chapter 2

Force and Newton's Laws

section 2 Newton's Second Law

What You'll Learn

- Newton's second law of motion
- why the direction of force is important

Before You Read

If someone told you that a car was accelerating, what would that mean to you?

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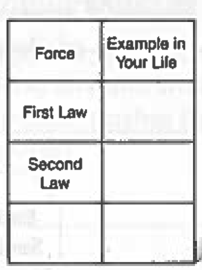
Mark the Text

Underline As you read, underline the main ideas under each heading. After you finish reading, review the main ideas that you have underlined.

FOLDABLES™

B Classify As you read this section, use your table Foldable to write about Newton's second law.



Read to Learn

Force and Acceleration

You know that it takes force to make a heavy shopping cart go faster. You must push harder and harder to make the cart speed up. When the heavy cart is moving, what do you have to do to slow it down? You have to use force to pull on the cart to make it slow down or stop. You also have to use force to turn a cart that is already moving. When the motion of an object changes, the object is accelerating. Speeding up, slowing down, and changing directions are all examples of acceleration.

<u>Newton's second law of motion</u> states that when a force acts on an object, the object accelerates in the direction of the force. You can calculate acceleration by using the equation below.

$$\textbf{acceleration} \text{ (in meters/second}^2\text{)} = \frac{\textbf{net force} \text{ (in newtons)}}{\textbf{mass} \text{ (in kilograms)}}$$

$$a = \frac{F_{net}}{m}$$

In this equation, a is acceleration, m is the mass of the object, and F_{net} is the net force. You can multiply both sides of the equation by the mass, and write the equation this way:

$$F_{net} = ma$$

What are the units of force?

Force is measured in newtons (N). The newton is an SI measurement. So, if you are calculating force, the mass must be measured in kilograms (kg). The acceleration must be measured in meters per second squared (m/s^2). One N is equal to 1 kg • m/s^2. ☑

Gravity

One force that you may already know about is gravity. Gravity is the force that pulls you downward when you jump into a pool or coast down a hill on a bike. Gravity also keeps Earth in orbit around the Sun and the Moon in orbit around Earth.

What is gravity?

Gravity is a force that exists between any two objects that have mass. It pulls two objects toward each other. Gravity depends on the mass of the objects and the distance between them. The force of gravity becomes weaker as objects move away from each other or as the mass of objects gets smaller. Large objects like Earth and the Sun have great gravitational forces. Objects with less mass like you or a pencil have weak gravitational forces.

There is a gravitational force between you and the Sun. There is also a gravitational force between you and Earth. Why doesn't the Sun's gravity pull you off of Earth? The gravitational force between you and the Sun is very weak because the Sun is so far away. Only Earth is close enough and massive enough to exert a noticeable gravitational force on you. Earth's gravitational force on you is 1,650 times greater than the Sun's gravitational force on you.

What is weight?

Earth's gravity causes all objects to fall toward Earth with an acceleration of 9.8 m/s^2. You can use the equation of Newton's second law to find the force of Earth's gravity on any object near Earth's surface:

$$F = ma = m \times (9.8\ m/s^2)$$

Weight is the amount of gravitational force on an object. Your weight on another planet would be different from your weight on Earth. That's because the gravitational force on other planets is different. Other planets have masses different from Earth's. So, your weight would be different on other planets.

Reading Check

1. **Explain** What units are used when force is measured?

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Applying Math

2. **Calculate** Jamie has a mass of 35 kg. What is her weight on Earth, in newtons? Use the formula for gravitational force. Show your work.

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How do weight and mass differ?

Weight and mass are different. Weight is the amount of gravitational force on an object. Your bathroom scale measures how much Earth's gravity pulls you down. Mass is the amount of matter in an object. Gravity doesn't affect the amount of matter in an object. Mass is always the same, even on different planets. A person with a mass of 60 kg has a mass of 60 kg on Earth or on Mars. But, the weight of the person on Earth and Mars would be different, as shown in the table. That's because the force of gravity on each planet is different. ☑

✔ Reading Check

3. **Use Definitions** If you were on Mars instead of on Earth, which would be different—your weight or your mass?

