SECTION 2

Newton's Laws of Motion

Imagine that you are playing baseball. The pitch comes in, and—crack—you hit the ball hard! But instead of flying off the bat, the ball just drops to the ground. Is that normal?

What You Will Learn

- Describe Newton's first law of motion, and explain how it relates to objects at rest and objects in motion.
- State Newton's second law of motion, and explain the relationship between force, mass, and acceleration.
- State Newton's third law of motion, and give examples of force pairs.

Vocabulary

inertia

READING STRATEGY

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

You would probably say no. You know that force and motion are related. When you exert a force on a baseball by hitting it with a bat, the baseball should move. In 1686, Sir Isaac Newton explained this relationship between force and the motion of an object with his three laws of motion.

Newton's First Law of Motion

An object at rest remains at rest, and an object in motion remains in motion at constant speed and in a straight line unless acted on by an unbalanced force.

Newton's first law of motion describes the motion of an object that has a net force of 0 N acting on it. This law may seem complicated when you first read it. But, it is easy to understand when you consider its two parts separately.

Part 1: Objects at Rest

An object that is not moving is said to be at rest. A chair on the floor and a golf ball balanced on a tee are examples of objects at rest. Newton's first law says that objects at rest will stay at rest unless they are acted on by an unbalanced force. For example, objects will not start moving until a push or a pull is exerted on them. So, a chair won't slide across the room unless you push the chair. And, a golf ball won't move off the tee unless the ball is struck by a golf club, as shown in **Figure 1.**

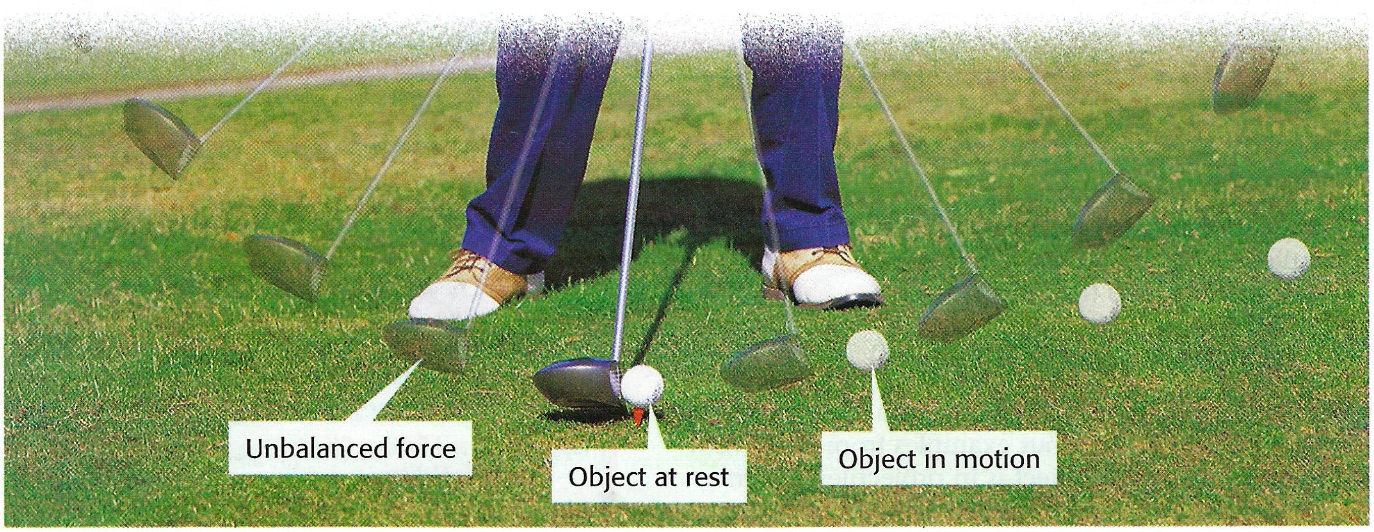


Figure 1 *A golf ball will remain at rest on a tee until it is acted on by the unbalanced force of a moving club.*

Part 2: Objects in Motion

The second part of Newton's first law is about objects moving with a certain velocity. Such objects will continue to move forever with the same velocity unless an unbalanced force acts on them.

