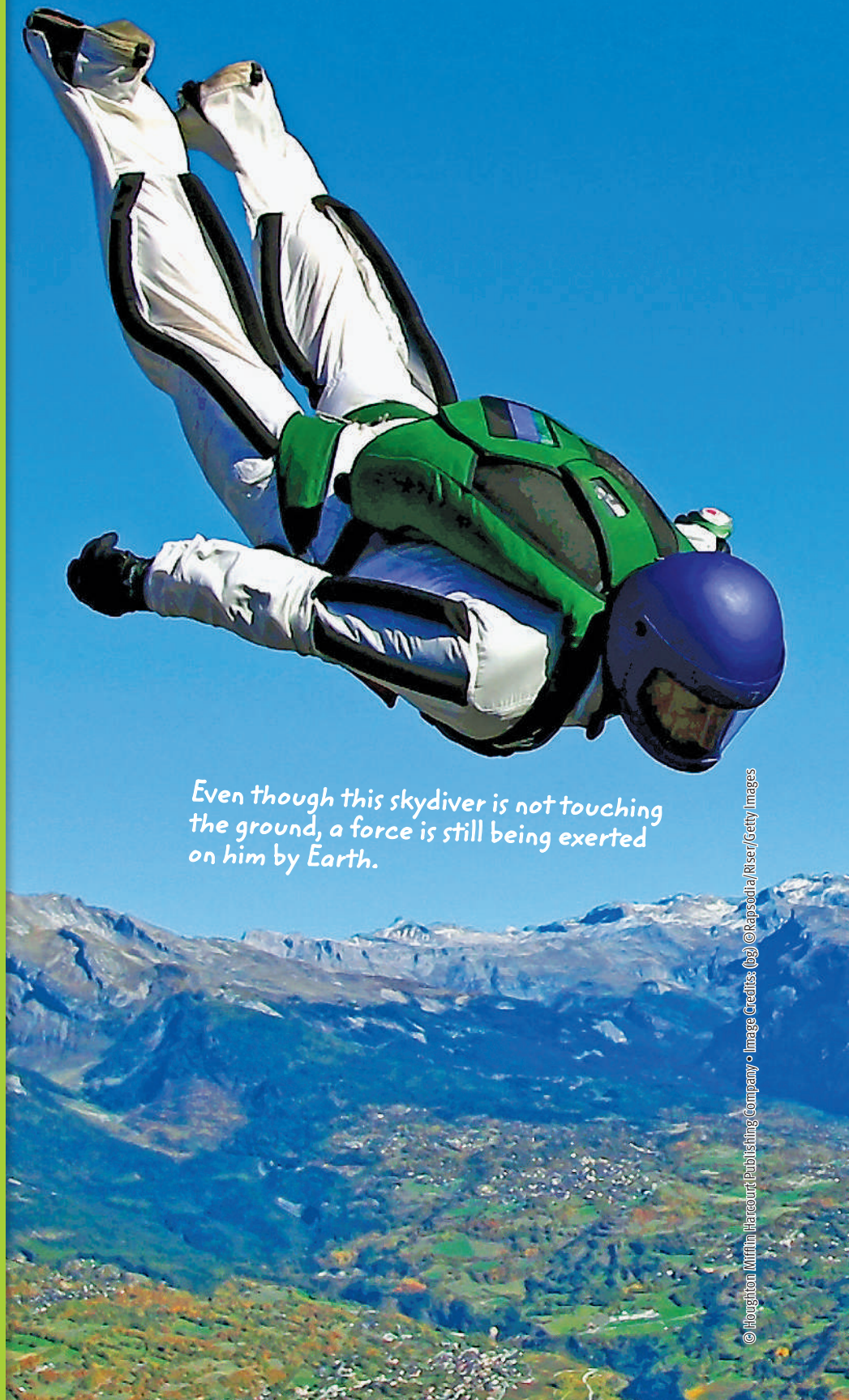
Lesson 3

Forces

ESSENTIAL QUESTION

How do forces affect motion?

By the end of this lesson, you should be able to describe different types of forces and explain the effect force has on motion.



Even though this skydiver is not touching the ground, a force is still being exerted on him by Earth.