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Weight of 60-kg Person on Different Planets

Place	Weight in Newtons If Your Mass Were 60 kg	Percent of Your Weight on Earth
Mars	223	38
Earth	588	100
Jupiter	1,388	236
Pluto	4	0.7

Applying Math

4. **Explain** By what number do you multiply 588 to get your weight in newtons on Pluto?

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Using Newton's Second Law

Newton's second law tells how to calculate the acceleration of an object. You must know the object's mass and the forces acting on the object. Remember that velocity is how fast an object is moving and in what direction. Acceleration tells how velocity changes.

How is speeding up acceleration?

When an object speeds up, it accelerates. Think about a soccer ball sitting on the ground. If you kick the ball, it starts moving. You exert a force on the ball. The ball accelerates only while your foot is in contact with the ball. While something is speeding up, something is pushing or pulling the object in the direction it is moving. The direction of the push or pull is the direction of the force. It is also the direction of the acceleration.

How is slowing down acceleration?

Slowing down also is acceleration. If you wanted to slow down an object, you would have to push or pull it against the direction it is moving.

Suppose you push a book across a tabletop. When you start pushing, the book speeds up. Sliding friction also acts on the book. After you stop pushing, sliding friction makes the book slow down and stop. In the figure, the boy is slowing down because the force exerted by his feet is in the opposite direction of his motion.

How do you calculate acceleration?

Calculate acceleration using the equation from Newton's second law of motion. For example, suppose you pull a 10-kg sled with a net force of 5 N. You can find the acceleration as follows:

$$a = \frac{F_{net}}{m} = \frac{5\ \text{N}}{10\ \text{kg}} = 0.5\ \text{m/s}^2$$

The sled keeps accelerating as long as you keep pulling on it. The acceleration does not depend on how fast the sled is moving. It depends only on the net force and the mass of the sled.

Picture This

5. Label In the figure, label one arrow "Force due to friction" and the other arrow "Direction of motion."

Applying Math

6. Calculate Suppose you kick a 2-kg ball with a force of 14 N. What is the acceleration of the ball? Show your work.

Think it Over

7. **Draw** Imagine that you throw a basketball and it goes through a basketball hoop. In the space below, sketch the path that the ball would follow.

Picture This

8. **Evaluate** Look at the figure. Suppose the ball was traveling in the opposite direction around the circle. What would be the direction of the centripetal force? Why?

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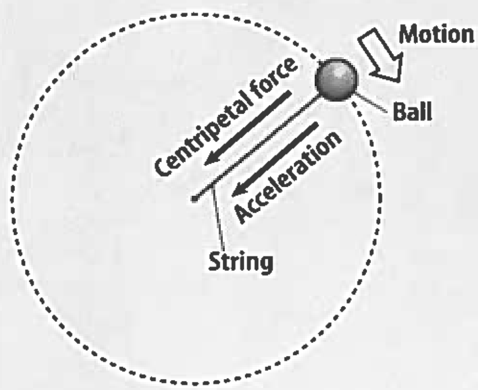
How do objects turn?

Forces and motion don't always happen in a straight line. If a net force acts at an angle to the direction an object is moving, the object will follow a curved path. Imagine shooting a basketball. When the ball leaves your hands, it doesn't continue to move in a straight line. Instead, it starts to curve downward due to gravity. The curved path of the ball is a combination of its original motion and the downward motion caused by gravity.

Circular Motion

You move in a circle when you ride on a merry-go-round. This motion is called circular motion. In circular motion, your direction of motion is constantly changing. This means you are constantly accelerating. There is a force acting on you the whole time. That's why you have to hold on tightly—to keep the force from causing you to fall off.

Imagine a ball on a string moving in a circle. The string pulls on the ball and keeps it moving in a circle. The force exerted by the string is called centripetal (cen TRIP eh tal) force. The centripetal force points to the center of the circle. Centripetal force is always perpendicular to the motion. The figure shows the direction of motion, centripetal force, and acceleration of a ball traveling in a circle on a string.