Think about driving a bumper car at an amusement park. Your ride is pleasant as long as you are driving in an open space. But the name of the game is bumper cars! Sooner or later you are likely to run into another car, as shown in **Figure 2.** Your bumper car stops when it hits another car. But, you continue to move forward until the force from your seat belt stops you.

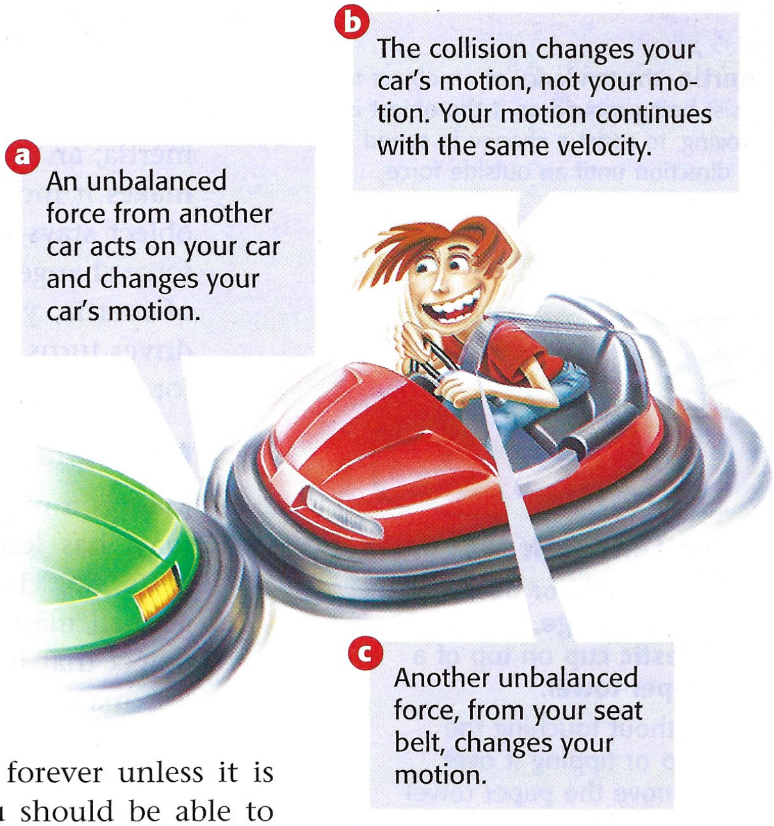


Figure 2 *Bumper cars let you have fun with Newton's first law.*

Friction and Newton's First Law

An object in motion will stay in motion forever unless it is acted on by an unbalanced force. So, you should be able to give your desk a push and send it sliding across the floor. If you push your desk, the desk quickly stops. Why?

There must be an unbalanced force that acts on the desk to stop its motion. That unbalanced force is friction. The friction between the desk and the floor works against the motion of the desk. Because of friction, observing the effects of Newton's first law is often difficult. For example, friction will cause a rolling ball to slow down and stop. Friction will also make a car slow down if the driver lets up on the gas pedal. Because of friction, the motion of objects changes.

Reading Check **When you ride a bus, why do you fall forward when the bus stops moving?** (*See the Appendix for answers to Reading Checks.*)

Quick Lab

First Law Skateboard

1. Place an **empty soda can** on top of a **skateboard.**
2. Ask a friend to catch the skateboard after you push it. Now, give the skateboard a quick, firm push. What happened to the soda can?
3. Put the can on the skateboard again. Push the skateboard gently so that the skateboard moves quickly but so that the can does not fall.
4. Ask your friend to stop the skateboard after he or she allows it to travel a short distance. What happened to the can?
5. Explain how Newton's first law applies to what happened.