- **S8P3.a** Speed, distance, velocity, and acceleration
- **S8P3.b** Newton's Laws of Motion
- **S8P3.c** Force, acceleration, and inertia
- **S8P5.a** Fields and forces

Lesson Labs

Quick Labs
- Net Force
- First Law of Skateboarding

S.T.E.M. Lab
- Newton's Laws of Motion

Engage Your Brain

1 Illustrate Draw a diagram showing how forces act on a ball tossed into the air.

2 Describe Write a caption for this photo.

Active Reading

3 Apply Many scientific words, such as *net*, also have everyday meanings. Use context clues to write your own definition for each meaning of the word *net*.

Example sentence
The fisherman scooped his catch out of the water with a net.

net:

Example sentence
Subtract the mass of the container from the total mass of the substance and the container to determine the net mass of the substance.

net:

Vocabulary Terms

- **force**
- **inertia**
- **net force**

4 Apply As you learn the definition of each vocabulary term in this lesson, create your own definition or sketch to help you remember the meaning of the term.

A Tour de Forces

What is a force, and how does it act on an object?

You have probably heard the word *force* used in conversation. People say, "Don't force the issue," or "Our team is a force to be reckoned with." Scientists also use the word *force*. What exactly is a force, as it is used in science?

A Force Is a Push or a Pull

Active Reading **5 Identify** As you read, underline the unit that is used to express force.

In science, a **force** is simply a push or a pull. All forces have both a size and a direction. A force can cause an object to change its speed or direction. When you see a change in an object's motion, one or more forces caused the change. The unit used to express force is the newton (N). You will learn how to calculate force a little later in this lesson.

Forces exist only when there is an object for them to act on. However, forces do not always cause an object to move. When you sit in a chair, the chair does not move. Your downward force on the chair is balanced by the upward force from the floor.

Visualize It!

6 Identify Draw arrows to represent the pushing forces in the image at left and the pulling forces in the image at right.

A Force Can Act Directly on an Object

It is not always easy to tell what is exerting a force or what is being acted on by a force. When one object touches or bumps into another object, we say that the objects are in contact with each other. A force exerted during contact between objects is a contact force. Friction is an example of a contact force between two surfaces. Suppose you slide a book across your desk. The amount of friction between the surface of the desk and the book cover determines how easily the book moves. Car tires rely on friction to keep a moving car from sliding off a road. Cars may slide on icy roads because ice lowers the force of friction on the tires.

A Force Can Act on an Object from a Distance

Forces can also act at a distance. One force that acts at a distance is called gravity. When you jump, gravity pulls you back to the ground even though you are not touching Earth. Magnetic force is another example of a force that can act at a distance. Magnetic force can be a push or a pull. A magnet can hold paper to a metal refrigerator door. The magnet touches the paper, not the metal, so the magnetic force is acting on the refrigerator door at a distance. Magnetic force also acts at a distance when the like poles of two magnets push each other apart. A magnetic levitation train floats because magnetic forces push the train away from its track.

Visualize It!

7 Identify The arrows in the picture below represent contact and distance forces. Label each arrow with a "C" if it is a contact force or "D" if it is a distance force.

In the Balance

What happens when multiple forces act on an object?

