SECTION 4

Newton's Second Law of Motion: The Rear-End Collision

Section Overview

Students explore the effects of rear-end collisions on passengers, focusing on whiplash. They model a driver by constructing a clay figure with its head attached to its body using a clay neck and a piece of wire. They investigate what happens to the clay figures during rear-end collisions between a moving vehicle and a stationary vehicle, and observe the differences between collisions involving drivers using a seat with a headrest and without a headrest. Students review Newton's second law and read about how the head whips back and then forward during a collision, which causes whiplash. Newton's first and second laws are applied to explain how whiplash occurs, and students use their observations as evidence to support the explanation. Students then describe, analyze, and explain situations involving collisions using Newton's first and second laws.

Background Information

Newton's second law states that if a net external force acts on an object, then the object's motion will change. If the mass of the object is constant then Newton's second law is expressed as

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

When the net external force acts in the direction of motion the object speeds up. When the net external force acts opposite to the direction of motion, the object slows down. When the net external force acts in a direction different from the direction of motion, then the object begins to move in that direction.

Whiplash is a term commonly used to describe injury to the muscles, ligaments, tendons, and/or bones in the neck due to hyperextension and hyperflexion of the neck. Whiplash can occur in any situation in which the neck gets snapped back and forth.

Crucial Physics

- Newton's first law—an object at rest will remain at rest and an object in motion will continue its motion with constant velocity (speed and direction) unless a net external force acts on the object.
- Newton's second law—when an object is acted upon by a net external force its motion changes such that the object accelerates in the direction of the force. The acceleration of the object is directly proportional to the net external force, and inversely proportional to the object's mass.

Learning Outcomes	Location in the Section	Evidence of Understanding
Evaluate, from simulated collisions, the effect of rear-end collisions on the neck muscles.	***Investigate*** Steps 7-9 ***What Do You Think Now?***	Students record their observations of what occurs to a clay driver, in particular, its head and neck, during a rear-end collision simulation involving two types of carts with seats that collide with each other in the presence and absence of headrests. Students explain their observations using Newton's first law. After reading about whiplash, students describe their observations using Newton's first and second laws.
Describe the causes of whiplash injuries.	***Physics Talk*** ***What Do You Think Now?*** ***Physics to Go*** Questions 1, 8	Students discuss and describe what whiplash is and what causes it.
Provide examples of Newton's first and second laws of motion in automobile crashes.	***Physics Talk*** ***What Do You Think Now?*** ***Physics Essential Questions*** ***Physics to Go*** Questions 1, 4, 5	Students describe various situations involving automobile collisions using Newton's first and second laws.
Analyze the role of safety devices in preventing whiplash injury.	***Investigate*** Steps 7-9 ***Physics Essential Questions*** ***Reflecting on the Section and the Challenge*** ***Physics to Go*** Questions 5-7	Students use their observations to support their ideas and analysis on how headrests help prevent whiplash injury.

Section 4 Materials, Preparation, and Safety

Materials and Equipment

PLAN A

Materials and Equipment	Group (4 students)	Class
Dynamics cart	2 per group	
Clay, modeling, lb	2 per group	
Inclined plane for lab cart	1 per group	
Large ring stand	1 per group	
Rod, aluminum, 12 in. (length) x 3/8 in. (diameter) (to act as cross arm)	1 per group	
Holder, Right Angle, Cast Iron	1 per group	
Scissors	1 per group	
Meter sticks	1 per group	
Weight, slotted, 100 g	6 per group	
File folders	3 per group	
Tape, masking		6 per group
Wire, magnet, #24, 60 ft roll		1 per class

*Additional items needed not supplied

PLAN B

Materials and Equipment	Group (4 students)	Class
Dynamics cart		2 per class
Clay, modeling, lb		2 per class
Inclined plane for lab cart		1 per class
Large ring stand		1 per class
Holder, Right Angle, Cast Iron		1 per class
Rod, aluminum, 12 in. (length) x 3/8 in. (diameter) (to act as cross arm)		1 per class
Scissors		1 per class
Meter sticks	1 per group	
Weight, slotted, 100 g		6 per class
File folders		3 per class
Tape, masking		6 per group
Wire, magnet, #24, 60 ft roll		1 per class

*Additional items needed not supplied

Note: Time, Preparation, and Safety requirements are based on Plan A, if using Plan B, please adjust accordingly.

Time Requirement

Allow one period for the students to design and run the tests. If the investigation is run over two days, students can try different configurations for the seats to protect the passengers.

Teacher Preparation

- The two templates for the driver's seat will need to be prepared in advance. Based on the width of the cart you will be using, the templates may have to be enlarged or reduced on a photocopy machine so that they fit securely on the cart.
- Build a model of the driver and seats to demonstrate to students how they should look when they are done constructing the models. Conduct the investigation in advance to determine what your students may have difficulties with.
- When increasing the mass of the cart, added masses should be taped in place so they do not shift during the collision.

Safety Requirements

- In all collision experiments, goggles and closed-toe shoes are of extra importance.
- Plastic dynamics carts may be used for this investigation if a spring bumper is used.
- See the caution for smoothing the transition from ramp to floor in *Section 1*.
- If the investigation is performed on a lab table, caution the students to stand back so any falling masses do not land on their feet.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Creating clay passengers	***Investigate*** Steps 2 and 3	**Augmentation** • Students who struggle with sensory integration and fine motor skills may have a difficult time making a clay passenger, either because they do not want to touch the clay or because they cannot form a shape similar to a human in a reasonable amount of time. Intentionally assign partners to compensate for these concerns. • Give students a time limit for creating their clay passengers. Emphasize that the directions require a torso, neck, and head that can sit up in a cart, but the details on the clay passenger are not important. **Accommodation** • Prepare clay passengers in advance and provide students with a clay passenger at the start of the *Investigate*.
Making scientific measurements Following a list of directions to build something	***Investigate*** Steps 5-7	**Augmentation** • Ask groups of students to read *Steps 5-7* and decide how they are going to make all of the required measurements to setup the ramp. Refer students to the diagram of the setup as a resource. • If students feel confident that they can set up the ramp independently and complete the measurements, allow them to begin. If students need help, instruct them to ask specific questions to clarify their confusion. (For example: How can I measure 2.7 m?) **Accommodation** • Provide one-on-one or small group assistance to teach students measurement skills. • Provide a checklist of steps necessary to complete the setup. 1) Set up a ramp that is 40 cm high. 2) Use a piece of stiff paper at the bottom of the ramp. 3) Mark off a distance of 2.7 m or 270 cm from the bottom of the ramp. 4) Etc.
Reading comprehension Imagining a scenario	***Physics Talk*** Newton's First and Second Laws of Motion and Whiplash ***Checking Up*** Questions 1-3 ***Physics Essential Questions***	**Augmentation** • The descriptions in this section clearly explains what happens during a rear-end collision, but students who struggle with reading will skim over information and miss important concepts. Ask students to act out a rear-end collision as a group. As they are acting out the collision, tell them to try to annotate the scenario using Newton's laws. • Some students will be able to write or explain what happens in a rear-end collision in their own words after they read this section. If students can explain the actions in their own words, they will be able to apply the concept more easily later. • Ask students to draw a comic strip of the events that happen in a rear-end collision and include physics vocabulary in their comics. • Allow students to experience their head's motion being different from their body's motion by asking them to sit in a desk chair with wheels and push the chair quickly from behind. This experience will be a good frame-of-reference for students to refer to when they are answering questions. • Show an Internet video clip of a person getting whiplash using video available on the Internet. **Accommodation** • Read the *Physics Talk* section aloud and have a group discussion to apply Newton's laws to the whiplash scenario.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Understanding concepts	***Physics Talk***	Once students have completed the *Investigate* and have read through the description of how a rear-end collision causes whiplash, hold a class discussion. Try and let students figure out how a headrest can reduce the extent of injury from whiplash. Encourage ELL students to participate actively in the discussion and practice their speaking skills. You may wish to use a notebook or file folder to serve as a headrest, and demonstrate how it prevents the head from fully hyperextending, thus reducing injury to the neck bones and vertebral column.
Cooperative learning	***Active Physics Plus***	Have students work in pairs or groups. Assign each group one of the given speeds (3 m/s, 5 m/s, 10 m/s, or 15 m/s) and have them calculate the force on the driver's neck muscles for the conditions given. Have each group draw the corresponding graph. Ask an ELL student to copy his or her group's graph on the board and explain it to the class. Repeat the process with a different student for the shorter time interval given in *Question 3*.
Vocabulary comprehension	***Reflecting on the Section and the Challenge***	Students may have difficulty discerning the meaning of "susceptible," which means "likely to be affected with or by."
Vocabulary comprehension	***Physics to Go Whiplash Quiz*** Question 5	The meaning of "threshold" may be difficult to determine from context. Help students understand that it is the point separating conditions that will produce an effect (in this case, cause injury) from conditions that will not produce an effect (not cause injury). Students may benefit from another example in a context they have likely encountered: Lengthy exposure to noise levels above 85 dB will damage hearing, while lengthy exposure to noise levels below 85 dB will not. Eighty-five dB is the threshold for hearing damage.
Research skills	***Inquiring Further***	ELL students may need some guidance in finding library and Internet sources of relevant information. To help them practice their language skills, encourage them to choose a presentation style that requires at least some time speaking to the class.

