Newton’s Third Law

Reading Preview
Key Concepts
• What is Newton’s third law of motion?
• How can you determine the momentum of an object?
• What is the law of conservation of momentum?

Key Terms
• momentum
• law of conservation of momentum

Target Reading Skill
Before you read, preview Figure 18. Then write two questions that you have about the diagram in a graphic organizer like the one below. As you read, answer your questions.

Conservation of Momentum

Q. What happens when two moving objects collide?
A. ...

Discover Activity

How Pushy Is a Straw?
1. Stretch a rubber band around the middle of the cover of a medium-size hardcover book.
2. Place four marbles in a small square on a table. Place the book on the marbles so that the cover with the rubber band is on top.
3. Hold the book steady by placing one index finger on the binding. Then, as shown, push a straw against the rubber band with your other index finger.
4. Push the straw until the rubber band stretches about 10 cm. Then let go of both the book and the straw at the same time.

Think It Over
Developing Hypotheses: What did you observe about the motion of the book and the straw? Write a hypothesis to explain what happened in terms of the forces on the book and the straw.

Newton’s Third Law of Motion

Newton proposed that whenever one object exerts a force on a second object, the second object exerts a force back on the first object. The force exerted by the second object is equal in strength and opposite in direction to the first force. Think of one force as the “action” and the other force as the “reaction.” Newton’s third law of motion states that if one object exerts a force on another object, then the second object exerts a force of equal strength in the opposite direction on the first object.

Another way to state Newton’s third law is that for every action there is an equal but opposite reaction.

Expected Outcome
The book and the straw will move in opposite directions, and the straw will move faster than the book.

Think It Over
Sample answer: The book and rubber band exerted a force on the straw while the straw exerted a force on the book and rubber band.

Objectives
After this lesson, students will be able to

M.2.4.1 State Newton’s third law of motion.
M.2.4.2 Explain how an object’s momentum is determined.
M.2.4.3 State the law of conservation of momentum.

Target Reading Skill
Previewing Visuals Explain that looking at the visuals before they read helps students activate prior knowledge and predict what they are about to read.

Answers
Sample questions and answers:
What happens when two moving objects collide? (In the absence of friction, the total momentum is the same before and after the collision.) What is the momentum of an object? (Its mass multiplied by its velocity)

Teaching Resources
- Transparency M17

Preteach
Build Background Knowledge
Action and Reaction Forces
Ask a volunteer to sit facing forward on a skateboard and toss a basketball to you. Ask: What happened when the student tossed the ball? (The student moved backward.) What made the ball move? (A force exerted by the student) What made the student move? (A force exerted by the ball)
Newton’s Third Law of Motion

Teach Key Concepts

Action and Reaction Forces

Focus

Provide this example for students:
When you hit a nail with a hammer, the hammer exerts a force on the nail. The nail exerts a reaction force on the hammer, causing the motion of the hammer to stop.

Teach

Write on the board: For every action there is an equal and opposite reaction.

Apply

Ask: What are some examples of action and reaction forces?
(Sample answer: You push on the ground with your foot when you walk; the ground pushes back on your foot so you move forward.)

Help Students Read

Using Prior Knowledge

Before reading about action-reaction pairs, have students brainstorm lists of things they know about action-reaction pairs, using Figure 15 as prompt. After reading the section, have students review their lists, replace any misconceptions with correct information, and add any new information that they learned while reading.

Instruct

Newton’s Third Law of Motion

Teach Key Concepts

Action and Reaction Forces

Focus

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Independent Practice

Teaching Resources

• Guided Reading and Study Worksheet: Newton’s Third Law

• Student Edition on Audio CD

Action-Reaction Pairs

You’re probably familiar with many examples of Newton’s third law. Pairs of action and reaction forces are all around you. When you jump, you push on the ground with your feet. This is an action force. The ground pushes back on your feet with an equal and opposite force. This is the reaction force. You move upward when you jump because the ground is pushing you! In a similar way, a kayaker moves forward by exerting an action force on the water with a paddle. The water pushes back on the paddle with an equal reaction force that propels the kayak forward.

Now you can understand what happens when you teach your friend to roller-skate. Your friend exerts an action force when he pushes against you to start. You exert a reaction force in the opposite direction. As a result, both of you move in opposite directions.

