

CHAPTER 6 Forces and Motion

SECTION

2

Newton's Laws of Motion

BEFORE YOU READ

After you read this section, you should, be able to answer these questions:

- What is net force?
- What happens to objects that have no net force acting on them?
- How are mass, force, and acceleration related?
- How are force pairs related by Newton's third law of motion?

National Science Education Standards

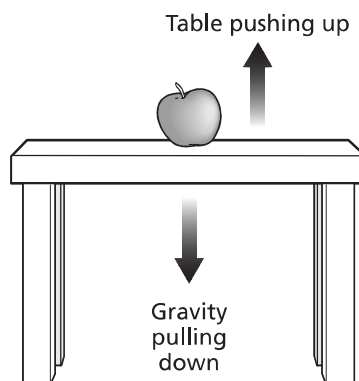
PS 2b, 2c

What Is a Net Force?

A *force* is a push or a pull. It is something that causes an object to change speed or direction. There are forces acting on all objects every second of the day. They are acting in all directions.

At first, this might not make sense. After all, there are many objects that are not moving. Are forces acting on an apple sitting on a desk? The answer is yes. Gravity is pulling the apple down. The desk is pushing the apple up.

In the figure below, the arrows represent the size and direction of the forces on the apple.

Forces Acting on an Apple

So, why doesn't the apple move? The apple is staying where it is because all the forces balance out. There are no unbalanced forces. That is, there is no net force on the apple. *Net force* is the total force acting on an object. If the net force on an object is zero, the object will not change speed or direction. ✓

STUDY TIP

Summarize in Pairs Read each of Newton's laws silently to yourself. After reading each law, talk about what you read with a partner. Together, try to figure out any ideas that you didn't understand.

TAKE A LOOK

1. Compare What is the size of the force pulling the apple down compared with the size of the force pushing it up?

READING CHECK

2. Explain What will not happen to an object if the net force acting on it is zero?

SECTION 2 Newton's Laws of Motion *continued*

READING CHECK

3. Identify What will happen to an object at rest if no unbalanced forces act on it?

4. Identify What will happen to an object moving at constant velocity?

TAKE A LOOK

5. Predict What would happen to the distances between the moving-ball images if the unbalanced force were greater?

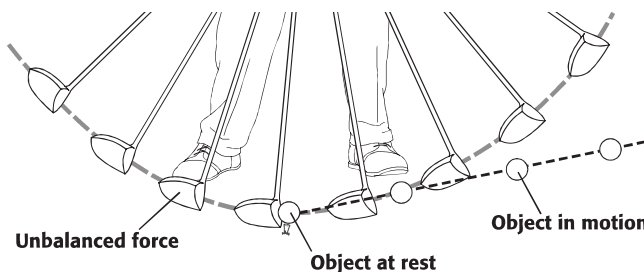
What Is Newton's First Law of Motion?

Newton's first law of motion describes objects that have no unbalanced forces, or no net force, acting on them. It has two parts:

1. An object at rest will remain at rest.
2. An object moving at a constant velocity will continue to move at a constant velocity. ✓

PART 1: OBJECTS AT REST

An object that is not moving is said to be at rest. A golf ball on a tee is an example of an object at rest. An object at rest will not move unless an unbalanced force is applied to it. The golf ball will keep sitting on the tee until it is struck by a golf club.

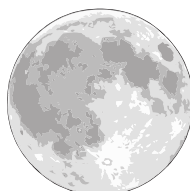


A golf ball will remain at rest on a tee until it is acted on by the unbalanced force of a moving club.

PART 2: OBJECTS IN MOTION

The second part of Newton's first law can be hard to picture. On Earth, all objects that are moving eventually slow down and stop, even if we are no longer touching them. This is because there is always a net force acting on these objects. We will talk about this force later.

However, in outer space, Newton's first law can be seen easily. During the Apollo missions to the moon, the spacecraft turned off its engine when it was in space. It then drifted thousands of miles to the moon. It could keep moving forward without turning on its engines because there was no unbalanced force to slow it down.