How do satellites stay in orbit?

Satellites are objects that orbit Earth. They go around Earth in nearly circular orbits. The centripetal force acting on a satellite is gravity. But why doesn't a satellite fall to Earth like a baseball? Actually, satellites do fall toward Earth.

When you throw a baseball, its path curves until it hits Earth. If you throw the baseball faster, it goes a little farther before it hits Earth. If you could throw the ball fast enough, its curved path would follow the curve of Earth's surface. The baseball would never hit the ground. It would keep traveling around Earth.

How fast must a satellite travel?

The speed at which a satellite must travel to stay in orbit near Earth's surface is 8 km/s, or about 29,000 km/h. To place satellites into orbit, rockets carry satellites to the proper height. Then the rockets give the satellites a push in a forward direction to get them moving fast enough to orbit around the Earth.

Air Resistance

Have you ever run against the wind? If so, you have felt the force of air resistance. When an object moves through air, there is friction between the object and the air. This friction, or air resistance, slows down the object. Air resistance is a force that gets larger as an object moves faster. Air resistance also depends on the shape of an object. Think about two pieces of paper. One piece is crumpled into a ball and the other piece is flat. The paper that is crumpled into a ball will fall faster than the flat piece of paper falls.

When an object falls it speeds up as gravity pulls it downward. At the same time, the force of air resistance pushing up on the object is increasing as the object moves faster. Finally, the upward force of air resistance becomes large enough to equal the downward force of gravity.

When the air resistance force equals the weight of an object, the net force on the object is zero. Newton's second law explains that the object's acceleration then is zero. Its speed no longer increases. When air resistance balances the force of gravity, the object falls at a constant speed. This constant speed is called the terminal velocity.

Center of Mass

Imagine throwing a stick. The stick spins while it flies through the air. Even though the stick spins, there is one point on the stick, the center of mass, that moves in a smooth path. The center of mass is the point in an object that moves as if all the object's mass was concentrated at that point. For a symmetrical object, such as a ball, the center of mass is the center of the object. ☑

Think it Over

9. **Infer** Imagine that you could throw a baseball at a speed of 29,000 km/h. What would happen to the ball if you threw it that fast?

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Reading Check

10. **Identify** Where is the center of mass of a ball?

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After You Read

Mini Glossary

center of mass: the point in an object that moves as if all the object's mass was concentrated at that point

Newton's second law of motion: when a force acts on an object, the object accelerates in the direction of the force

weight: the amount of gravitational force on an object

1. Review the terms and their definitions in the Mini Glossary. What are three ways an object can accelerate? Answer in complete sentences.

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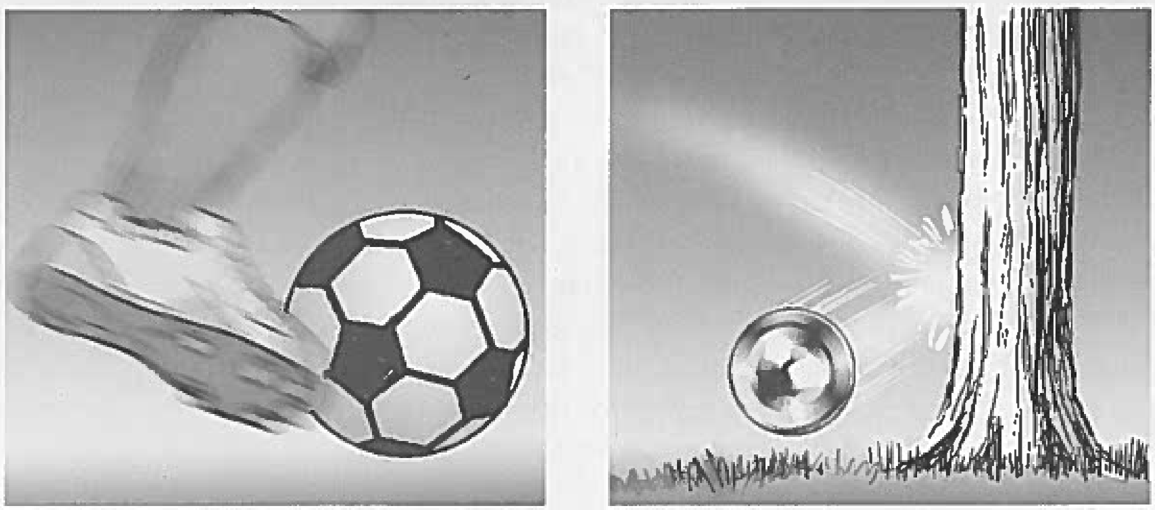
2. Look at the figures below. For each object, draw and label an arrow to show the direction of the motion. Then draw and label an arrow to show the direction of acceleration.