Active Reading

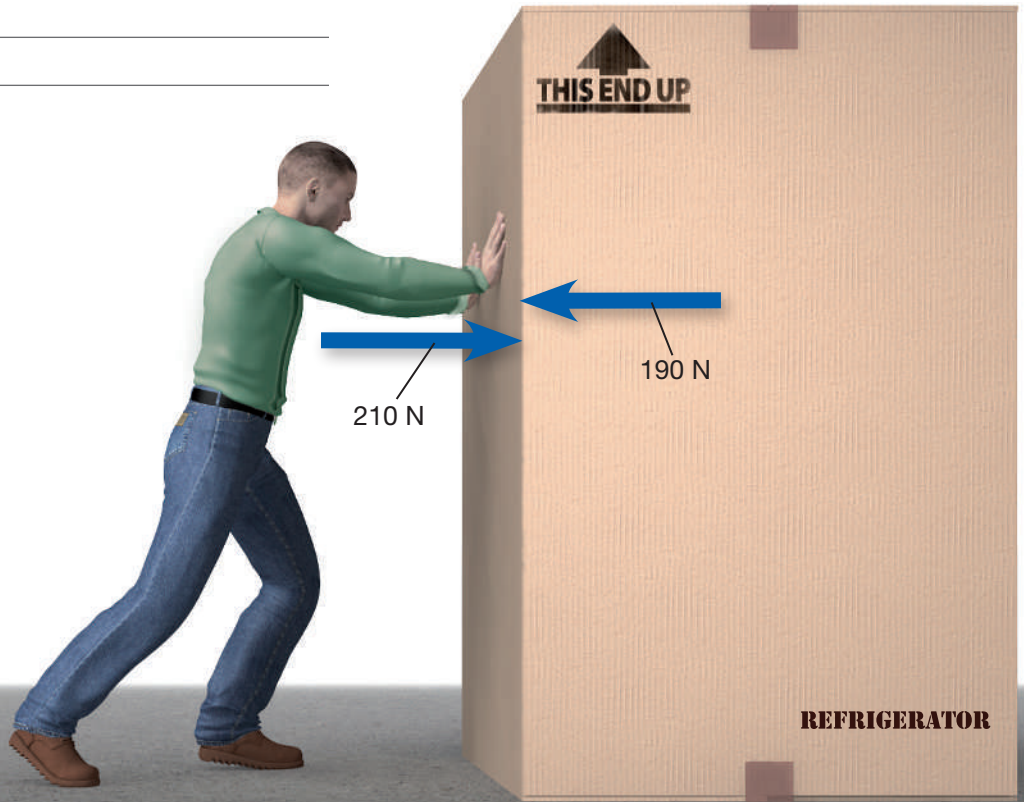
8 Identify As you read, underline how one determines net force.

Usually, more than one force is acting on an object. The combination of all the forces acting on an object is called the **net force**. How do you determine net force? The answer depends on the directions of the forces involved.

When forces act in the same direction, you simply add them together to determine the net force. For example, when forces of 1 N and 2 N act in the same direction on an object, the net force is 1 N + 2 N = 3 N. When forces act in opposite directions, you subtract the smaller force from the larger force to determine the net force: 2 N – 1 N = 1 N.

Visualize It!

9 Calculate Calculate the net force acting on the appliance box and use it to determine if the box will move.



The Forces Can Be Balanced

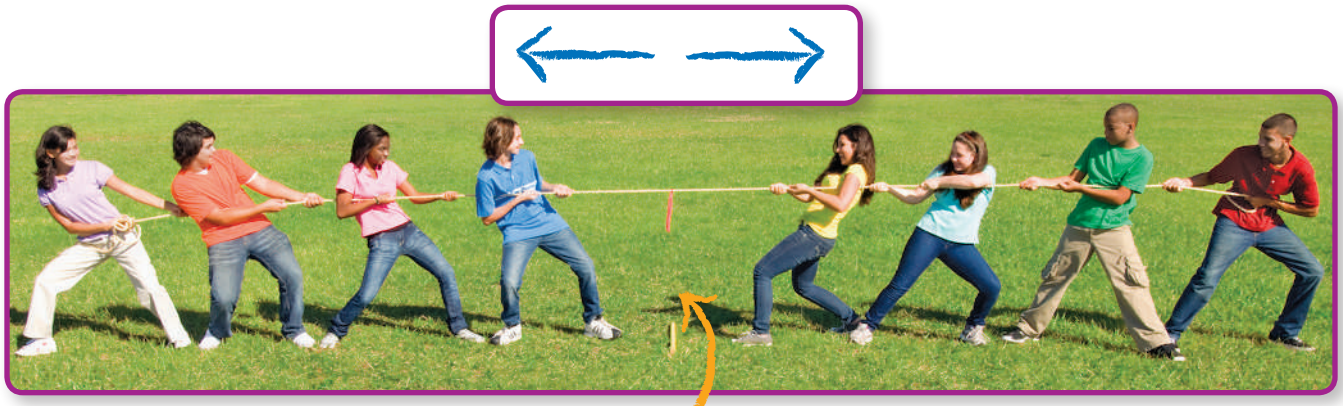
When the forces on an object produce a net force of 0 N, the forces are balanced. Balanced forces will not cause a change in the motion of a moving object or cause a nonmoving object to start moving. Many objects around you have only balanced forces acting on them. A light hanging from the ceiling does not move, because the force of gravity pulling downward on the light is balanced by the force of the chain pulling the light upward.