TAKE A LOOK

6. Apply Concepts What must the spacecraft do to land softly on the moon?

SECTION 2 Newton's Laws of Motion *continued*

How Does Friction Affect Newton's First Law?

On Earth, friction makes observing Newton's first law difficult. If there were no friction, a ball would roll forever until something got in its way. Instead, it stops quickly because of friction.

Friction is a force that is produced whenever two surfaces touch each other. Friction always works against motion. ✓

Friction makes a rolling ball slow down and stop. It also makes a car slow down when its driver lets up on the gas pedal.

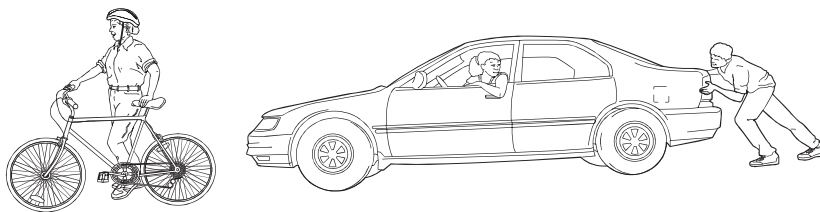
What Is Inertia?

Newton's first law is often called the *law of inertia*. **Inertia** is the ability of an object to resist any change in motion. In order to change an object's motion, a force has to overcome the object's inertia. So, in order to move an object that is not moving, you have to apply a force to it. Likewise, in order to change the motion of an object that is moving, you have to apply a force to it. The greater the object's inertia, the harder it is to change its motion.

How Are Mass and Inertia Related?

An object that has a small mass has less inertia than an object with a large mass. Imagine a golf ball and a bowling ball. Which one is easier to move?

The golf ball has much less mass than the bowling ball. The golf ball also has much less inertia. This means that a golf ball will be much easier to move than a bowling ball. ✓



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.

✓ **READING CHECK**

7. Describe How does friction affect the forward motion of an object?

STANDARDS CHECK

PS 2b An object that is not subjected to a force will continue to move at constant speed and in a straight line.

Word Help: constant
a quantity whose value does not change

8. Explain When a moving car stops suddenly, why does a bag of groceries on the passenger seat fly forward into the dashboard?

✓ **READING CHECK**

9. Explain Why is a golf ball easier to throw than a bowling ball?

SECTION 2 Newton's Laws of Motion *continued***What Is Newton's Second Law of Motion?**

Newton's second law of motion describes how an object moves when an unbalanced force acts on it. The second law has two parts:

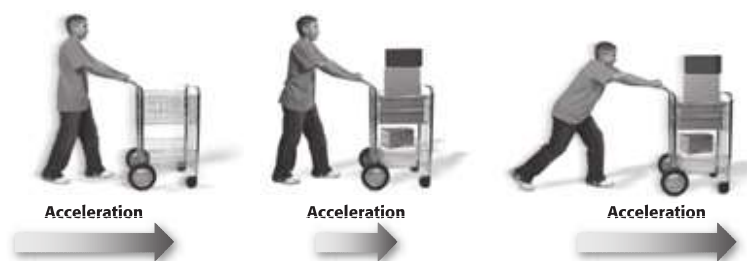
1. The acceleration of an object depends on the mass of the object. If two objects are pushed or pulled by the same force, the object with the smaller mass will accelerate more. ✓
2. The acceleration of an object depends on the force applied to the object. If two objects have the same mass, the one you push harder will accelerate more.

READING CHECK

10. Apply Concepts Which object will accelerate more if the same force is applied to both: a pickup truck or a tractor-trailer truck?

TAKE A LOOK

11. Compare On the figure, draw arrows showing the size and direction of the force that the person is applying to the cart in each picture.



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 increases when a larger force is exerted.

How Is Newton's Second Law Written as an Equation?

Newton's second law can be written as an equation. The equation shows how acceleration, mass, and net force are related to each other:

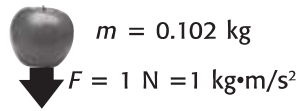
$$a = \frac{F}{m}, \text{ or } F = m \times a$$

In the equation, a is acceleration (in meters per second squared), m is mass (in kilograms), and F is net force (in newtons, N). One newton is equal to one kilogram multiplied by one meter per second squared. ✓

Newton's second law explains why all objects fall to Earth with the same acceleration. In the figure on the top of the next page, you can see how the larger force of gravity on the watermelon is balanced by its large mass.