Inertia and Newton's First Law

Newton's first law of motion is sometimes called the *law of inertia*. **Inertia** (in UHR shuh) is the tendency of all objects to resist any change in motion. Because of inertia, an object at rest will remain at rest until a force makes it move. Likewise, inertia is the reason a moving object stays in motion with the same velocity unless a force changes its speed or direction. For example, because of inertia, you slide toward the side of a car when the driver turns a corner. Inertia is also why it is impossible for a plane, car, or bicycle to stop immediately.

inertia the tendency of an object to resist being moved or, if the object is moving, to resist a change in speed or direction until an outside force acts on the object

Mass and Inertia

Mass is a measure of inertia. An object that has a small mass has less inertia than an object that has a large mass. So, changing the motion of an object that has a small mass is easier than changing the motion of an object that has a large mass. For example, a softball has less mass and therefore less inertia than a bowling ball. Because the softball has a small amount of inertia, it is easy to pitch a softball and to change its motion by hitting it with a bat. Imagine how difficult it would be to play softball with a bowling ball! **Figure 3** further shows the relationship between mass and inertia.

Quick Lab

First-Law Magic

1. On a **table or desk**, place a **large, empty plastic cup** on top of a **paper towel.**
2. Without touching the cup or tipping it over, remove the paper towel from under the cup. How did you accomplish this? Repeat this step.
3. Fill the cup half full with **water,** and place the cup on the paper towel.
4. Once again, remove the paper towel from under the cup. Was it easier or harder to do this time?
5. Explain your observations in terms of mass, inertia, and Newton's first law of motion.

Figure 3 *Inertia makes it harder to accelerate a car than to accelerate a bicycle. Inertia also makes it easier to stop a moving bicycle than a car moving at the same speed.*

Newton's Second Law of Motion

The acceleration of an object depends on the mass of the object and the amount of force applied.

Newton's second law describes the motion of an object when an unbalanced force acts on the object. As with Newton's first law, you should consider the second law in two parts.

Part 1: Acceleration Depends on Mass

Suppose you are pushing an empty cart. You have to exert only a small force on the cart to accelerate it. But, the same amount of force will not accelerate the full cart as much as the empty cart. Look at the first two photos in **Figure 4.** They show that the acceleration of an object decreases as its mass increases and that its acceleration increases as its mass decreases.

Part 2: Acceleration Depends on Force

Suppose you give the cart a hard push, as shown in the third photo in **Figure 4.** The cart will start moving faster than if you gave it only a soft push. So, an object's acceleration increases as the force on the object increases. On the other hand, an object's acceleration decreases as the force on the object decreases.

The acceleration of an object is always in the same direction as the force applied. The cart in **Figure 4** moved forward because the push was in the forward direction.

Reading Check **What is the relationship between the force on an object and the object's acceleration?**