The Forces Can Be Unbalanced

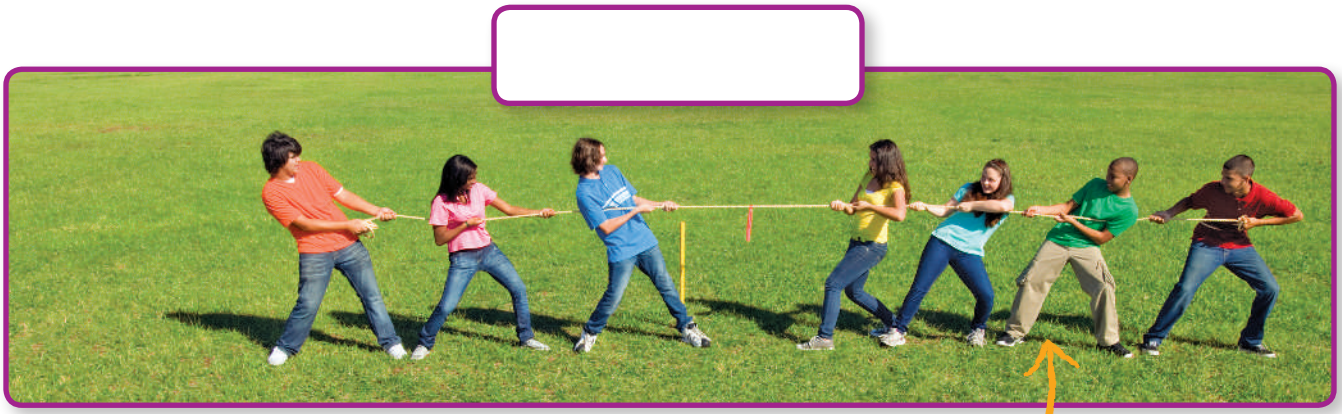
When the net force on an object is not 0 N, the forces are unbalanced. Unbalanced forces produce a change in the object's motion. It could be a change in its speed or direction or both. This change in motion is called acceleration. The acceleration is always in the direction of the net force. For example, when a big dog and a small dog play with a tug toy, the bigger dog pulls with greater force, so the acceleration is in the direction of the bigger dog.

Visualize It!

10 Apply The arrows in the first image show that the forces on the rope are balanced. Draw arrows on the second image to show how the forces on the rope are unbalanced.



These two tug-of-war teams are pulling on the rope with equal force to produce a net force of 0 N. The rope does not move.



One of these teams is pulling on the rope with more force. The rope moves in the direction of the stronger team.

It's the Law

What is Newton's First Law of Motion?

Force and motion are related. In the 1680s, British scientist Sir Isaac Newton explained this relationship between force and motion with three laws of motion.

Newton's first law describes the motion of an object that has a net force of 0 N acting on it. The law states: *An object at rest stays at rest, and an object in motion stays in motion at the same speed and direction, unless it experiences an unbalanced force.* Let's look at the two parts of this law more closely.

An Object at Rest Stays at Rest

Active Reading **11 Identify** As you read, underline examples of objects affected by inertia.

Newton's first law is also called the law of inertia. **Inertia** (ih•NER•shuh) is the tendency of all objects to resist a change in motion. An object will not move until a force makes it move. So a chair will not slide across the floor unless a force pushes the chair, and a golf ball will not leave the tee until a force pushes it off.

Visualize It!