Consider finishing this section with a cloze activity. Cloze activities are useful tools for summarizing material and for giving English-language learners an opportunity to practice using their science vocabulary words in context. Write the following paragraph on the board, replacing the underlined words with write-on-lines. Encourage volunteers to fill in the blanks.

An automobile is hit from behind and begins to move. Newton's <u>second</u> law says the automobile <u>accelerates</u> because of the <u>unbalanced</u> force acting on the back of the automobile. The driver's torso moves <u>with</u> the automobile, but the driver's unsupported head does not. Then the neck muscles whip the head <u>forward</u>. The head moves until it is ahead of the torso. Newton's <u>first</u> law tells why an object in <u>motion</u> stays in motion. Then the neck muscles pull the head back to its usual position. The driver suffers a <u>whiplash</u> injury.

NOTES

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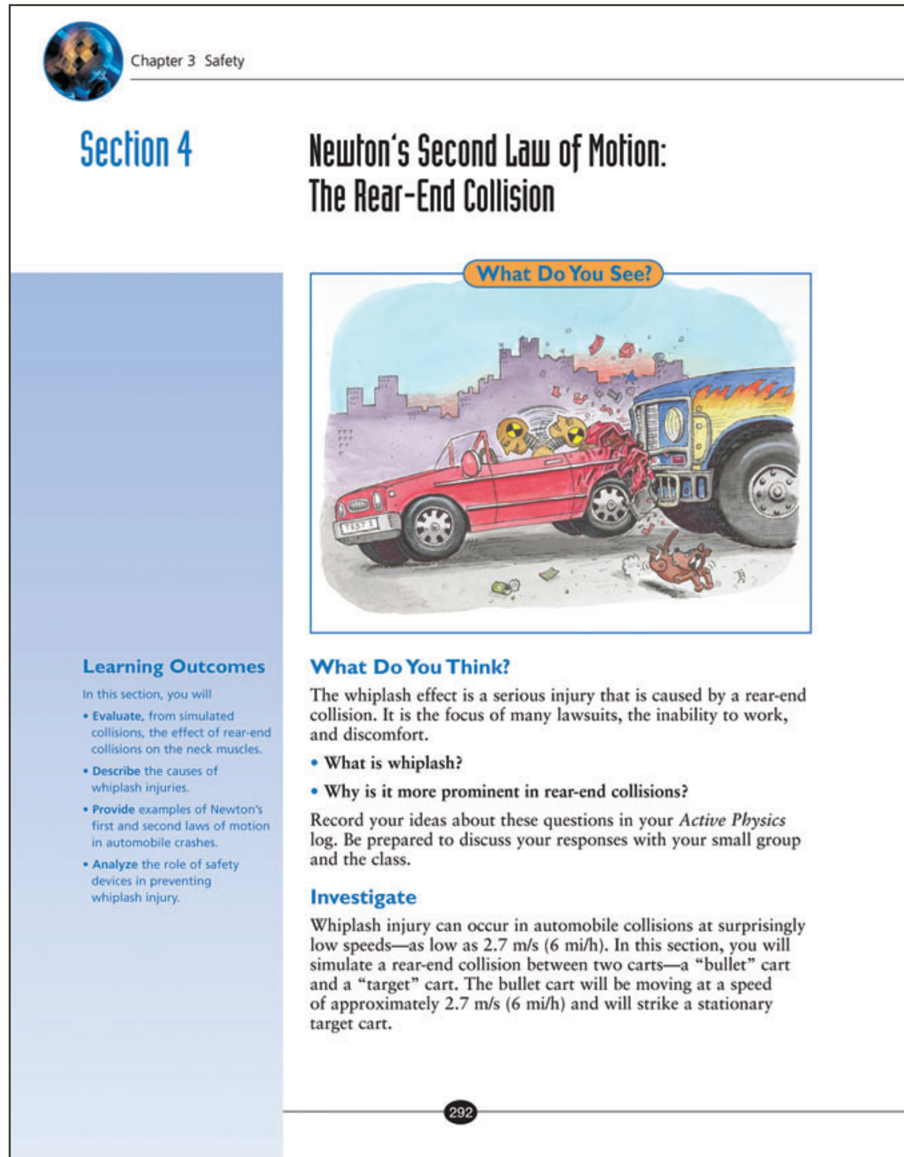
Teaching Suggestions and Sample Answers



Section 4

Newton's Second Law of Motion: The Rear-End Collision

What Do You See?

Learning Outcomes

In this section, you will

- **Evaluate**, from simulated collisions, the effect of rear-end collisions on the neck muscles.
- **Describe** the causes of whiplash injuries.
- **Provide** examples of Newton's first and second laws of motion in automobile crashes.
- **Analyze** the role of safety devices in preventing whiplash injury.

What Do You Think?

The whiplash effect is a serious injury that is caused by a rear-end collision. It is the focus of many lawsuits, the inability to work, and discomfort.

- What is whiplash?
- Why is it more prominent in rear-end collisions?

Record your ideas about these questions in your *Active Physics* log. Be prepared to discuss your responses with your small group and the class.

Investigate

Whiplash injury can occur in automobile collisions at surprisingly low speeds—as low as 2.7 m/s (6 mi/h). In this section, you will simulate a rear-end collision between two carts—a "bullet" cart and a "target" cart. The bullet cart will be moving at a speed of approximately 2.7 m/s (6 mi/h) and will strike a stationary target cart.

What Do You See?

Have students consider the illustration and the *Learning Outcomes* of this section. Use an overhead of the illustration to help focus the discussion. Ask students what they think the illustration depicts and record their responses. This elicitation helps to get their initial ideas and provides a focus for the science content. Consider asking students how the illustration captures Newton's first and second laws.

What Do You Think?

These preliminary questions are designed to elicit students' prior knowledge and to focus students on the issue. After students record their responses in their log, have them discuss their ideas with

Students' Prior Conceptions

The examination of rear-end collisions and the subsequent analysis of the transfer of energies and the work involved in these collisions provides real-life examples that lead students to alter their prior conceptions.

1. **Collision severity is less for the automobile that hits a second automobile in a rear-end collision than for the automobile being hit.** This misconception arises due to a misunderstanding of action-reaction forces and a misconstrued application of the laws of motion. Hands-on inquiry, measurement, and analysis require the student to examine the laws of motion and to reconstruct a model for what happens to each vehicle during the collision.

2. **In a collision, the extent of injury to passengers is related to the speed of the automobile in which they are traveling.** Students generally believe that traveling at low velocities does not cause extensive or severe impact damage during collisions. To remove this misconception, refer to *Investigate*, *Steps 7* and *8,* and the subsequent analysis in the *Physics Talk* of whiplash during a rear-end collision, based on Newton's laws of motion. This is also a good time to review the velocity squared rule developed in *Chapter 1*, *Section 5.*

their group members to come up with their best group response. Then have a class discussion and record the class's ideas. Remind them that the correctness of their response is not the issue; what matters is their ability to construct and to convey their ideas in response to the questions.

Investigate

Discuss the investigation steps with the class. Show students the completed driver's seats and make these available for students to view while they are assembling their driver's seats. Describe for students how their clay figures should be constructed and emphasize the importance of using the wire to model the spinal column and neck, and that the seated clay figure should have its head just above the seat without the headrest.

What Do You Think?