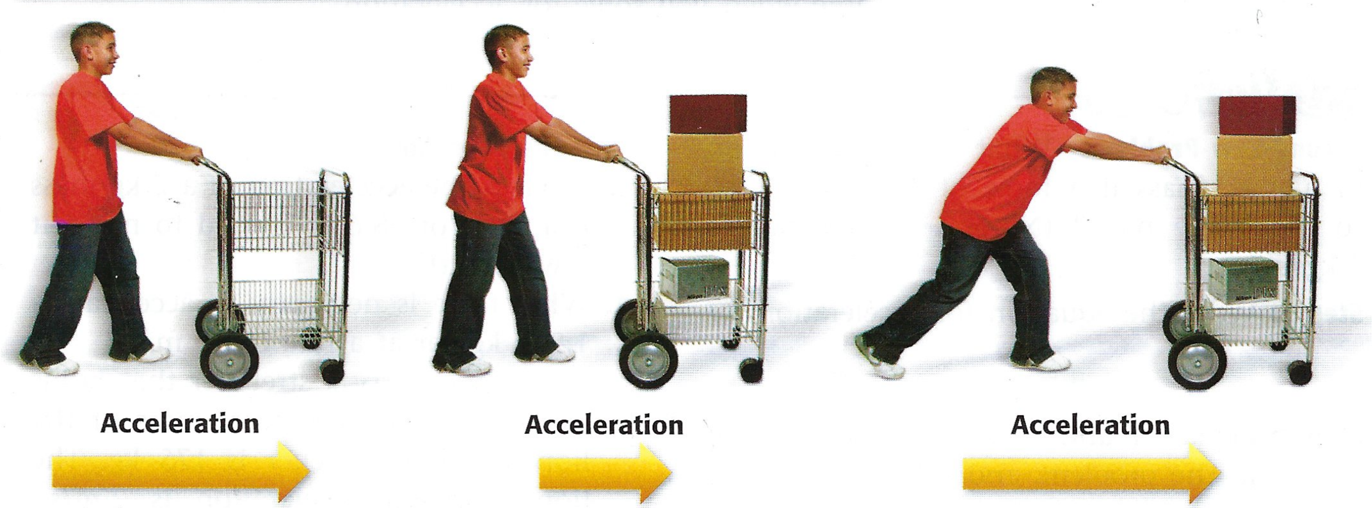
CONNECTION TO Environmental Science

Car Sizes and Pollution

On average, newer cars pollute the air less than older cars do. One reason for this is that newer cars have less mass than older cars have. An object that has less mass requires less force to achieve the same acceleration as an object that has more mass. So, a small car can have a small engine and still have good acceleration. Because small engines use less fuel than large engines use, small engines create less pollution. Research three models of cars from the same year, and make a chart to compare the mass of the cars with the amount of fuel they use.

ACTIVITY

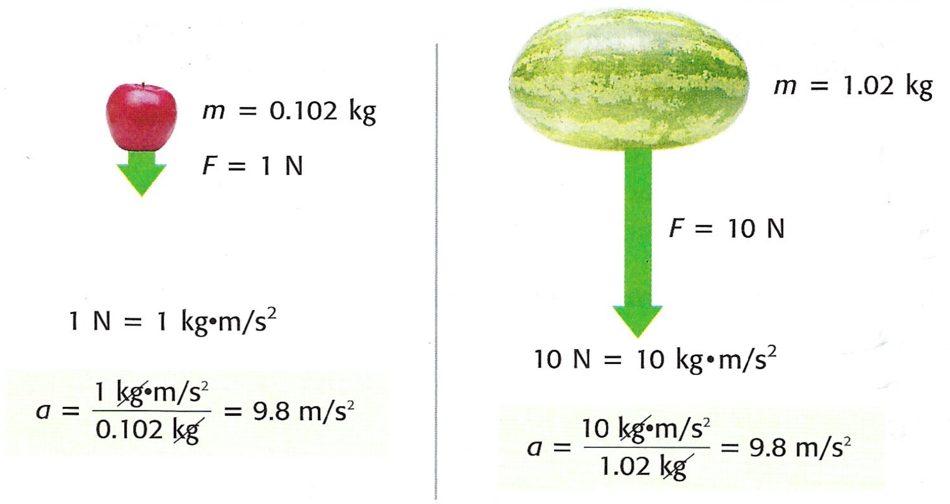
Figure 4 **Mass, Force, and Acceleration**



If the force applied to the carts is the same, the acceleration of the empty cart is greater than the acceleration of the loaded cart.

Acceleration will increase when a larger force is exerted.

Figure 5 Newton's Second Law and Acceleration Due to Gravity



The apple has less mass than the watermelon does. So, less force is needed to give the apple the same acceleration that the watermelon has.

Expressing Newton's Second Law Mathematically

The relationship of acceleration (a) to mass (m) and force (F) can be expressed mathematically with the following equation:

$$a = \frac{F}{m}, \text{ or } F = m \times a$$

Notice that the equation can be rearranged to find the force applied. Both forms of the equation can be used to solve problems.

Newton's second law explains why objects fall to Earth with the same acceleration. In **Figure 5,** you can see how the large force of gravity on the watermelon is offset by its large mass. Thus, you find that the accelerations of the watermelon and the apple are the same when you solve for acceleration.