12 Explain Do the dishes on a table have inertia? Provide evidence from the illustrations below. Explain your reasoning.

An Object in Motion Stays in Motion

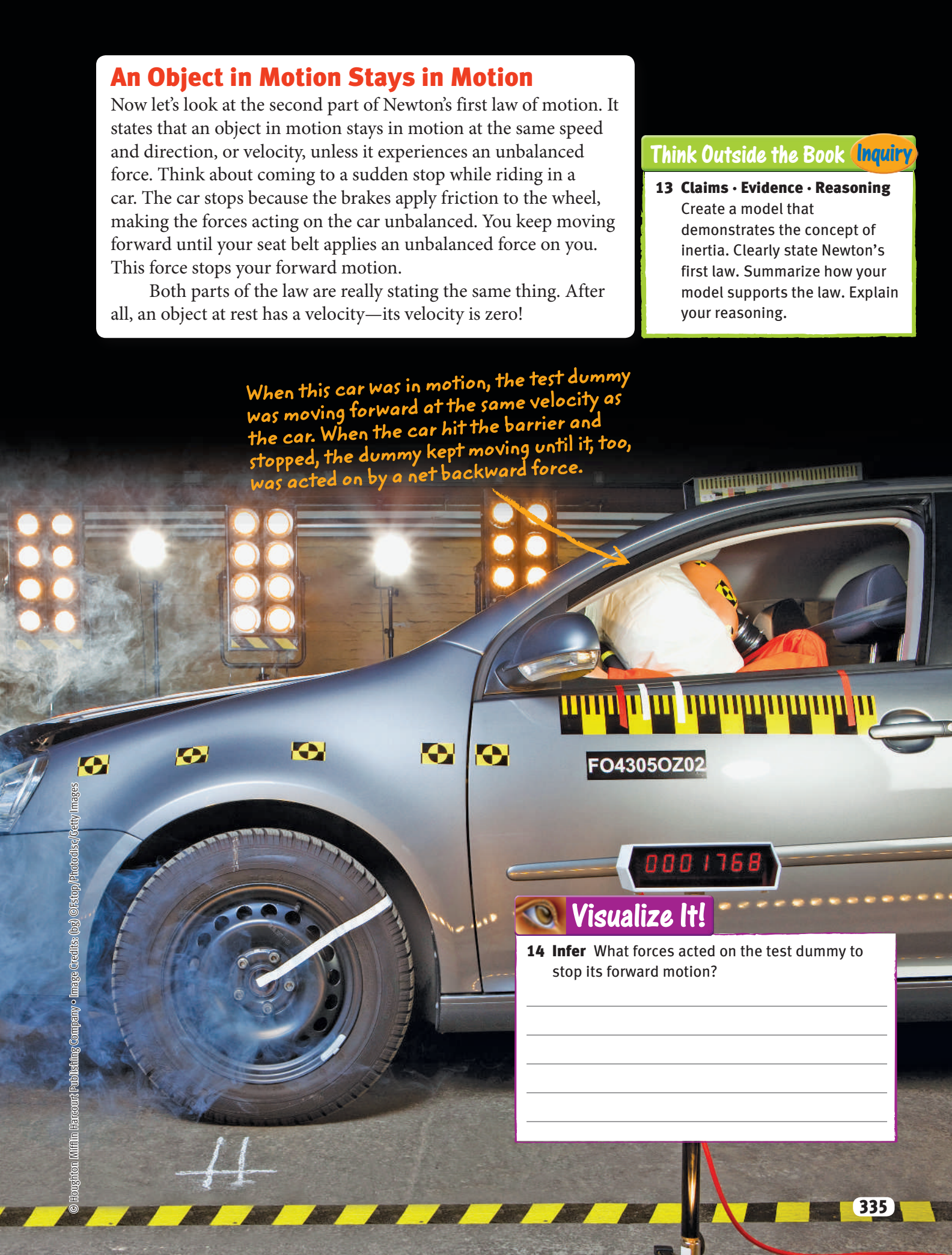
Now let's look at the second part of Newton's first law of motion. It states that an object in motion stays in motion at the same speed and direction, or velocity, unless it experiences an unbalanced force. Think about coming to a sudden stop while riding in a car. The car stops because the brakes apply friction to the wheel, making the forces acting on the car unbalanced. You keep moving forward until your seat belt applies an unbalanced force on you. This force stops your forward motion.

Both parts of the law are really stating the same thing. After all, an object at rest has a velocity—its velocity is zero!

Think Outside the Book Inquiry

13 Claims · Evidence · Reasoning Create a model that demonstrates the concept of inertia. Clearly state Newton's first law. Summarize how your model supports the law. Explain your reasoning.