A Physicist's Response

In whiplash, neck muscles, ligaments, and/or tendons become damaged. Whiplash occurs when the head moves far back, and then far forward, causing the neck muscles and vertebrae to hyperextend and then hyperflex. The injury caused is even more severe if the head is turned to the side rather than forward. To understand why whiplash is more prominent in rear-end collisions, assume a driver is at rest within the automobile. Applying Newton's first law, the driver will remain at rest unless a net external force acts on the driver. If the vehicle is rear-ended, there is a net external force acting on the vehicle during the collision. Applying Newton's second law, the vehicle accelerates forward. The back of the seat pushes the driver forward and the driver's torso moves forward with the automobile. The driver's head, however, is not pushed forward by the seat, and obeys Newton's first law, so it stays back until the neck muscles holding the head to the body pull the head forward. At this point, the hyperextended muscles whip the head forward, accelerating it according to Newton's second law. The head then continues its forward motion following Newton's first law, until it gets ahead of the body, and the neck muscles attached to the body are hyperflexed and pull it back to its usual position. If the seat has a padded headrest it can reduce injury because it can support the head so that it does not hyperextend. A padded headrest will also absorb some of the energy so that the head does not hyperflex.

In a front-end collision, the vehicle accelerates backward because of the unbalanced force exerted on it. According to Newton's first law, the passenger remains in place until an unbalanced force is exerted on the passenger. The seat belt exerts a force on the passenger causing the body to be pushed back, and the head, according to Newton's first law, would remain where it was until the neck muscles pulled the head backward. The head would then continue moving backward until it was pulled forward to its normal location. Whiplash can still occur in this case, but usually the muscles in the neck are not as hyperflexed and hyperextended during a front-end collision. The head, which naturally has a greater forward than backward mobility, is not affected as severely as during a rear-end collision. Also, the body bends forward with the head so the neck muscles are not flexed as much initially before the head moves back.

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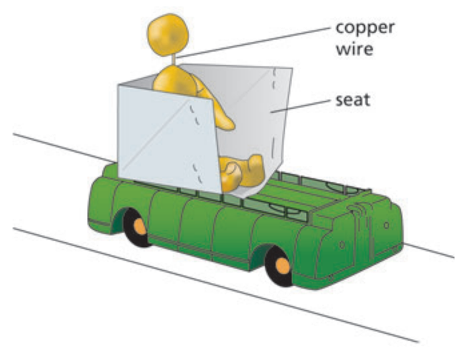
1.

Two templates are provided for a driver's seat – one that has a headrest and one that does not. Have students fold along the solid lines and cut along the dotted lines to create the two seats.

2. - 3.

Once the seats are built, have each group of students create two identical clay dummies to fit the seats, so that the heads of the dummies will be just above the back of the driver's seat that is without a headrest. The head of each dummy needs to be created as a separate part with a small piece of clay that represents the neck. Do not use the clay neck to attach the head of the dummy to the torso. Use a 1-inch piece of 24-gauge wire to secure the head through the neck to the torso, as shown in the image. Attach the seats to the carts with tape to keep them in place to have a realistic collision. Students should place the clay figure in the seat with the headrest with its head against the headrest. The clay figure in the seat without a headrest should have its shoulders level with the top of the seat.



3-4a Blackline Master

4.

Students should create seat belts using masking tape, or ribbon if preferred.

5.

To set up the ramp so that a speed of about 2.7 m/s (about 6 mi/h) will occur as the car traverses the level portion of the track, almost the entire height of 40 cm will be needed. Check that students have placed a stiff piece of paper at the bottom of the ramp to smooth out the junction between the ramp and table. Check that students have marked the position on the ramp with, for example, a piece of masking tape.

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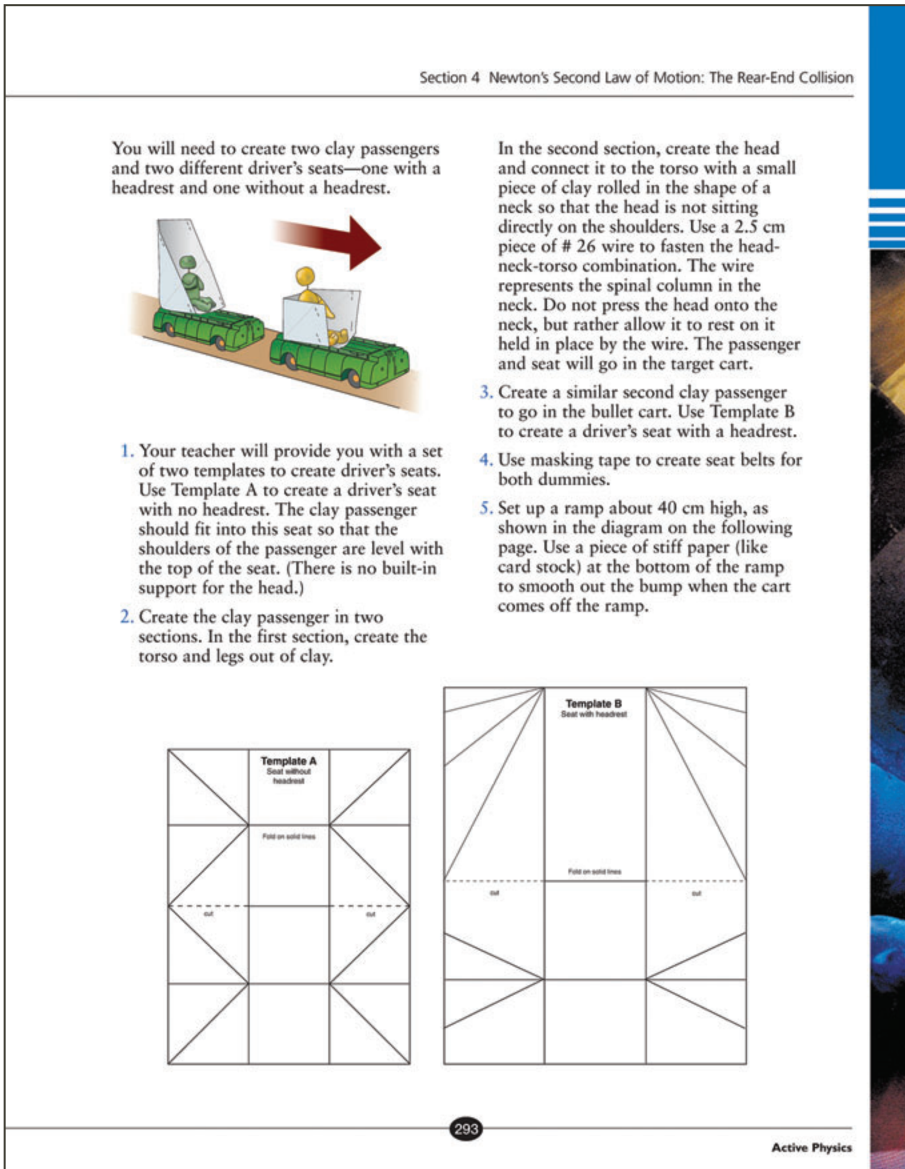

Section 4 Newton's Second Law of Motion: The Rear-End Collision

You will need to create two clay passengers and two different driver's seats—one with a headrest and one without a headrest.

1. Your teacher will provide you with a set of two templates to create driver's seats. Use Template A to create a driver's seat with no headrest. The clay passenger should fit into this seat so that the shoulders of the passenger are level with the top of the seat. (There is no built-in support for the head.)
2. Create the clay passenger in two sections. In the first section, create the torso and legs out of clay. In the second section, create the head and connect it to the torso with a small piece of clay rolled in the shape of a neck so that the head is not sitting directly on the shoulders. Use a 2.5 cm piece of # 26 wire to fasten the head-neck-torso combination. The wire represents the spinal column in the neck. Do not press the head onto the neck, but rather allow it to rest on it held in place by the wire. The passenger and seat will go in the target cart.
3. Create a similar second clay passenger to go in the bullet cart. Use Template B to create a driver's seat with a headrest.
4. Use masking tape to create seat belts for both dummies.
5. Set up a ramp about 40 cm high, as shown in the diagram on the following page. Use a piece of stiff paper (like card stock) at the bottom of the ramp to smooth out the bump when the cart comes off the ramp.

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8.

With the target cart having a seat with a headrest, the students should notice that the head is not bent backward, as in the previous step. Newton's first law states that an object at rest remains at rest until acted upon by an unbalanced force. The head and body move forward together because they have the same unbalanced force acting on them from the seat and headrest.

Teaching Tip

To double and triple the mass of the bullet cart, carts may be stacked one on top of the other, or masses may be added. If masses are added, tape them in place to ensure that they do not slide during the collision.

9.

Students should observe that as the mass of the bullet cart is increased, the amount that the head bends back in the target cart without the headrest increases. They should notice no change if the target cart has the seat with the headrest.

3-4b Blackline Master

3-4c Blackline Master

6.