MATH FOCUS

Second-Law Problems What is the acceleration of a 3 kg mass if a force of 14.4 N is used to move the mass? (Note: 1 N is equal to 1 kg•m/s^2)

Step 1: Write the equation for acceleration.

$$a = \frac{F}{m}$$

Step 2: Replace F and m with the values given in the problem, and solve.

$$a = \frac{14.4 \text{ kg•m/s}^2}{3 \text{ kg}} = 4.8 \text{ m/s}^2$$

Now It's Your Turn

1. What is the acceleration of a 7 kg mass if a force of 68.6 N is used to move it toward Earth?
2. What force is necessary to accelerate a 1,250 kg car at a rate of 40 m/s^2?
3. Zookeepers carry a stretcher that holds a sleeping lion. The total mass of the lion and the stretcher is 175 kg. The lion's forward acceleration is 2 m/s^2. What is the force necessary to produce this acceleration?

Newton's Third Law of Motion

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

Newton's third law can be simply stated as follows: All forces act in pairs. If a force is exerted, another force occurs that is equal in size and opposite in direction. The law itself addresses only forces. But the way that force pairs interact affects the motion of objects.

How do forces act in pairs? Study **Figure 6** to learn how one force pair helps propel a swimmer through water. Action and reaction force pairs 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. The force is equal to your weight.

Reading Check How are the forces in each force pair related?

SCHOOL to HOME

Newton Ball

Play catch with an adult. As you play, discuss how Newton's laws of motion are involved in the game. After you finish your game, make a list in your **science journal** of what you discussed.

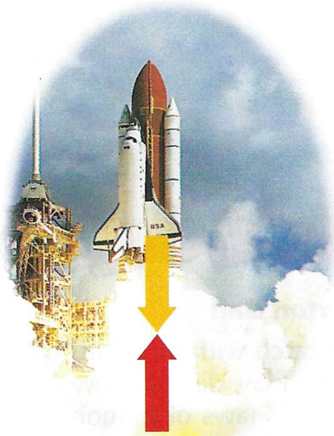
ACTIVITY

Force Pairs Do Not Act on the Same Object

A force is always exerted by one object on another object. This rule is true for all forces, including action and reaction forces. However, action and reaction forces in a pair do not act on the same object. If they did, the net force would always be 0 N and nothing would ever move! To understand how action and reaction forces act on objects, look at **Figure 6** again. The action force was exerted on the water by the swimmer's hands. But the reaction force was exerted on the swimmer's hands by the water. The forces did not act on the same object.

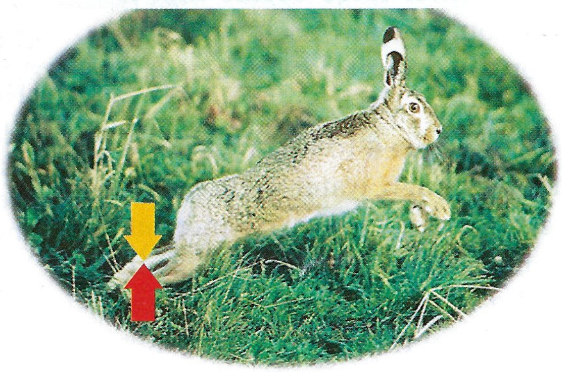
Figure 6 *The action force and reaction force are a pair. The two forces are equal in size but opposite in direction.*

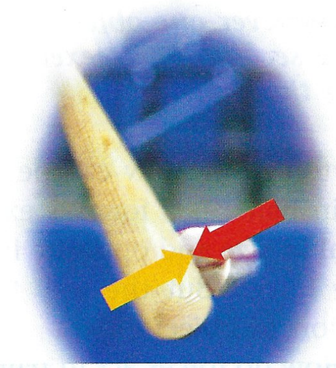
Figure 7 Examples of Action and Reaction Force Pairs



The space shuttle's thrusters push the exhaust gases downward as the gases push the shuttle upward with an equal force.