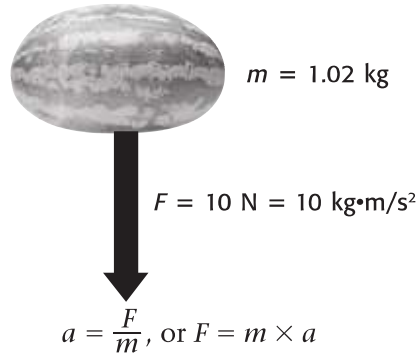
READING CHECK

12. Identify What are the units of force?

SECTION 2 Newton's Laws of Motion *continued*

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

$$a = \frac{1 \text{ kg}\cdot\text{m}/\text{s}^2}{0.102 \text{ kg}} = 9.8 \text{ m}/\text{s}^2$$



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

$$a = \frac{\boxed{} \text{ kg}\cdot\text{m}/\text{s}^2}{\boxed{} \text{ kg}} = \boxed{} \text{ m}/\text{s}^2$$

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.

Math Focus

13. Calculate In the figure, fill in the boxes with the correct numbers to calculate the acceleration of the watermelon.

How Can You Solve Problems Using Newton's Second Law?

You can use the equation $F = ma$ to calculate how much force you need to make a certain object accelerate a certain amount. Or you can use the equation $a = \frac{F}{m}$ to calculate how much an object will accelerate if a certain net force acts on it.

For example, what is the acceleration of a 3 kg mass if a force of 14.4 N is used to move the mass?

Step 1: Write the equation that you will use.

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

Step 2: Replace the letters in the equation with the values from the problem.

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

Math Focus

14. Calculate What force is needed to accelerate a 1,250 kg car at a rate of 40 m/s²? Show your work in the space below.

What Is Newton's Third Law of Motion?

All forces act in pairs. Whenever one object exerts a force on a second object, the second object exerts a force on the first object. The forces are always equal in size and opposite in direction.

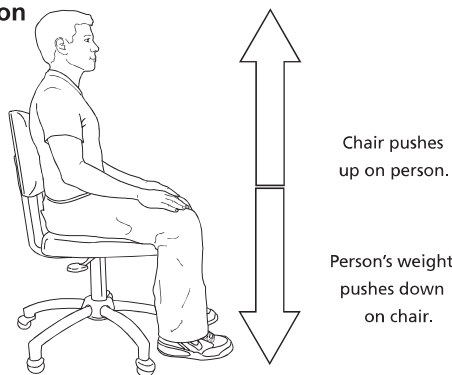
For example, when you sit on a chair, the force of your weight pushes down on the chair. At the same time, the chair pushes up on you with a force equal to your weight.

SECTION 2 Newton's Laws of Motion *continued*

ACTION AND REACTION FORCES

The figure below shows two forces acting on a person sitting in a chair. The *action force* is the person's weight pushing down on the chair. The *reaction force* is the chair pushing back up on the person. These two forces together are known as a *force pair*.