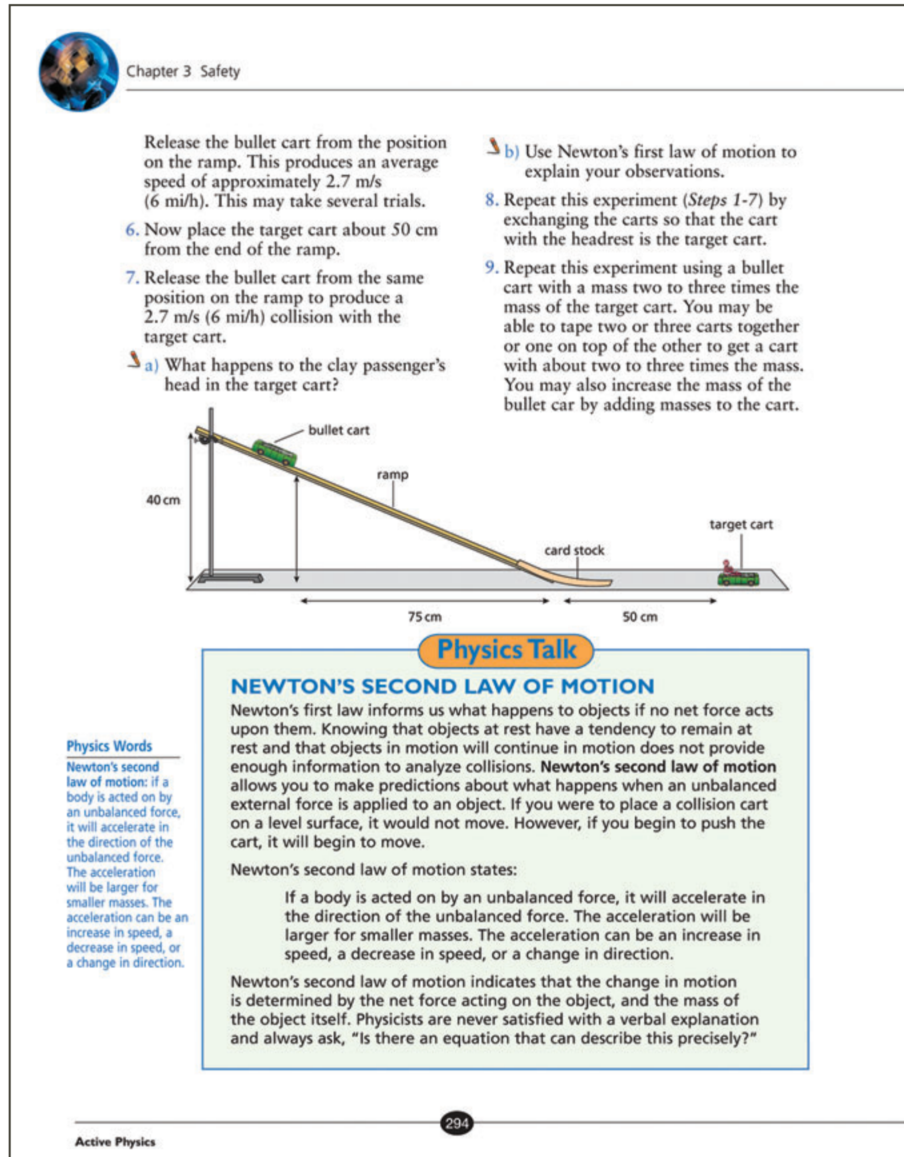
Students should place the target cart about 50 cm from the end of the ramp. (For the first run, *Steps 1-7*, the target cart has the seat with no headrest.)

7.a)

Students should notice that the unsupported head of the passenger in the target cart is bent backward after the collision.

7.b)

Newton's first law states that an object at rest (the clay model's head) remains at rest until acted upon by an unbalanced force, so the head tends to remain at rest while the rest of the "body" is pushed rapidly forward. The head begins to move forward when the body begins to pull it forward.


Chapter 3 Safety

Release the bullet cart from the position on the ramp. This produces an average speed of approximately 2.7 m/s (6 mi/h). This may take several trials.

6. Now place the target cart about 50 cm from the end of the ramp.

7. Release the bullet cart from the same position on the ramp to produce a 2.7 m/s (6 mi/h) collision with the target cart.

a) What happens to the clay passenger's head in the target cart?

b) Use Newton's first law of motion to explain your observations.

8. Repeat this experiment (*Steps 1-7*) by exchanging the carts so that the cart with the headrest is the target cart.

9. Repeat this experiment using a bullet cart with a mass two to three times the mass of the target cart. You may be able to tape two or three carts together or one on top of the other to get a cart with about two to three times the mass. You may also increase the mass of the bullet car by adding masses to the cart.

Physics Talk

NEWTON'S SECOND LAW OF MOTION

Newton's first law informs us what happens to objects if no net force acts upon them. Knowing that objects at rest have a tendency to remain at rest and that objects in motion will continue in motion does not provide enough information to analyze collisions. **Newton's second law of motion** allows you to make predictions about what happens when an unbalanced external force is applied to an object. If you were to place a collision cart on a level surface, it would not move. However, if you begin to push the cart, it will begin to move.

Newton's second law of motion states:

> If a body is acted on by an unbalanced force, it will accelerate in the direction of the unbalanced force. The acceleration will be larger for smaller masses. The acceleration can be an increase in speed, a decrease in speed, or a change in direction.

Newton's second law of motion indicates that the change in motion is determined by the net force acting on the object, and the mass of the object itself. Physicists are never satisfied with a verbal explanation and always ask, "Is there an equation that can describe this precisely?"

Physics Words

Newton's second law of motion: if a body is acted on by an unbalanced force, it will accelerate in the direction of the unbalanced force. The acceleration will be larger for smaller masses. The acceleration can be an increase in speed, a decrease in speed, or a change in direction.

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Physics Talk

This *Physics Talk* discusses Newton's second law, whiplash, and how Newton's first and second laws can be used to explain the cause of whiplash. Consider eliciting students' initial ideas about Newton's first and second laws. Ask them what they remember about each of these laws and to provide an example of each law. Elicit their ideas on how Newton's first and second laws can be used to explain whiplash. Then have a class discussion on Newton's first and second laws of motion and whiplash.

Emphasize to students that Newton's second law states that if an unbalanced force acts on an object of unchanging mass, its motion will change, which means it will accelerate. An accelerating object may change its speed, its direction, or both, as was discussed in *Chapters 1* and *2*. Discuss whiplash, describing what happens within the body. Use the information in the student text to guide the discussion. Point out to students that if the head is turned during this motion of the neck and head, the injury is increased due to greater forces acting on the soft tissues in the neck. Emphasize that whiplash is a term used when any of the soft tissues in the neck (muscles, ligaments, and tendons) are damaged due to the sudden motion of the head forward and/or backward.

Describe how each interaction during a rear-end collision can be explained using Newton's first and second laws of motion, and how they can explain the entire motion of the head that causes whiplash to occur. Discuss each bulleted point, describing how Newton's first and second laws help to explain what is happening to the head during a collision. Check student understanding by asking them to explain their observations during the *Investigate* using Newton's laws.

Summarize Newton's second law and emphasize what net force, force, acceleration, and mass are. Discuss the examples in the student text. Check students' understanding by asking questions about these concepts or having them provide an example similar to the one in the student text. Ask students to provide examples of these concepts.

Section 4 Newton's Second Law of Motion: The Rear-End Collision

Newton's second law does have such an equation that can be written as:

$$F = ma \text{ or } a = \frac{F}{m}$$

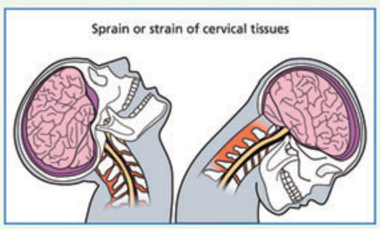
From this equation, one can see that "if a body is acted upon by an unbalanced force, it will accelerate in the direction of the unbalanced force." One can also see that the "acceleration will be larger for smaller masses."

What is Whiplash?

In the collision in the investigation you completed, where the target cart did not have a headrest, the clay head swung back during the collision. **Whiplash** is a serious injury that can be caused by a rear-end collision. The back of the automobile seat pushes forward on the torso of the driver and the passengers and their bodies lunge forward. The head remains still for a very short time. The body moving forward and the head remaining still causes the head to snap backward. The neck muscles and bones of the vertebral column (spine) become damaged. The same muscles must then snap the head back to its place atop the shoulders.

Physics Words

whiplash: the common name for a type of neck injury to muscles of the neck.