The rabbit's legs exert a force on Earth. Earth exerts an equal force on the rabbit's legs and causes the rabbit to accelerate upward.





The bat exerts a force on the ball and sends the ball flying. The ball exerts an equal force on the bat, but the bat does not move backward because the batter is exerting another force on the bat.

All Forces Act in Pairs—Action and Reaction

Newton's third law says that all forces act in pairs. When a force is exerted, there is always a reaction force. A force never acts by itself. **Figure 7** shows some examples of action and reaction force pairs. In each example, the action force is shown in yellow and the reaction force is shown in red.

The Effect of a Reaction Can Be Difficult to See

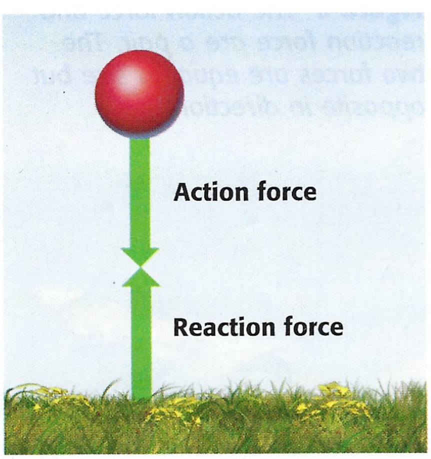


Figure 8 *The force of gravity between Earth and a falling object is a force pair.*

Another example of a force pair is shown in **Figure 8.** Gravity is a force of attraction between objects that is due to their masses. If you drop a ball, gravity pulls the ball toward Earth. This force is the action force exerted by Earth on the ball. But gravity also pulls Earth toward the ball. The force is the reaction force exerted by the ball on Earth.

It's easy to see the effect of the action force—the ball falls to Earth. Why don't you notice the effect of the reaction force—Earth being pulled upward? To find the answer to this question, think about Newton's second law. It states that the acceleration of an object depends on the force applied to it and on the mass of the object. The force on Earth is equal to the force on the ball. But the mass of Earth is much larger than the mass of the ball. Thus, the acceleration of Earth is much smaller than the acceleration of the ball. The acceleration of the Earth is so small that you can't see or feel the acceleration. So, it is difficult to observe the effect of Newton's third law on falling objects.

Reading Check Why do objects fall toward Earth?

SECTION Review

Summary

- Newton's first law of motion states that the motion of an object will not change if no unbalanced forces act on it.
- Objects at rest will not move unless acted upon by an unbalanced force.
- Objects in motion will continue to move at a constant speed and in a straight line unless acted upon by an unbalanced force.
- Inertia is the tendency of matter to resist a change in motion. Mass is a measure of inertia.
- Newton's second law of motion states that the acceleration of an object depends on its mass and on the force exerted on it.
- Newton's second law is represented by the following equation: $F = m \times a$.
- Newton's third law of motion states that whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first object.

Using Key Terms

1. In your own words, write a definition for the term *inertia*.

Understanding Key Ideas

2. Which of the following will increase the acceleration of an object that is pushed by a force?
   a. decreasing the mass of the object
   b. increasing the mass of the object
   c. increasing the force pushing the object
   d. Both (a) and (c)
3. Give three examples of force pairs that occur when you do your homework.
4. What does Newton's first law of motion say about objects at rest and objects in motion?
5. Use Newton's second law to describe the relationship between force, mass, and acceleration.

Math Skills

6. What force is necessary to accelerate a 70 kg object at a rate of 4.2 m/s^2?

Critical Thinking

7. **Applying Concepts** When a truck pulls a trailer, the trailer and truck accelerate forward even though the action and reaction forces are the same size but are in opposite directions. Why don't these forces balance each other?
8. **Making Inferences** Use Newton's first law of motion to explain why airbags in cars are important during head-on collisions.

Interpreting Graphics

9. Imagine you accidentally bumped your hand against a table, as shown in the photo below. Your hand hurts after it happens. Use Newton's third law of motion to explain what caused your hand to hurt.