Detecting Motion

Can you always detect motion when paired forces are in action? The answer is no. For example, when Earth’s gravity pulls on an object, you cannot detect Earth’s equal and opposite reaction. Suppose you drop your pencil. Gravity pulls the pencil downward. At the same time, the pencil pulls Earth upward with an equal and opposite reaction force. You don’t see Earth accelerate toward the pencil because Earth’s inertia is so great that its acceleration is too small to notice.
Do Action-Reaction Forces Cancel? Earlier you learned that if two equal forces act in opposite directions on an object, the forces are balanced. Because the two forces add up to zero, they cancel each other out and produce no change in motion. Why then don’t the action and reaction forces in Newton’s third law of motion cancel out as well? After all, they are equal and opposite.

The action and reaction forces do not cancel out because they are acting on different objects. Look at the volleyball player on the left in Figure 16. She exerts an upward action force on the ball. In return, the ball exerts an equal but opposite downward reaction force back on her wrists. The action and reaction forces act on different objects.

On the other hand, the volleyball players on the right are both exerting a force on the same object—the volleyball. When they hit the ball from opposite directions, each of their hands exerts a force on the ball equal in strength but opposite in direction. The forces on the volleyball are balanced and the ball does not move either to the left or to the right.

Why don’t action and reaction forces cancel each other?

**FIGURE 16** Action-Reaction Forces
In the photo on the left, the player’s wrists exert the action force. In the photo below, the ball exerts reaction forces on both players.

Interpreting Diagrams In the photo below, which forces cancel each other out? What force is not cancelled? What will happen to the ball?

**Forces**
Show the Video Field Trip to let students experience how gravity, velocity, acceleration, and friction all are involved in roller coasters. Discussion question: What are the main forces acting on passengers during a roller coaster ride? (Sample answer: Gravity and acceleration)

**Monitor Progress**
**Skills Check** Have students apply Newton’s third law of motion to a pogo stick. Ask: What are the action and reaction forces in a pogo stick jump? (Action force: person jumping on the pogo stick; reaction force: pogo stick pushing up on the person)

**Answers**
**Figure 15** Possible answers might include a hand and a ball, a swimmer and the water, and a horse and a cart.

**Figure 16** The forces in the picture on the right cancel. The forces in the picture on the left do not cancel, so the ball will move in an upward direction.

**Reading Strategies** Action-reaction forces do not cancel each other because they act on different objects.
Momentum

Teach Key Concepts

Relating Mass, Velocity, and Momentum

Focus
Ask: If a bicycle and a fire engine are both moving at a speed of 5 km/h, which would be easier to stop? (The bicycle) Why? (Sample answer: It has less mass, and therefore has less momentum.)

Teach
Tell students that the momentum of an object depends on its mass and velocity. Write Momentum = Mass \times Velocity on the board. Ask: How could an object with a large mass have the same momentum as an object with a small mass? (They could have the same momentum if they have different velocities.)

Apply
Ask: When a car slows down, its velocity decreases and its mass stays the same. How does slowing down affect the car's momentum? (The momentum decreases.)

Learning modality: logical/mathematical

Math Skill
Calculating momentum

Focus
Remind students that formulas and equations can be used to find an unknown value.

Teach
Check that students understand which values are known and which are unknown. Remind students to perform the same operations on the units that they do on the numbers.

Answers
1. Golf ball: 0.045 kg \times 16 \text{ m/s} = 0.72 \text{ kg\cdot m/s}
   Baseball: 0.14 kg \times 7 \text{ m/s} = 0.98 \text{ kg\cdot m/s}
   The baseball has greater momentum.
2. 0.27 kg\cdot m/s (0.018 kg \times 15 \text{ m/s} = 0.27 \text{ kg\cdot m/s})

Teaching Resources
• Transparency M18

Momentum
All moving objects have what Newton called a “quantity of motion.” What is this quantity of motion? Today we call it momentum. 

\text{Momentum (moh MÖN-tum)} is a characteristic of a moving object that is related to the mass and the velocity of the object. The momentum of a moving object can be determined by multiplying the object’s mass and velocity.

\text{Momentum} = \text{Mass} \times \text{Velocity}

Since mass is measured in kilograms and velocity is measured in meters per second, the unit for momentum is kilogram-meters per second (kg\cdot m/s). Like velocity, acceleration, and force, momentum is described by its direction as well as its quantity. The momentum of an object is in the same direction as its velocity.

Sample Problem

Calculating Momentum
Which has more momentum: a 3.0-kg sledgehammer swung at 1.5 m/s, or a 4.0-kg sledgehammer swung at 0.9 m/s?