A headrest can prevent whiplash injury. The headrest must be adjusted for the height of the passenger.

Newton's First and Second Laws of Motion and Whiplash

The activity in this section demonstrated the effects of a rear-end collision. Newton's first law and Newton's second law can help explain the "whiplash" injury that passengers suffer during this kind of collision.

Imagine looking at the rear-end collision in slow motion. Think about all that happens.

- An automobile is stopped at a red light. This is the automobile in which the driver is going to receive a whiplash injury. It was the target cart in your investigation. The driver is at rest within the automobile.

CHAPTER 3

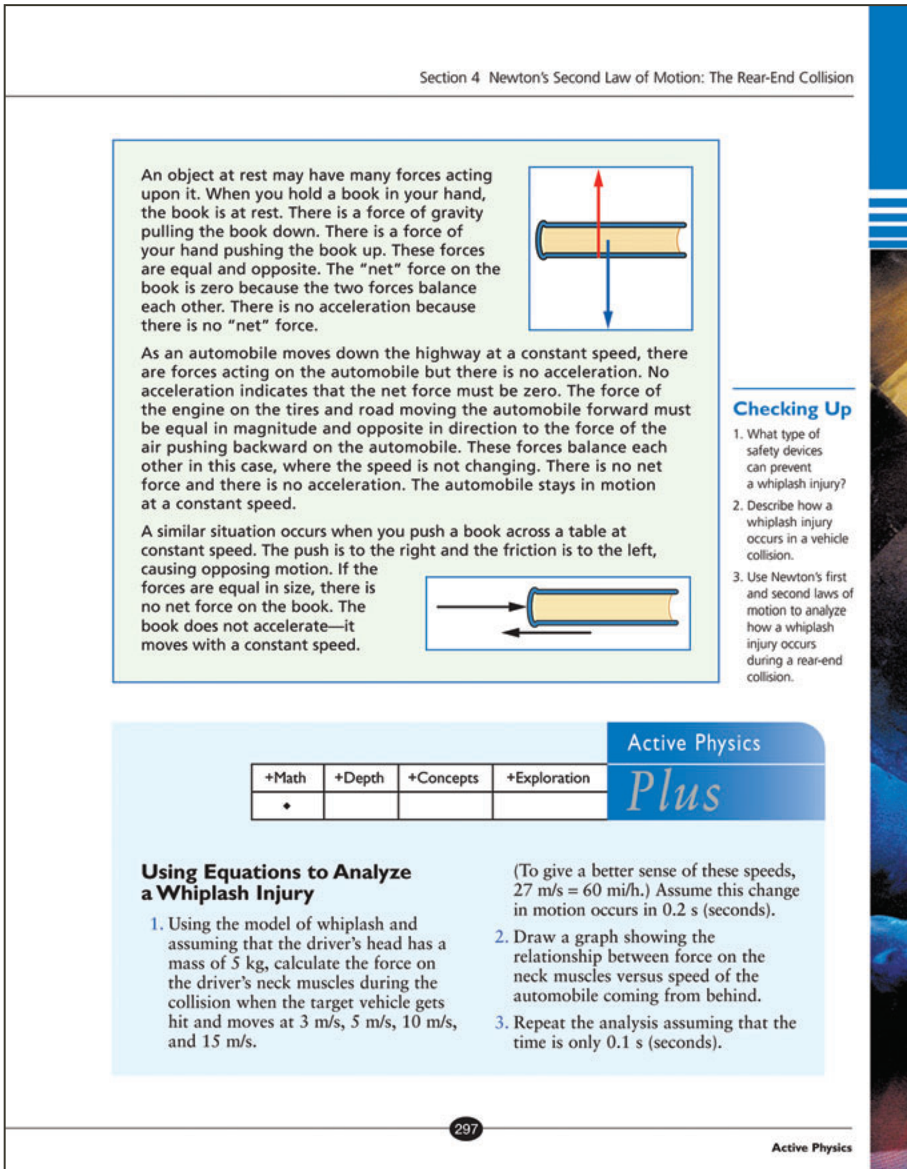
- The stopped automobile gets hit from the rear.
- The automobile begins to move. The back of the seat pushes the driver forward and the driver's torso moves with the automobile. The driver's head is not supported and tends to stay back where it is.

- The neck muscles hold the head to the torso as the body moves forward. The muscles then "whip" the head forward. The head keeps moving until it gets ahead of the torso. The neck muscles stop the head, and pull it back to its usual position. Ouch!

Let's repeat the description of the collision and insert all of the places where Newton's first law and Newton's second law apply (in color).

- An automobile is stopped at a red light. This is the automobile in which the driver is going to receive a whiplash injury. The driver is at rest within the automobile. Newton's first law: An object at rest stays at rest, and an object in motion stays in motion unless acted upon by an unbalanced, outside force.
- The stopped automobile gets hit from the rear.
- The automobile begins to move. Newton's second law: The automobile accelerates because of the unbalanced, outside force from the rear: $F = ma$. The back of the seat pushes the driver forward and the driver's torso moves with the automobile. Newton's second law: The torso accelerates because of the unbalanced, outside force from the back of the seat: $F = ma$. The driver's head is not supported and stays back where it is. Newton's first law: an object (the driver's head) at rest stays at rest.
- The neck muscles hold the head to the body as the body moves forward. The muscles then "whip" the head forward. Newton's second law: The head accelerates because of the unbalanced force of the muscles: $F = ma$. The head keeps moving until it gets ahead of the torso. Newton's first law: An object (the head) in motion stays in motion. The head is stopped by the neck muscles. The muscles pull the head back to its usual position. Newton's second law: The head accelerates (slows down) because of the unbalanced force from the neck muscles: $F = ma$. Ouch!

Newton's second law informs you that all accelerations are caused by *unbalanced, outside* forces. It does not say that all forces cause accelerations, only those that are unbalanced.



An object at rest may have many forces acting upon it. When you hold a book in your hand, the book is at rest. There is a force of gravity pulling the book down. There is a force of your hand pushing the book up. These forces are equal and opposite. The "net" force on the book is zero because the two forces balance each other. There is no acceleration because there is no "net" force.

As an automobile moves down the highway at a constant speed, there are forces acting on the automobile but there is no acceleration. No acceleration indicates that the net force must be zero. The force of the engine on the tires and road moving the automobile forward must be equal in magnitude and opposite in direction to the force of the air pushing backward on the automobile. These forces balance each other in this case, where the speed is not changing. There is no net force and there is no acceleration. The automobile stays in motion at a constant speed.

A similar situation occurs when you push a book across a table at constant speed. The push is to the right and the friction is to the left, causing opposing motion. If the forces are equal in size, there is no net force on the book. The book does not accelerate—it moves with a constant speed.

Checking Up

1. What type of safety devices can prevent a whiplash injury?
2. Describe how a whiplash injury occurs in a vehicle collision.
3. Use Newton's first and second laws of motion to analyze how a whiplash injury occurs during a rear-end collision.

Active Physics *Plus*

+Math	+Depth	+Concepts	+Exploration
•			

Using Equations to Analyze a Whiplash Injury

1. Using the model of whiplash and assuming that the driver's head has a mass of 5 kg, calculate the force on the driver's neck muscles during the collision when the target vehicle gets hit and moves at 3 m/s, 5 m/s, 10 m/s, and 15 m/s.

(To give a better sense of these speeds, 27 m/s = 60 mi/h.) Assume this change in motion occurs in 0.2 s (seconds).

2. Draw a graph showing the relationship between force on the neck muscles versus speed of the automobile coming from behind.
3. Repeat the analysis assuming that the time is only 0.1 s (seconds).

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Checking Up

1.

A headrest can reduce the delay between the motion of the body and the motion of the head by not allowing the head to go back very far and by absorbing some of the kinetic energy of the head. This helps to reduce and/or prevent whiplash injury.

2.

Whiplash can be caused by a rear-end collision. The back of the automobile seat pushes forward on the body of the driver. The body lunges forward, but the head remains still for a very short time. This causes the head to snap backward and then forward. The neck muscles and bones can become damaged as the motion of the head pushes and then pulls the muscles, tendons, ligaments, and vertebrae one way and then the other. The same muscles then snap the head back into place.

3.

Students should explain how whiplash occurs using Newton's first and second laws. Their responses should contain the information in the *Physics Talk*, but should be in their own words. Consider asking students to describe another situation in which whiplash could occur, for example, on a roller coaster while skateboarding, and so on.

CHAPTER 3

Active Physics Plus

This *Active Physics Plus* provides students with the opportunity to apply the physics concepts of Newton's first and second laws to problem-solve situations algebraically.