When this car was in motion, the test dummy was moving forward at the same velocity as the car. When the car hit the barrier and stopped, the dummy kept moving until it, too, was acted on by a net backward force.



Visualize It!

14 Infer What forces acted on the test dummy to stop its forward motion?

What is Newton's Second Law of Motion?

Active Reading

15 Identify As you read, underline Newton's second law of motion.

When an unbalanced force acts on an object, the object accelerates. Newton's second law describes this motion. The law states: *The acceleration of an object depends on the mass of the object and the amount of force applied.*

In other words, objects that have different masses will have different accelerations if the same amount of force is used. Imagine pushing a shopping cart. When the cart is empty, you need only a small force to accelerate it. But if the cart is full of groceries, the same amount of force causes a much smaller acceleration.

Force Equals Mass Times Acceleration

Newton's second law links force, mass, and acceleration. We can express this relationship using the equation $F = ma$, where F stands for applied force, m stands for mass, and a stands for acceleration. This equation tells us that a given force applied to a large mass will result in a small acceleration. When the same force is applied to a smaller mass, the acceleration will be larger.

Do the Math — Sample Problem

These players train by pushing a massive object. If the players push with a force of 150 N, and the object has a mass of 75 kg, what is the object's acceleration? One newton is equal to 1 kg•m/s^2.

Use Newton's law:

$$F = ma$$
$$150\ \text{kg•m/s}^2 = (75\ \text{kg})(a)$$
$$a = \frac{150}{75}\ \text{m/s}^2$$
$$a = 2.0\ \text{m/s}^2$$

You Try It

16 Calculate For a more difficult training session, the mass to be pushed is increased to 160 kg. If the players still push with a force of 150 N, what is the acceleration of the object?

Use Newton's law:

$$F = ma$$
$$150\ N =$$

How is the law of force and acceleration applied to everyday situations?

The law of force and acceleration indicates that an object with greater mass requires a larger force in order to accelerate the object. For example, you know that a strong adult can lift a heavier object than a small child can. This is because the adult has larger muscles and can exert more force.

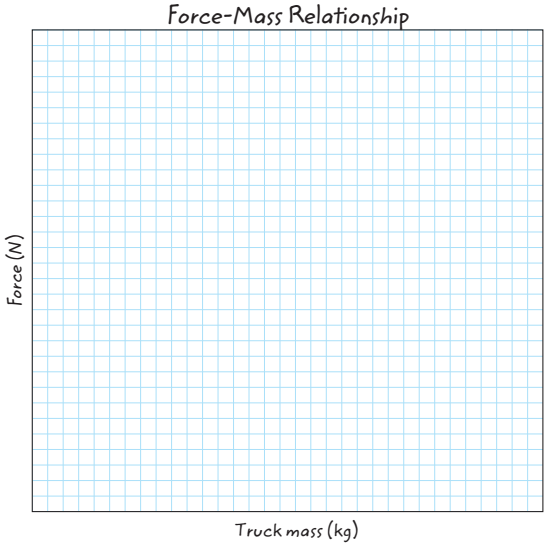
Engineers use the law of force and acceleration when they design engines for vehicles and construction equipment. The larger the vehicle, the more powerful the engine that will be needed in order to make the vehicle move.

Visualize It!

17 Explain Look at the picture to the right. The truck is out of gas. The truck has a mass of 1500 kg and is loaded with 1000 kg of furniture. The man must apply 82 N of force for 60 seconds to bring the truck from rest to a velocity of 2.0 m/s. If the man had first unloaded half of the furniture (500 kg), only 66 N of force for 60 seconds would be needed to reach the same velocity. If he had unloaded all of the furniture, only 50 N of force for 60 seconds would be needed to reach the same velocity. Calculate the acceleration of the loaded truck, half-loaded truck, and empty truck.

A

B Plot the data above in the space below.



C How does the amount of force needed to accelerate an object relate to the object's mass? State your claim and use the graph as evidence to support it.

What is Newton's Third Law of Motion?

Newton also devised a third law of motion. The law states: *Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.*

So when you push against a wall, Newton's law tells you that the wall is actually pushing back against you.