1. Read and Understand
   What information are you given?
   Mass of smaller sledgehammer = 3.0 kg
   Velocity of smaller sledgehammer = 1.5 m/s
   Mass of larger sledgehammer = 4.0 kg
   Velocity of larger sledgehammer = 0.9 m/s

2. Plan and Solve
   What quantities are you trying to calculate?
   The momentum of each sledgehammer
   The formula contains the given quantities and the unknown quantity:
   \text{Momentum} = \text{Mass} \times \text{Velocity}
   Perform the calculations.
   Smaller sledgehammer: 3.0 \text{ kg} \times 1.5 \text{ m/s} = 4.5 \text{ kg\cdot m/s}
   Larger sledgehammer: 4.0 \text{ kg} \times 0.9 \text{ m/s} = 3.6 \text{ kg\cdot m/s}

3. Look Back and Check
   Does your answer make sense?
   The 3.0-kg hammer has more momentum than the 4.0-kg one. This answer makes sense because it is swung at a greater velocity.
Conservation of Momentum

The more momentum a moving object has, the harder it is to stop. The mass of an object affects the amount of momentum the object has. For example, you can catch a baseball moving at 20 m/s, but you cannot stop a car moving at the same speed. The car has more momentum because it has a greater mass. The velocity of an object also affects the amount of momentum an object has. For example, an arrow shot from a bow has a large momentum because, although it has a small mass, it travels at a high velocity.

What must you know to determine an object’s momentum?

Conservation of Momentum

The word conservation has a special meaning in physical science. In everyday language, conservation means saving resources. You might conserve water or fossil fuels, for example. In physical science, conservation refers to the conditions before and after some event. An amount that is conserved is the same amount after an event as it was before.

The amount of momentum objects have is conserved when they collide. Momentum may be transferred from one object to another, but none is lost. This fact is called the law of conservation of momentum.

The law of conservation of momentum states that, in the absence of outside forces, the total momentum of objects that interact does not change. The amount of momentum is the same before and after they interact. The total momentum of any group of objects remains the same, or is conserved, unless outside forces act on the objects. Friction is an example of an outside force.

Colliding Cars

Momentum is always conserved—even by toys!
1. Find two nearly identical toy cars that roll easily.
2. Make two loops out of masking tape (sticky side out). Put one loop on the front of one of the cars and the other loop on the back of the other car.
3. Place on the floor the car that has tape on the back. Then gently roll the other car into the back of the stationary car. Was momentum conserved?

How do you know?

Predicting What will happen if you put masking tape on the fronts of both cars and roll them at each other with equal speeds? Will momentum be conserved in this case? Test your prediction.

Expected Outcome Sample answer: The cars will stick together and stop. Yes, momentum will be conserved. The cars had equal and opposite momentums before colliding, resulting in a total momentum of zero after the collision.

Conservation of Momentum

Teach Key Concepts

Visualizing Conservation of Momentum

Focus Tell students that when objects collide, momentum is not lost if there is no friction.

Teach Direct students’ attention to Figure 18. Point out the calculation of momentum found under each diagram. Ask: In part A, why does the blue car move more slowly after the collision? (Some of its momentum is transferred to the green car.)

Extend Ask: Describe an example of conservation of momentum you have observed during a sporting event. (Sample answer: One ice hockey player collides with another, and both players move forward.)

Learning modality: visual

Skills Focus Predicting

Materials masking tape, two toy cars with the same mass and low-friction wheels

Time 10 minutes

Tips If the cars collide with too much force, friction, which is an external force, will affect the conservation of momentum.

Expected Outcome Sample answer: The cars will stick together and stop. Yes, momentum will be conserved. The cars had equal and opposite momentums before colliding, resulting in a total momentum of zero after the collision.

Extend Have students predict what would happen if the front of one car collided with the side of the other car. Learning modality: kinesthetic

Monitor Progress

Skills Check Ask students to determine the momentum of a 3.0 kg object moving at a velocity of 6.0 m/s (30 kg·m/s)

Answers Figure 17 The dog with the greater mass will have the greater momentum.
Materials plastic ruler with groove down the middle, two marbles of equal mass

Time 10 minutes

Focus Ask: If a marble rolling in the groove of the ruler strikes an unmoving marble, what do you predict will happen? (Sample answer: The moving marble will stop, and the unmoving marble will start moving.)

Teach Place a marble in the groove of the ruler. Roll another marble of equal mass so it strikes the unmoving marble. The moving marble will stop, and the stationary marble will start moving.

Apply Ask: Which part of Figure 18 shows the same situation as this demonstration? (Part B—one moving object and one stationary object) Use the ruler and marbles to demonstrate the other situations shown in Figure 18.

In the absence of friction, momentum is conserved when two train cars collide. Interpreting Diagrams In which diagram is all of the momentum transferred from the blue car to the green car?