1.

The mass, the initial speed, the final speed, and the time the change in speed occurs are given. To calculate the force ($F = ma$), the acceleration is needed. To find the average acceleration, use the equation:

$$a = \frac{v_{\text{final}} - v_{\text{initial}}}{t}.$$

For $v_{\text{initial}} = 3$ m/s, $a = -15$ m/s^2, and $F = -75$ N.

For $v_{\text{initial}} = 5$ m/s, $a = -25$ m/s^2, and $F = -125$ N.

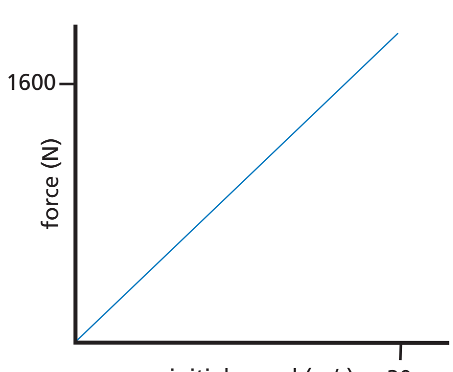
For $v_{\text{initial}} = 10$ m/s, $a = -50$ m/s^2, and $F = -250$ N.

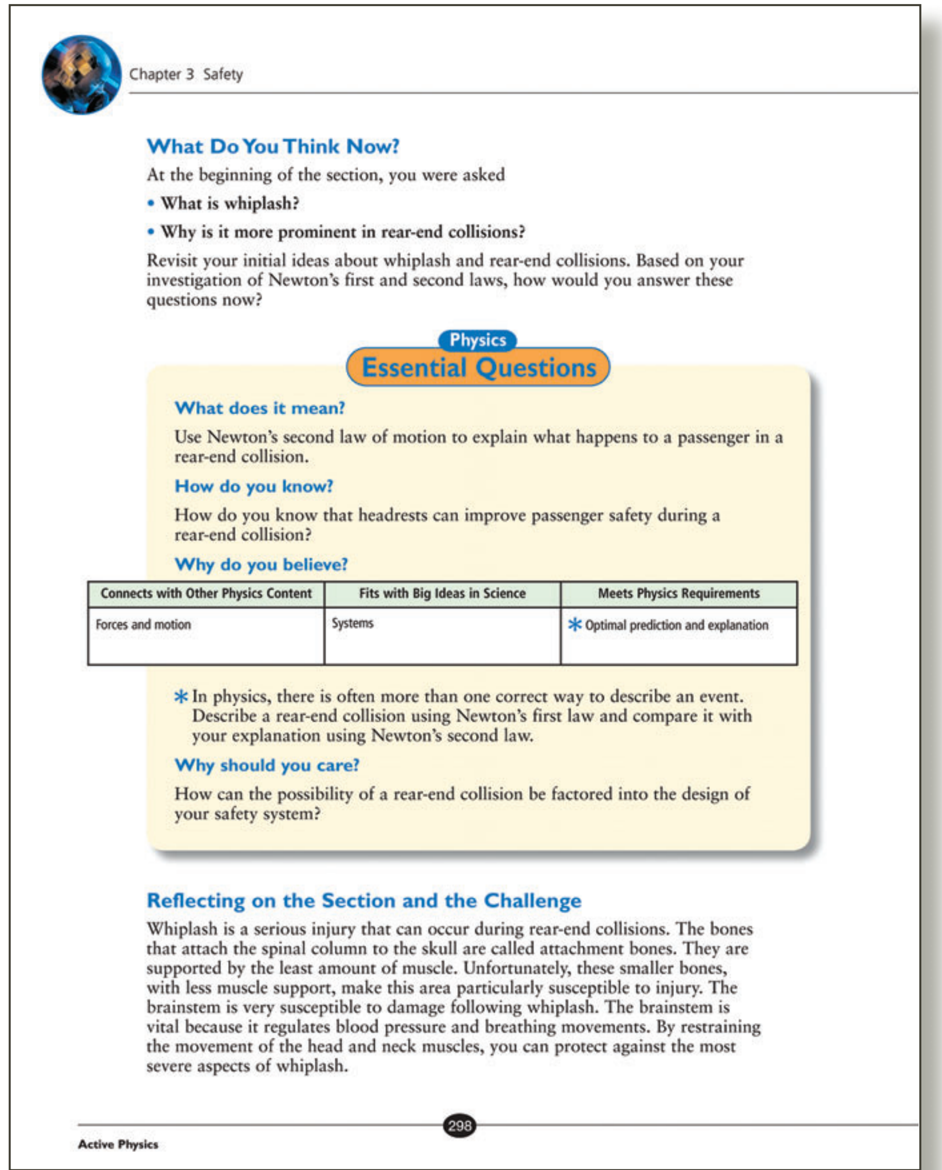
For $v_{\text{initial}} = 15$ m/s, $a = -75$ m/s^2, and $F = -375$ N.

The negative sign indicates that the acceleration and the force point opposite to the direction of the initial velocity.

2.

Students' graphs should look similar to the one below and at right.




Chapter 3 Safety

What Do You Think Now?

At the beginning of the section, you were asked

- **What is whiplash?**
- **Why is it more prominent in rear-end collisions?**

Revisit your initial ideas about whiplash and rear-end collisions. Based on your investigation of Newton's first and second laws, how would you answer these questions now?

Physics
Essential Questions

What does it mean?

Use Newton's second law of motion to explain what happens to a passenger in a rear-end collision.

How do you know?

How do you know that headrests can improve passenger safety during a rear-end collision?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Forces and motion	Systems	* Optimal prediction and explanation

* In physics, there is often more than one correct way to describe an event. Describe a rear-end collision using Newton's first law and compare it with your explanation using Newton's second law.

Why should you care?

How can the possibility of a rear-end collision be factored into the design of your safety system?

Reflecting on the Section and the Challenge

Whiplash is a serious injury that can occur during rear-end collisions. The bones that attach the spinal column to the skull are called attachment bones. They are supported by the least amount of muscle. Unfortunately, these smaller bones, with less muscle support, make this area particularly susceptible to injury. The brainstem is very susceptible to damage following whiplash. The brainstem is vital because it regulates blood pressure and breathing movements. By restraining the movement of the head and neck muscles, you can protect against the most severe aspects of whiplash.

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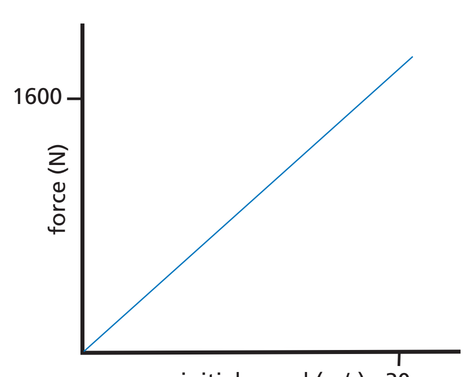
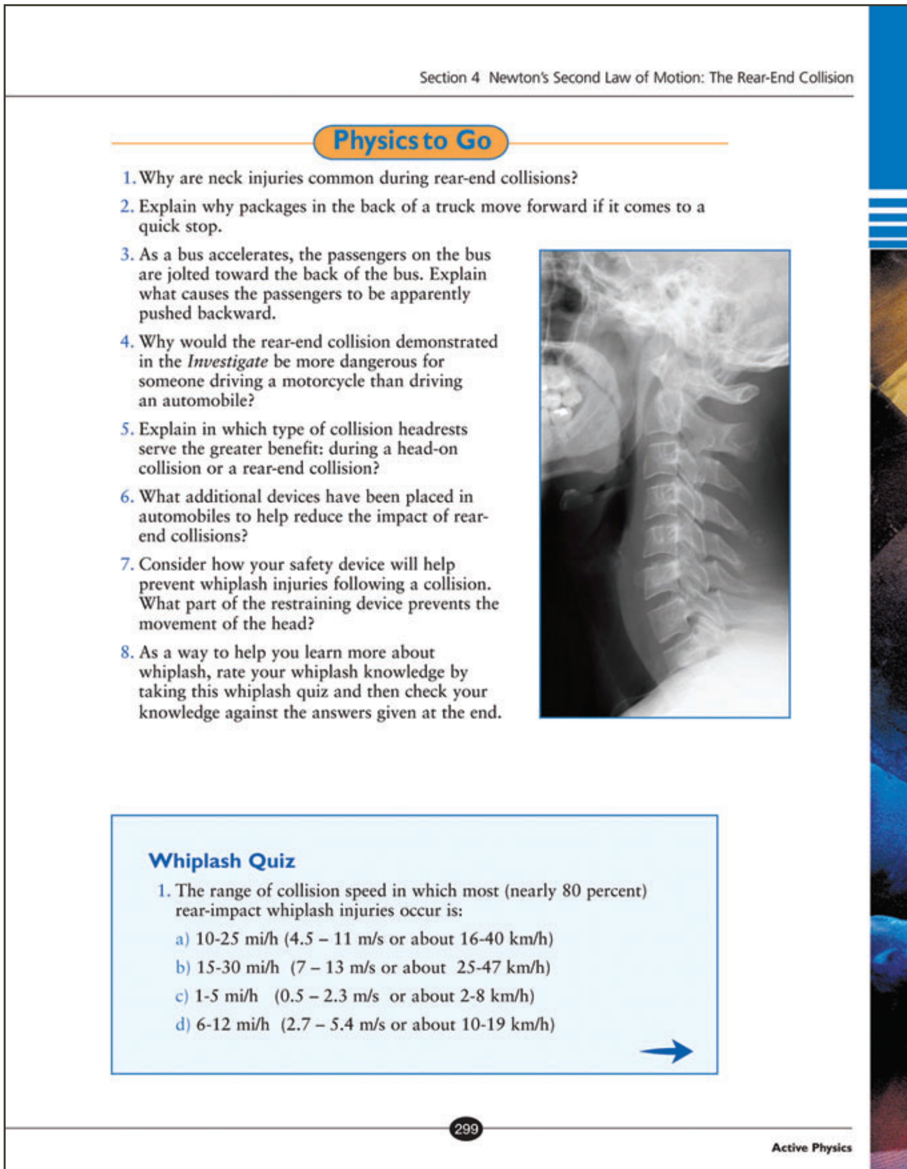
Active Physics