Forces on a Person in a Chair



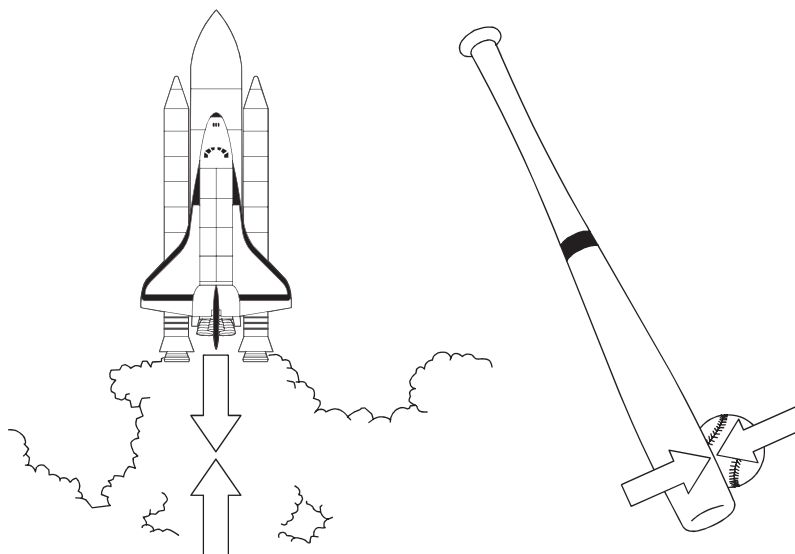
TAKE A LOOK

15. Identify On the figure, label the action force and the reaction force.

Action and reaction forces are also present when there is motion. The figures below show some more examples of action and reaction forces.

TAKE A LOOK

16. Describe How big is the reaction force compared with the action force in each picture?



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

The bat exerts a force on the ball and sends the ball flying. The ball exerts an equal force on the bat.

Critical Thinking

17. Apply Concepts If the ball exerts a force on the bat, why doesn't the bat move backward?

The action force and reaction force always act on different objects. For example, when you sit in a chair, the action force (your weight) acts on the chair. However, the reaction force (the chair pushing up on you) acts on you.

SECTION 2 Newton's Laws of Motion *continued***HARD-TO-SEE REACTION FORCES**

In the figure below, a ball is falling toward the Earth's surface. The action force is the Earth's gravity pulling down on the ball. What is the reaction force?



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

Believe it or not, the reaction force is the ball pulling up on Earth. Have you ever felt this reaction force when you have dropped a ball? Of course not. However, both forces are present. So, why don't you see or feel Earth rise?

To answer this question, recall Newton's second law. Acceleration depends on the mass and the force on an object. The force acting on Earth is the same as the force acting on the ball. However, Earth has a very, very large mass. Because it has such a large mass, its acceleration is too small to see or feel. ✓

You can easily see the ball's acceleration because its mass is small compared with Earth's mass. Most of the objects that fall toward Earth's surface are much less massive than Earth. This means that you will probably never feel the effects of the reaction force when an object falls to Earth.

TAKE A LOOK

18. Identify On the figure, draw and label arrows showing the size and direction of the action force and the reaction force for the ball falling to the Earth.

 **READING CHECK**

19. Explain Why can't you feel the effect of the reaction force when an object falls to Earth?

Section 2 Review

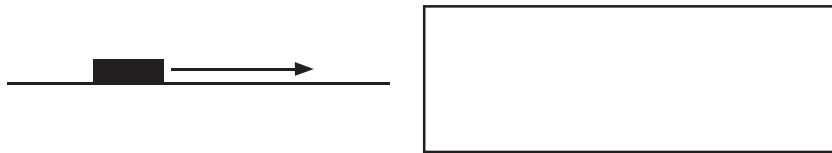
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SECTION VOCABULARY

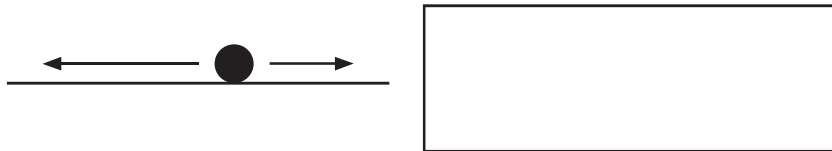
inertia the tendency of an object to resist being moved or, if the object is moving, to resist a change in speed or direction until an outside force acts on the object

1. **Explain** How are inertia and mass related?

2. **Use Graphics** The hockey puck shown below is moving on the ice at a constant velocity. The arrow represents the constant velocity. In the box, draw the arrow that represents the velocity of the puck if no unbalanced forces act on the puck.



3. **Use Graphics** The ball shown below has two forces acting on it. The arrows represent the size and direction of the forces. In the box, draw the arrow that represents the net force on the ball.



4. **Identify** Describe two things you can do to increase the acceleration of an object.

5. **Identify** Identify the action and reaction forces when you kick a soccer ball.

6. **Calculate** What force is needed to accelerate a 40 kg person at a rate of 4.5 m/s²? Show your work.