Objects Exert Force on Each Other

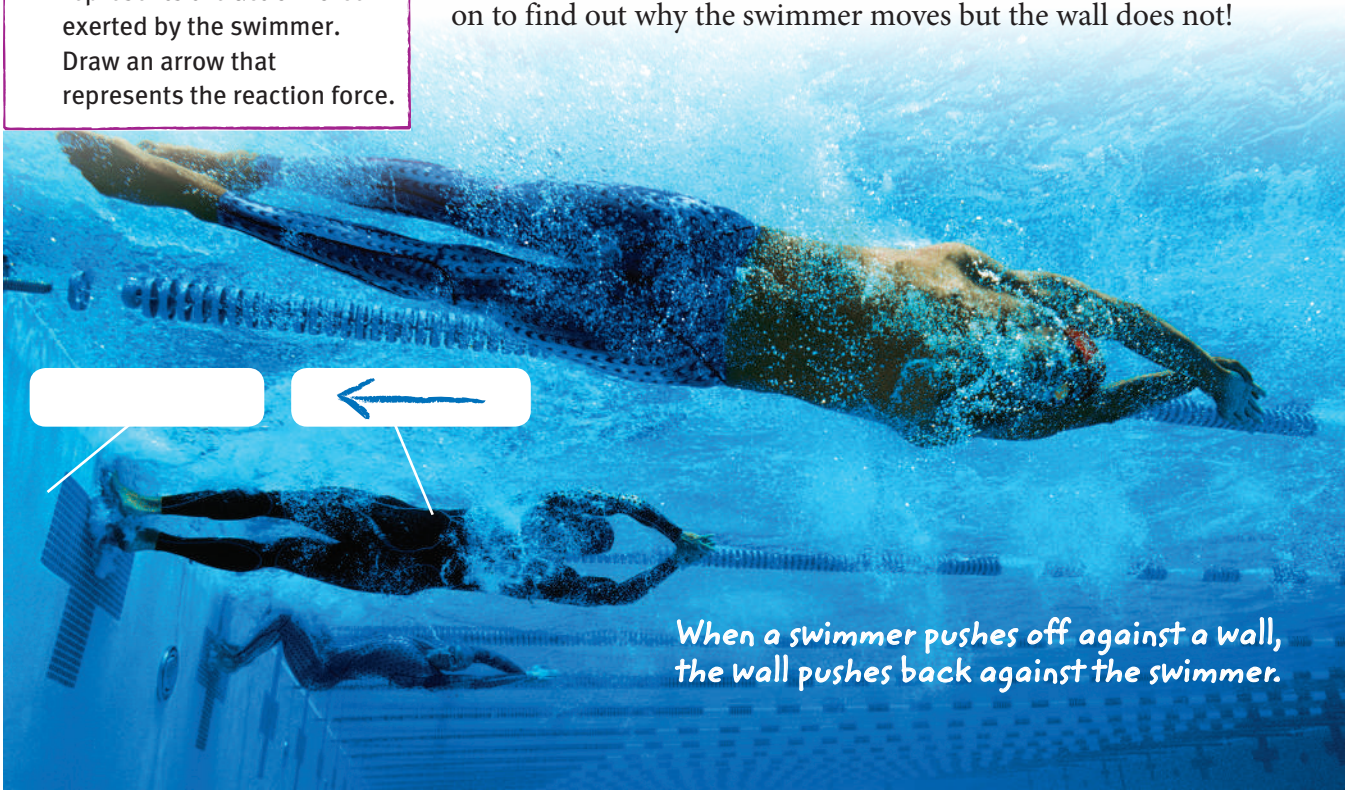
Newton's third law also can be stated as: All forces act in pairs. Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first. There are action forces and reaction forces. Action and reaction forces are present even when there is no motion. For example, you exert a force on a chair when you sit on it. Your weight pushing down on the chair is the action force. The reaction force is the force exerted by the chair that pushes up on your body.

Forces in Pairs Have Equal Size but Opposite Directions

When an object pushes against another object, the second object pushes back equally hard, in the opposite direction. In the pool below, the swimmer's feet push against the wall as he moves forward. This push is the action force. The wall also exerts a force on the swimmer. This is the reaction force, and it moves the swimmer forward. The forces do not act on the same object. Read on to find out why the swimmer moves but the wall does not!

Visualize It!

