

Section 3

Newton's Laws of Motion

Key Concept Newton's laws of motion describe the relationship between forces and the motion of an object.

What You Will Learn

- Newton's first law of motion states that the motion of an object will change only if unbalanced forces act on the object.
- Newton's second law of motion states that the acceleration of an object depends on the object's mass and on the force exerted on the object.
- 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.

Why It Matters

Newton's laws of motion will help you understand why you and the objects around you move in certain ways.

Imagine that you are playing softball. 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?

You would probably say no. You know that force and motion are related. When you exert a force on a softball by hitting it with a bat, the softball 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

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 is easier to understand if 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 on a tee are examples of objects at rest. Newton's first law states that objects at rest will stay at rest unless they are acted on by an unbalanced force. So, objects will not start moving until a push or a pull is exerted on them. 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**.

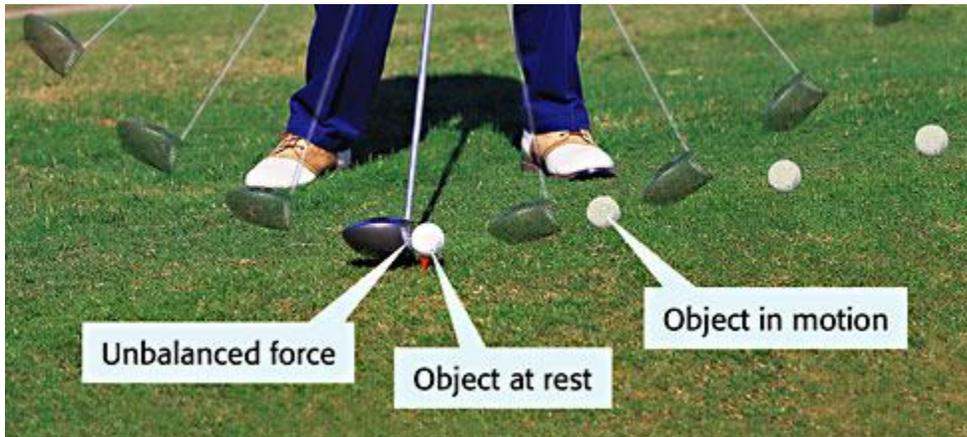


Figure 1 A golf ball will remain at rest on a tee until it is acted on by the unbalanced force of a moving club.

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.