3. You were asked to underline the main ideas as you read this section, then review what you underlined. Why do you think you were asked to review what you underlined?

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End of Section

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chapter 2 Force and Newton's Laws

section 3 Newton's Third Law

Before You Read

Imagine stepping out of a canoe onto the shore of a lake. What happens to the canoe when you step out?

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What You'll Learn

- about forces that objects exert on each other

Read to Learn

Study Coach

Outline As you read the section, create an outline using each heading from the text. Under each heading, write the main points or ideas that you read.

Action and Reaction

Newton's first two laws of motion explain how the motion of one object changes. You have learned that if balanced forces act on an object, the object will remain at rest or stay in motion with constant velocity. If the forces are unbalanced, the object will accelerate in the direction of the net force.

Another of Newton's laws describes something else that happens when one object exerts a force on another object. When you push on a wall, did you know that the wall also pushes on you? <u>Newton's third law of motion</u> states that forces always act in equal but opposite pairs. When you push on a wall, you apply a force to the wall. But, the wall also applies a force equal in strength to you. When one object applies a force on another object, the second object exerts the same size force on the first object.

FOLDABLES

B Classify As you read this section, use your table Foldable to write about Newton's third law.

Force	Example in Your Life
First Law	
Second Law	
Third Law	

Why don't action and reaction forces cancel?

The forces that two objects put on each other are called an action-reaction force pair. The forces in a force pair are equal in strength, but opposite in direction. The forces in a force pair don't cancel each other out because they act on different objects. Forces can cancel each other only if they act on the same object.

Action and Reaction Forces Imagine a bowling ball hitting a bowling pin. The action force from the bowling ball acts on the pin. The pin flies in the direction of the force. The reaction force from the pin acts on the ball. It causes the ball to slow down.

How do action-reaction force pairs work on large and small objects?

When you walk forward, your shoe pushes Earth backward. Earth pushes your shoe forward. So why do you move when Earth does not? Earth has so much mass compared to you that it does not appear to move when you push on it. If you step on a skateboard, the force from your shoe makes the skateboard roll backward. This is because you have more mass than the skateboard. ☑

Reading Check

1. **Describe** Why doesn't Earth appear to move when you push down on it with your foot?

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How do rockets take off?

The launching of a space shuttle is a good example of Newton's third law. When the fuel in the shuttle's engines is ignited, a hot gas is produced. The gas molecules collide with the inside walls of the engines. The walls exert an action force that pushes the gas out of the bottom of the engine. The gas molecules put reaction forces on the walls of the engine. These reaction forces are what push the engine and the rocket forward. The force of the rocket engines is called thrust.

Weightlessness

You may have seen pictures of astronauts floating inside a space shuttle. The astronauts are said to be weightless—as if Earth's gravity were not pulling on them. But, Earth's gravity is what keeps a shuttle in orbit. Newton's laws of motion can explain why the astronauts float as if there weren't any forces acting on them.

How is weight measured?

Think about how you measure your weight. When you stand on a bathroom scale, your weight pushes down on the scale. This causes the scale pointer to show your weight. Newton's third law tells you that the scale pushes back up on you with a force equal to your weight. This force balances the downward pull of gravity on you, as shown in the figure on the left on the next page. ☑

Reading Check

2. **Explain** When you stand on a scale, which force balances the downward pull of gravity on you?