3.




Section 4 Newton's Second Law of Motion: The Rear-End Collision

Physics to Go

1. Why are neck injuries common during rear-end collisions?
2. Explain why packages in the back of a truck move forward if it comes to a quick stop.
3. As a bus accelerates, the passengers on the bus are jolted toward the back of the bus. Explain what causes the passengers to be apparently pushed backward.
4. Why would the rear-end collision demonstrated in the *Investigate* be more dangerous for someone driving a motorcycle than driving an automobile?
5. Explain in which type of collision headrests serve the greater benefit: during a head-on collision or a rear-end collision?
6. What additional devices have been placed in automobiles to help reduce the impact of rear-end collisions?
7. Consider how your safety device will help prevent whiplash injuries following a collision. What part of the restraining device prevents the movement of the head?
8. As a way to help you learn more about whiplash, rate your whiplash knowledge by taking this whiplash quiz and then check your knowledge against the answers given at the end.

Whiplash Quiz

1. The range of collision speed in which most (nearly 80 percent) rear-impact whiplash injuries occur is:
   a) 10-25 mi/h (4.5 – 11 m/s or about 16-40 km/h)
   b) 15-30 mi/h (7 – 13 m/s or about 25-47 km/h)
   c) 1-5 mi/h (0.5 – 2.3 m/s or about 2-8 km/h)
   d) 6-12 mi/h (2.7 – 5.4 m/s or about 10-19 km/h)

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Active Physics

What Do You Think Now?

Revisit the *What Do You Think?* questions, and review students' initial ideas. Ask students how they would now answer these questions using Newton's first and second laws. After discussing how students would revise their answers, consider discussing *A Physicist's Response* with the class to give them a better understanding of what whiplash is and why it occurs in rear-end collisions.

Reflecting on the Section and the Challenge

Have a discussion on why the neck area is so susceptible to serious injury, and the possible severity of whiplash, using the information in the student text. Then emphasize to the class that by restraining the movement of the head and neck muscles, drivers and passengers can protect against the possible severe effects of whiplash. Ask students what evidence they have of this from their investigation and how

Physics Essential Questions

What does it mean?

A vehicle is hit from behind and accelerates forward. The force of the back of the seat of the vehicle pushes on the passenger and he or she accelerates forward.

How do you know?

Without a headrest, as the passenger accelerates forward, the passenger's head would remain where it was until the neck muscles pulled it forward. This would cause the body to move in front of the head. A headrest applies a force to the head to keep it moving with the body.

Why do you believe?

A vehicle is at rest and stays at rest until hit with a force from behind (Newton's first law).

A vehicle begins to accelerate forward due to the force (Newton's second law).

A passenger remains at rest while the vehicle accelerates (Newton's first law).

The back of the seat accelerates the passenger forward (Newton's second law).

Why should you care?

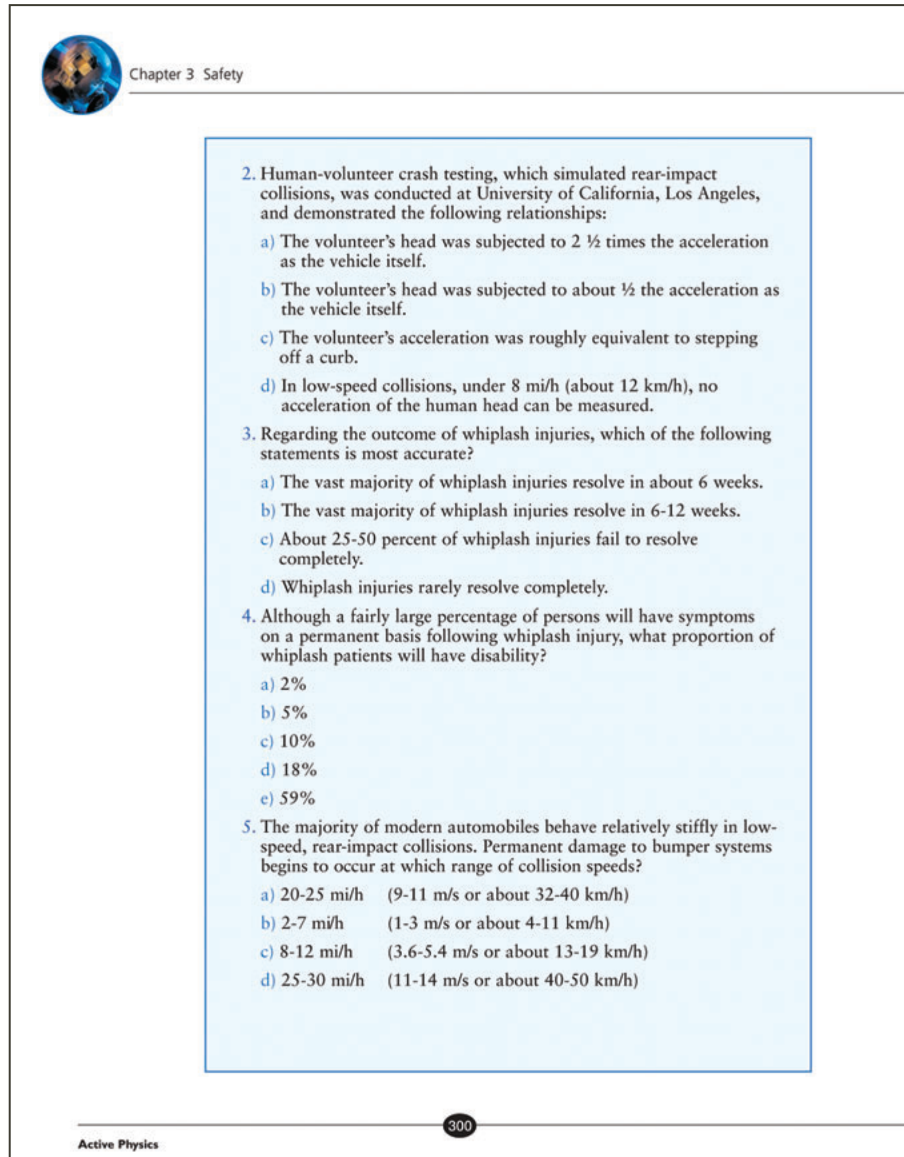
The design could include something like headrests to protect the head if the body abruptly moves forward.

Newton's first and second laws explain this. Discuss how they could use this information for the *Chapter Challenge*.

Physics to Go

1.