For: Momentum activity
Visit: PHSchool.com
Web Code: cgp-3024

Students can interact with conservation of momentum online.

English Learners/Beginning Comprehension: Key Concept Have students locate the boldface sentence found under the head Conservation of Momentum. Read the sentence aloud for students. Have students point out the momentum in the Before and After sections of each part of Figure 18. Students should note that the Before and After momentums are equal in each section.

learning modality: visual

English Learners/Intermediate Comprehension: Key Concept Extend the Beginning activity by having students write the boldface sentence on a sheet of paper. Have students underline any words they can’t define. Then, pair students with others who are proficient in English. Have the student teams look up the unfamiliar words in a dictionary.

learning modality: verbal
Collisions With Two Moving Objects In Figure 18A, a train car is traveling at 4 m/s down the same track as another train car traveling only 2 m/s. Eventually, the blue car will catch up with the green car and bump into it. During the collision, the speed of each car changes. The blue car slows down to 2 m/s, and the green car speeds up to 4 m/s. Momentum is conserved—the momentum of one train car decreases while the momentum of the other increases.

Collisions With One Moving Object In Figure 18B, the blue car travels at 4 m/s but the green car is not moving. Eventually the blue car hits the green car. After the collision, the blue car is no longer moving, but the green car travels at 4 m/s. Even though the situation has changed, momentum is conserved. All of the momentum has been transferred from the blue car to the green car.

Collisions With Connected Objects Suppose that, instead of bouncing off each other, the two train cars couple together when they hit. Is momentum still conserved in Figure 18C? After the collision, the coupled train cars make one object with twice the mass. The velocity of the coupled trains is 2 m/s—half the velocity of the blue car before the collision. Since the mass is doubled and the velocity is divided in half, the total momentum remains the same.

### Target Reading Skill

**Previewing Visuals** Refer to your questions and answers about Figure 18 to help you answer Question 3 below.

### Reviewing Key Concepts

1. **a. Reviewing** State Newton’s third law of motion.
   - b. Summarizing According to Newton’s third law of motion, how are action and reaction forces related?
   - c. Applying Concepts What would happen if you tried to catch a ball while standing on roller skates?

2. **a. Defining** What is momentum?
   - b. Predicting What is the momentum of a parked car?
   - c. Relating Cause and Effect Why is it important for drivers to allow more distance between their cars when they travel at faster speeds?

3. **a. Identifying** What is conservation of momentum?
   - b. Applying The total momentum of two marbles before a collision is 0.08 kg m/s. No outside forces act on the marbles. What is the total momentum of the marbles after the collision?

### Math Practice

1. **Calculating Momentum** What is the momentum of a 920-kg car moving at a speed of 25 m/s?
2. **Calculating Momentum** Which has more momentum: a 250-kg dolphin swimming at 4 m/s, or a 350-kg manatee swimming at 2 m/s?

### Assessment

#### Math Skill

**Calculating momentum**

**Answers**

1. 23,000 kg·m/s
   
   (920 kg × 25 m/s = 23,000 kg·m/s)

2. Dolphin: 1,000 kg·m/s
   
   (250 kg × 4 m/s = 1,000 kg·m/s)

Manatee: 700 kg·m/s

(350 kg × 2 m/s = 700 kg·m/s)

The dolphin has more momentum.

### Monitor Progress

#### Answers

**Figure 18** All of the momentum is transferred to the green car in Part B.

In the absence of摩擦, the total momentum is equal to the total momentum before the collision.

#### Reviewing Key Concepts

1. **a.** If one object exerts a force on another object, the second object exerts an equal and opposite force on the first object. **b.** Action and reaction forces are equal in strength and opposite in direction. **c.** When you caught the ball, you (with the ball in your hand) would move in the direction of the ball’s initial motion.

2. **a.** Momentum is a characteristic of a moving object equal to the product of its mass and its velocity. **b.** Because the velocity of a parked car is zero, its momentum is zero. **c.** Cars traveling at faster speeds have more momentum and are more difficult to stop than cars traveling at slower speeds.

#### Reteach

Have each student create a concept map that includes information about momentum and conservation of momentum. Challenge students to include as much information as possible.

#### Performance Assessment

**Skills Check** Have students write and solve a problem in which they must calculate the momentum of two objects before and after a collision.

### Chapter Resources

- **Section Summary:** Newton’s Third Law
- **Review and Reinforce:** Newton’s Third Law
- **Enrich:** Newton’s Third Law
Forced to Accelerate

Prepare for Inquiry

Key Concept
Unbalanced forces cause acceleration.