18 Apply The arrow below represents the action force exerted by the swimmer. Draw an arrow that represents the reaction force.



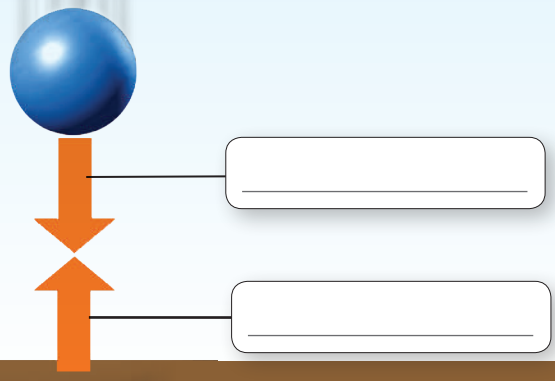
When a swimmer pushes off against a wall, the wall pushes back against the swimmer.

Forces Acting in Pairs Can Have Unequal Effects

Even though action and reaction forces are equal in size, their effects are often different. Gravitation is a force pair between two objects. If you drop a ball, gravity in an action force pulls the ball toward Earth. But the reaction force pulls Earth toward the ball! It's easy to see the effect of the action force. Why don't you see the effect of the reaction force—Earth being pulled upward? Newton's second law answers this question. The force on the ball is the same size as the force on Earth. However, Earth has much more mass than the ball. So Earth's acceleration is much smaller than that of the ball!

Visualize It!

19 Identify Label the action force and reaction force in the image below.



Forces Can Act in Multiple Pairs

An object can have multiple forces acting on it at once. When this happens, each force is part of a force pair. For example, when a baseball bat hits a baseball, the bat does not fly backward. A force is exerted on the ball by the bat. The bat does not fly backward, because the player's hands are exerting another force on the bat. What then keeps the player's hands from flying backward when the bat hits the ball? The bones and muscles in the player's arms exert a force on the hands. As you can see, a simple activity such as playing baseball involves the action of many forces at the same time.

20 Claims · Evidence · Reasoning. Can Earth's gravitational field exert a force on objects not in contact with Earth? Use evidence and Newton's laws of motion to support your claim.

Visual Summary

To complete this summary, fill in the blanks with the correct word or phrase. Then use the key below to check your answers. You can use this page to review the main concepts of the lesson.

Forces

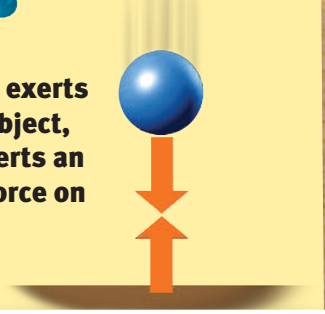
An object at rest will remain at rest and an object in constant motion will remain in motion unless acted upon by an unbalanced force.

21 Newton's first law is also called the law of _____

When an unbalanced force acts on an object, the object moves with accelerated motion.

22 In the formula $F = ma$, m stands for _____

Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.



23 Forces in the same pair have equal size but opposite _____

Answers: 21: inertia; 22: mass; 23: direction

24 Synthesize A car designer is designing a new model of a popular car. He wants to use the same engine as in the old model, but improve the new car's acceleration. Use Newton's second law to explain how to improve the car's acceleration without redesigning the engine.

Lesson Review

Vocabulary

Draw a line to connect the following terms to their definitions.

1 force
2 inertia
3 newton

A resistance of an object to a change in motion
B the unit that expresses force
C a push or a pull

Key Concepts

4 Describe What is the action force and the reaction force when you sit down on a chair?

5 Summarize How do you determine net force?

6 Explain How do tests with crash dummies, seat belts, and air bags illustrate Newton's first law of motion?

Critical Thinking

Use this photo to answer the following questions.

7 Identify This rock, known as Balanced Rock, sits on a thin spike of rock in a canyon in Idaho. Explain the forces that keep the rock balanced on its tiny pedestal.

8 Calculate Balanced Rock has a mass of about 36,000 kg. If the acceleration due to gravity is 9.8 m/s^2, what is the force that the rock is exerting on its pedestal?

9 Infer What would happen to the moon if Earth stopped exerting the force of gravity on it?

My Notes