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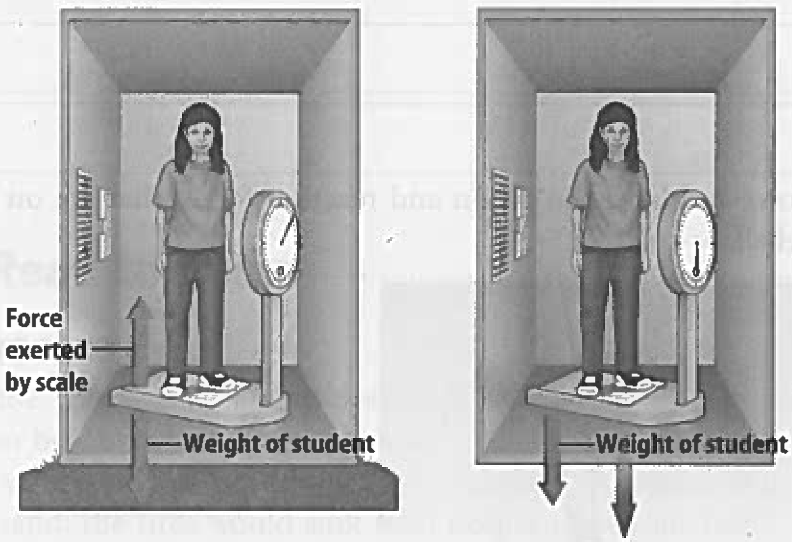
How does free fall cause weightlessness?

Imagine standing on a scale in an elevator that is falling, as shown in the figure on the right below. An object is in free fall when the only force acting on it is gravity. The elevator, you, and the scale are all in free fall. In free fall, the scale doesn't push back up on you. That's because the only force acting on you is gravity. According to Newton's third law, you are also not pushing down on the scale. So, the scale pointer stays at zero. You seem to be weightless. However, you are not really weightless. Earth's gravity is still pulling down on you. But, because nothing is pushing up on you, you have no sensation of weight.



Why are spacecraft in orbit weightless?

Remember that an object will orbit Earth when its path follows the curve of Earth's surface. Gravity keeps pulling the object down. But, the forward motion keeps it from falling straight downward. Objects that orbit the Earth, like satellites and the space shuttle, are in free fall.

Objects inside the shuttle are also in free fall. This makes the shuttle and everything inside it seem weightless, even though gravity is acting on them.

Suppose an astronaut in the shuttle is holding a ball. When she lets go of the ball, it will not move unless she pushes it. The ball does not move because the ball, the astronaut, and the shuttle are all falling at the same speed. If the astronaut pushes the ball forward, it accelerates to a speed that is faster than the shuttle and astronaut. The ball moves forward inside the shuttle.

Think it Over

3. **Explain** Why isn't an object in free fall really weightless?

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Picture This

4. **Describe** Look at the figure. What is the only force acting on the girl in the elevator on the right?

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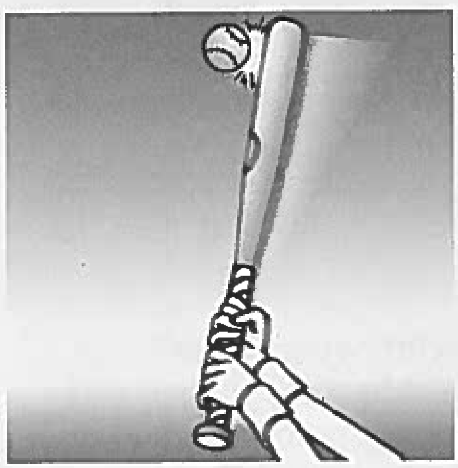
After You Read

Mini Glossary

Newton's third law of motion: forces always act in equal but opposite pairs

1. Review the term and its definition in the Mini Glossary. What are the action and reaction forces that make a rocket move forward? Answer in complete sentences.

2. On the figure below, draw arrows and label the action and reaction forces that are on the objects as the bat hits the baseball.



3. How could you use a skateboard to show Newton's third law of motion to a group of elementary school students?

End of Section

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