Responses should include a description of whiplash and how it is explained using Newton's first and second laws. For example, during a rear-end collision, the automobile gets hit from the rear. The automobile begins to move because an unbalanced force is acting on it during the collision (Newton's second law). The back of the seat pushes the driver forward and the driver's torso moves forward with the automobile because an unbalanced force is acting on the driver (Newton's second law). The driver's head is not supported and stays back where it is because at this moment, no unbalanced forces are acting on it, obeying Newton's first law. The neck muscles hold the head to the body as the body moves forward. When the muscles have been extended as far as possible, they apply an unbalanced force on the head and pull the head forward, accelerating the head (Newton's second law). The head keeps moving until it gets ahead of the torso because an object in motion stays in motion until an unbalanced force acts on it (Newton's first law). When the muscles on the other side of the neck have reached their maximum stretch, they pull the head back, accelerating it, and moving it to its usual position (Newton's second law).



Chapter 3 Safety

2. Human-volunteer crash testing, which simulated rear-impact collisions, was conducted at University of California, Los Angeles, and demonstrated the following relationships:

a) The volunteer's head was subjected to 2 ½ times the acceleration as the vehicle itself.

b) The volunteer's head was subjected to about ½ the acceleration as the vehicle itself.

c) The volunteer's acceleration was roughly equivalent to stepping off a curb.

d) In low-speed collisions, under 8 mi/h (about 12 km/h), no acceleration of the human head can be measured.

3. Regarding the outcome of whiplash injuries, which of the following statements is most accurate?

a) The vast majority of whiplash injuries resolve in about 6 weeks.

b) The vast majority of whiplash injuries resolve in 6-12 weeks.

c) About 25-50 percent of whiplash injuries fail to resolve completely.

d) Whiplash injuries rarely resolve completely.

4. Although a fairly large percentage of persons will have symptoms on a permanent basis following whiplash injury, what proportion of whiplash patients will have disability?

a) 2%

b) 5%

c) 10%

d) 18%

e) 59%

5. The majority of modern automobiles behave relatively stiffly in low-speed, rear-impact collisions. Permanent damage to bumper systems begins to occur at which range of collision speeds?

a) 20-25 mi/h (9-11 m/s or about 32-40 km/h)

b) 2-7 mi/h (1-3 m/s or about 4-11 km/h)

c) 8-12 mi/h (3.6-5.4 m/s or about 13-19 km/h)

d) 25-30 mi/h (11-14 m/s or about 40-50 km/h)

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Active Physics

2.

Explanations should use Newton's first law. For example, packages in the back of a truck move forward if the truck comes to a quick stop because an object in motion continues its motion unless an unbalanced force acts on it. The packages were moving at the same speed as the truck before the truck's brakes were applied. After the truck applied it brakes, the packages continued to move forward because the friction between the packages and the surfaces they were in contact with was not great enough to hold them in place. Remind students that this is similar to passengers moving forward when a vehicle stops abruptly, and the importance of seat belts restraining passengers so that they do not hit the vehicle parts in front of them.

6. According to the authors of one series of full-scale, rear-impact crash tests using human volunteers, the threshold for cervical spine soft tissue injury (whiplash injury) occurs at speeds of:
   a) 12 mi/h (5.4 m/s or about 19 km/h)
   b) 5 mi/h (2.3 m/s or about 8 km/h)
   c) 2 mi/h (0.9 m/s or about 3 km/h)
   d) 15 mi/h (7 m/s or about 25 km/h)

(Source: *Dynamic Chiropractic*, August 11, 1997, volume 15, issue 17)

Answers:

1. (d)
2. (a)
3. (c)
4. (e)
5. (c)
6. (b)

Inquiring Further

Crash-test dummies

Investigate crash-test dummies on the Internet. Prepare a 5-minute presentation for the class or a paper including information about how much they cost, their functions, and the variety that exist.

3.

Students should use Newton's first and second laws in their explanations. When the bus accelerates, the passengers are at rest and remain at rest until an unbalanced force acts on them from the seat bottoms pushing the passengers forward, following Newton's second law. Meanwhile, the passengers' torsos are still at rest (obeying Newton's first law) until they come in contact with the back of the seat, and the back of the seat pushes them forward (Newton's second law), or until their muscles pull them forward. So, the passengers are not really "pushed backward," rather they try to remain in the same place until they are pushed forward.

4.

Students' responses should refer to their observations of an increased mass hitting the target cart, and their graphs from the previous section in which they showed that there is a greater amount of work done to stop an object as the mass increases. This can also be explained by conservation of energy. The energy being transferred to a vehicle and a motorcycle are the same. Because the motorcycle has less mass, it will have a greater speed after the collision than if a vehicle were involved in the same collision. Because of this, it will take more work or more energy to stop the motorcycle and its driver after the collision. This also results in the damage and severity of injury being greater for the motorcycle.

5.

Students' responses should indicate that headrests are important for both front-end and rear-end collisions, however, the headrest is most important for rear-end collisions in which the vehicle moves forward as the person's head tries to remain in place. In this case, the headrest helps to absorb some of the energy from the head as it pushes into the head, and prevents the neck muscles from hyperextending because it does not allow the head to be in a position behind the back. This also reduces the amount the head whips forward, reducing the hyperflexing of the neck muscles. For a front-end collision, the passenger's body moves backward and the head stays in place. The neck muscles are hyperflexed. Usually the neck is not as hyperflexed as in a rear-end collision because the body also bends forward, reducing

CHAPTER 3

the amount of flexion in the neck muscles. The neck muscles then whip the head back into the headrest, which absorbs some of the energy and prevents the neck muscles from being hyperextended.

6.

Students should list devices besides headrests that help reduce the impact of a rear-end collision such as seat belts, air bags, and padding in seats.

7.

Students' responses should include the features they plan to use in their design that will restrain head movement during a collision.

8.

Students should record their answers for the whiplash quiz and their grade. Consider having students reflect on their responses and showing their work for any questions they answered incorrectly.

Inquiring Further

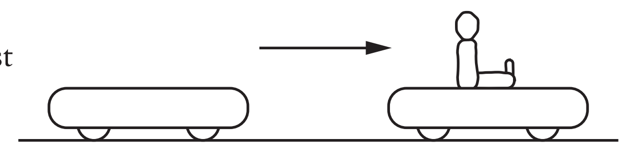
Consider having students work in groups, or individually, to prepare a five-minute presentation to the class and/or a report on crash-test dummies. As you assess students' work, check to see that students include the cost, function, and variety that exist. Encourage students to indicate which crash dummies have special sensors and where those sensors are located.

NOTES

SECTION 4 QUIZ

3-4d **Blackline Master**

1. In an experiment, a student rests a figure made of modeling clay on a lab cart at rest on a table. The student then collides a second lab cart of equal mass with the first into the stationary cart, and notices the modeling-clay figure topple over backward. The physical principle that explains why the figure tumbled over is



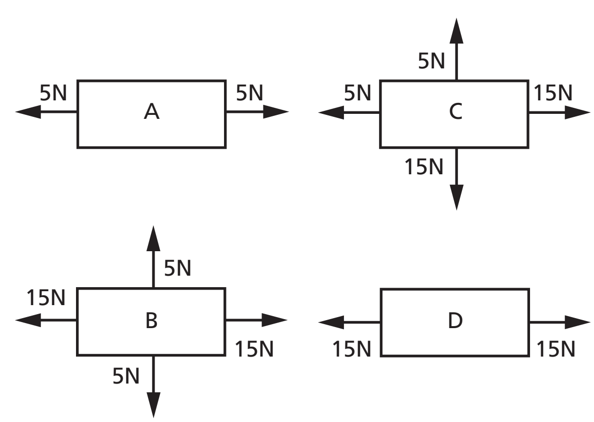
   a) Newton's first law.
   b) Newton's second law.
   c) the law of action-reaction.
   d) whiplash.

2. In the collision in *Question 1*, the modeling-clay passenger would be prevented from toppling over backward by

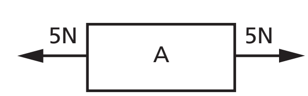
   a) using a seat belt.
   b) having an air bag in front.
   c) sitting in a chair with a head restraint.
   d) Any of the above.

3. In which of the diagrams below does the block have a net external force acting on it?

   a) A
   b) B
   c) C
   d) D



4. The diagram at right shows all the forces acting on block A. As a result, block A cannot be



   a) at rest.
   b) moving with constant speed to the right.
   c) moving at constant speed upward.
   d) accelerating.

5. A constant net force of 20 N acts on an object of mass 5 kg. As the mass of the object is increased, the acceleration of the object will

   a) decrease.
   b) increase.
   c) remain the same.
   d) increase until the mass equals the force.

SECTION 4 QUIZ ANSWERS

1. a) Newton's first law.
2. c) sitting in a chair with a head restraint.
3. c) C.
4. d) accelerating.
5. a) decrease.

NOTES

NOTES