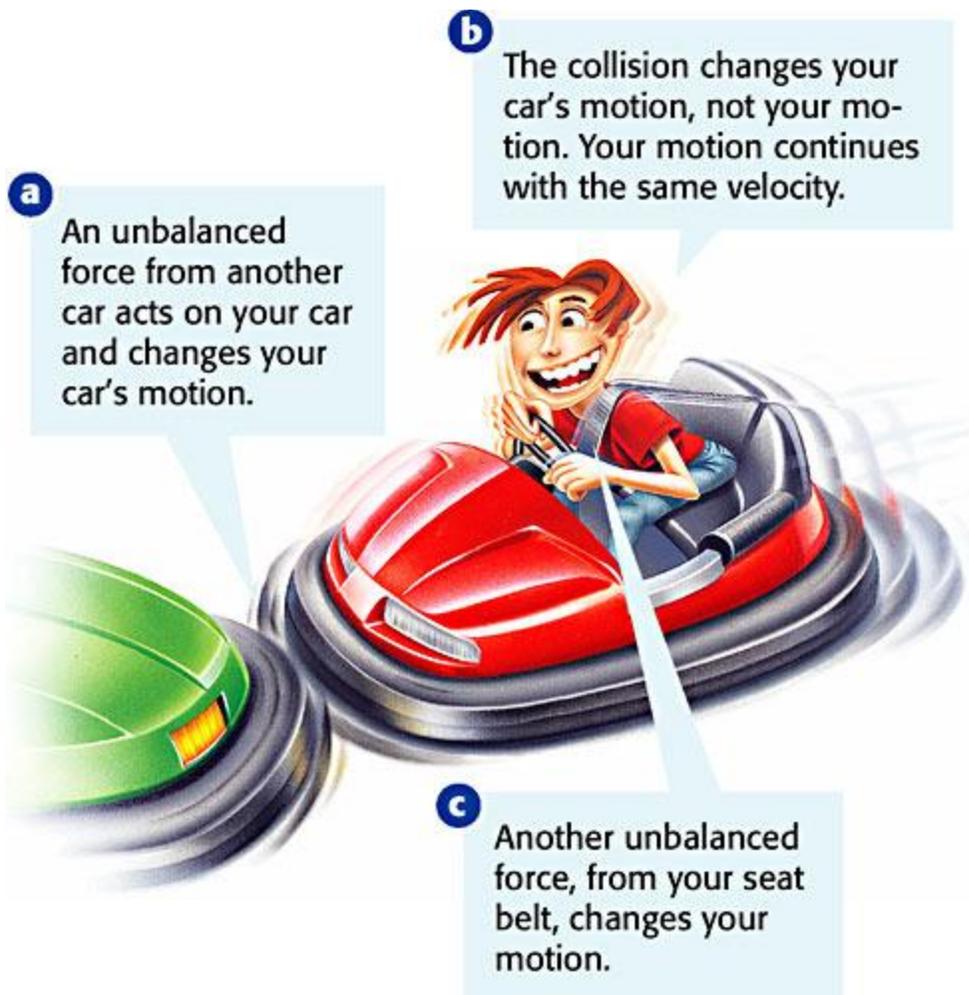


Figure 2 Bumper cars let you have fun with Newton's first law.

Friction and Newton's First Law

The motion of an object will not change unless the object 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?

The desk stops because an unbalanced force changes its motion. That unbalanced force is friction. Friction changes the motion of objects. The friction between the desk and the floor slows 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.

Standards Check What must be true about the forces acting on an object if the motion of the object does not change?

□

Inertia and Newton's First Law

Newton's first law of motion is sometimes called the *law of inertia*. **Inertia** 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 that 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 the reason why a plane, car, or bicycle cannot stop immediately.

Standards Check Why must a force be exerted on an object to change its velocity?

□

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.



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 and Mass

Suppose that you are using a cart to help your teacher move some heavy boxes. When the cart is empty, you have to exert only a small force on the cart to accelerate it. But

the same amount of force will not accelerate the fully loaded cart as much as the empty cart. **Figure 4** shows part of Newton's second law. The length of the arrows shows the amount of acceleration of the cart. You can see that for the same force, the acceleration of an object decreases as its mass increases. On the other hand, the acceleration of an object increases as its mass decreases.



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

Standards Check Describe how the mass of an object is related to the object's acceleration.

□



Part 2: Acceleration and Force

How can you give the loaded cart the same acceleration as the empty cart? You have to exert a greater force on the loaded cart than you exerted on the empty cart. **Figure 5** shows that the loaded cart has a greater acceleration when it is pushed harder. This example shows the other part of Newton's second law. 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.



Figure 5 The acceleration of a loaded cart will increase when a larger force is exerted on it.

Standards Check Compare the forces needed to give the same rate of change in motion to two objects that have different masses.

□



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. For example, when your hand applies a force to a ball, the ball applies a force that is equal in size and opposite in direction to your hand. The law itself addresses only forces. But the way that force pairs interact changes the movement of objects.

How do forces act in pairs? **Figure 6** shows how one force pair helps move a swimmer through water. Action and reaction force pairs are present even when there is no movement. For example, you apply a force to a chair when you sit on it. Your weight pushing down on the chair is the action force. The reaction force is the force applied by the chair that pushes up on your body. The force applied by the chair is equal in size to your weight but opposite in direction.