Skills Objectives
After this lab, students will be able to
• calculate velocity and acceleration
• graph data of acceleration vs. force
• interpret data about the relationship between force and acceleration for a constant mass

Prep Time 20 minutes
Class Time 40 minutes

Advance Planning
Ask volunteers to bring skateboards from home. Check calibration of the spring scales. Practice the experiment.

Safety
Review the safety guidelines in Appendix A.

Teaching Resources
• Lab Worksheet: Forced to Accelerate

Guide Inquiry

Invitation
Put a skateboard on the floor and put a brick on it. Have a student accelerate it for about 1 meter using a spring scale. Ask: Why did the skateboard accelerate? (A force acted on it.) Have students brainstorm ways they could investigate the effects of force on acceleration.

Introduce the Procedure
Demonstrate how to zero and use a spring scale. Review the concepts of average speed and acceleration. Ask: What are the manipulated and responding variables in this experiment? (Manipulated variable: force with which the skateboard is pulled; responding variable: acceleration of the skateboard) Have students look at the figure to clarify the procedure.

Problem
How is the acceleration of a skateboard related to the force that is pulling it?

Skills Focus
calculating, graphing, interpreting data

Materials
• skateboard • meter stick • string
• stopwatch • masking tape
• spring scale, 5-N
• several bricks or other large masses

Procedure
1. Attach a loop of string to a skateboard. Place the bricks on the skateboard.
2. Using masking tape, mark off a one-meter distance on a level floor. Label one end “Start” and the other “Finish.”
3. Attach a spring scale to the loop of string. Pull it so that you maintain a force of 2.0 N. Be sure to pull with the scale straight out in front. Practice applying a steady force to the skateboard as it moves.
4. Copy the data table into your notebook.
5. Find the smallest force needed to pull the skateboard at a slow, constant speed. Do not accelerate the skateboard. Record this force on the first line of the table.
6. Add 0.5 N to the force in Step 5. This will be enough to accelerate the skateboard. Record this force on the second line of the table.
7. Have one of your partners hold the front edge of the skateboard at the starting line. Then pull on the spring scale with the force you found in Step 6.
8. When your partner says “Go” and releases the skateboard, maintain a constant force until the skateboard reaches the finish line. A third partner should time how long it takes the skateboard to go from start to finish. Record the time in the column labeled Trial 1.
9. Repeat Steps 7 and 8 twice more. Record your results in the columns labeled Trial 2 and Trial 3.
10. Repeat Steps 7, 8, and 9 using a force 1.0 N greater than the force you found in Step 5.
11. Repeat Steps 7, 8, and 9 twice more. Use forces that are 1.5 N and 2.0 N greater than the force you found in Step 5.

Data Table

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>Trial 1 Time (s)</th>
<th>Trial 2 Time (s)</th>
<th>Trial 3 Time (s)</th>
<th>Average Time (s)</th>
<th>Average Speed (m/s)</th>
<th>Final Speed (m/s)</th>
<th>Acceleration (m/s²)</th>
</tr>
</thead>
</table>

Troubleshooting the Experiment
• Keep the mass on the skateboard constant throughout the experiment.
• The spring scale must be held horizontal, pulled straight, and zeroed before each use.

• If the spring scale is calibrated in grams, multiply by 0.01 to obtain newtons.
• Force should be measured after the skateboard starts moving.
• Final speed can be calculated using average speed because acceleration is constant.
Expected Outcome

Students’ graphs should show that acceleration is proportional to force. Possible sources of error include improper use of the spring scale, errors during calculation, and failing to pull with constant force.

Analyze and Conclude

1. Sample answer: With a force of 2.2 N and a mass of 4.0 kg, the average time to accelerate for 1.0 m will be approximately 2 s.
2. Sample answer: For the same data, the average speed will be about 0.5 m/s.
3. Sample answer: For the same data, the final speed will be around 1 m/s.
4. Sample answer: For the same data, the acceleration will be around 0.5 to 0.6 m/s².
5. Students’ graphs should show that force and acceleration are directly proportional.
6. The force for an acceleration of zero was measured in Step 5, when acceleration was zero.
7. Acceleration is proportional to pulling force.
8. Force is the manipulated variable; acceleration is the responding variable.
9. Friction and errors in timing and pulling force might have affected the outcome.

Extend Inquiry

Design an Experiment

Sample answer: Our experiment would be essentially the same, except we would vary the mass (using a different number of bricks) and keep the accelerating force constant. We would need to measure mass using a balance.