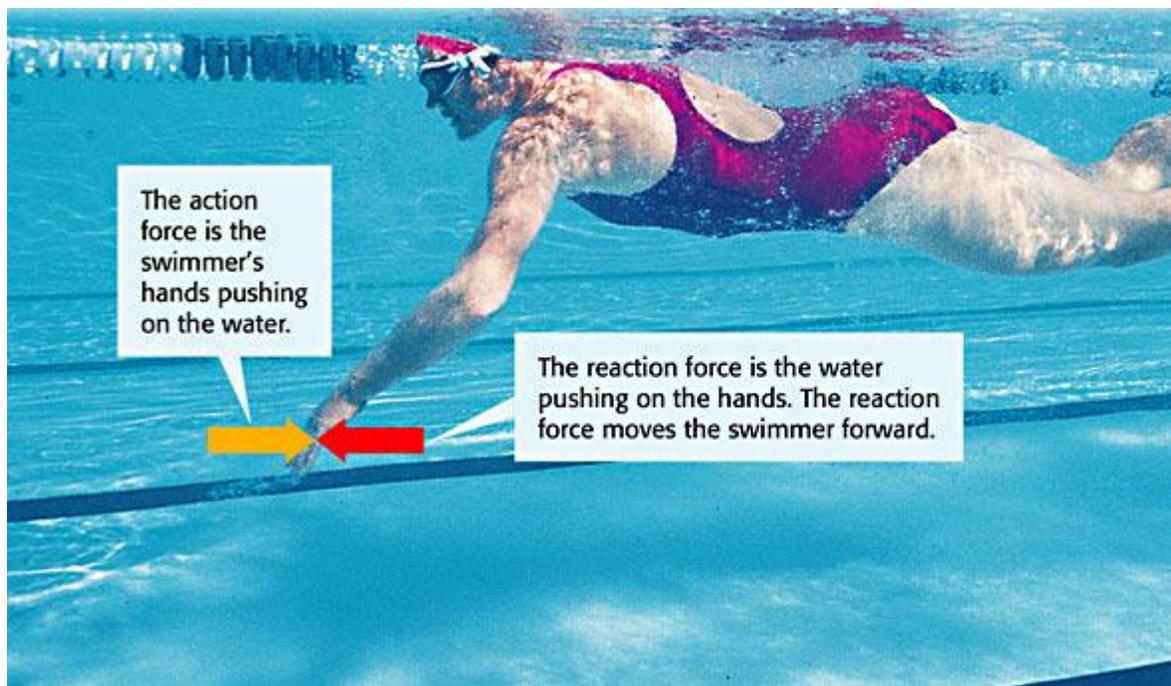


Figure 6 The action force and reaction force are a pair. The two forces are equal in size but opposite in direction.

Force Pairs Applied to Objects

A force is always applied 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. So, nothing would ever move! Look at **Figure 6** again. The action force is applied to the water by the swimmer's hands. But the reaction force is applied to the swimmer's hands by the water. The forces do not act on the same object.

Action and Reaction Force Pairs

Newton's third law states 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.

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



The ball exerts a force on the bat as the bat swings. The bat exerts an equal force on the ball and causes the ball to accelerate upward.

Noticing the Effects of a Reaction Force

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.

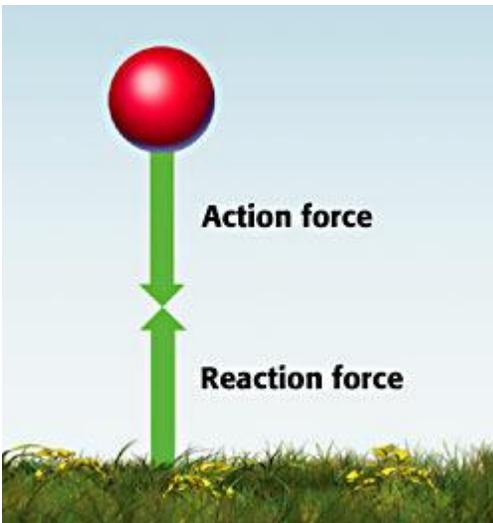


Figure 8 The force of gravity between Earth and a falling object is a force pair.

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 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.



Section Summary

- Newton's first law of motion states that the motion of an object will not change if the forces on it are balanced.
- 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 the mass of the object and the amount of force applied.
- The greater the mass of an object is, the greater the force needed to achieve the same acceleration.
- 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.



Chapter Summary

The Big Idea

Unbalanced forces cause changes in motion that can be predicted and described.

Section 1

Gravity: A Force of Attraction

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

- 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.

Gravity can change the movement of an object.



Section 2

Gravity and Motion

Key Concept Gravity can be an unbalanced force that causes predictable changes in motion.

- The acceleration due to gravity is the same for all objects near Earth's surface.
- Air resistance is a force that opposes the motion of objects through air.
- Projectile motion has two components—horizontal motion and vertical motion.



The two components of projectile motion combine to form a curved path.

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