SECTION 7

Impulse and Changes in Momentum: Crumple Zone

Section Overview

Students consider the ideas of conservation of energy and reduction of force on passengers in designing and testing a crumple zone. Using probes, they measure the force and velocity over time during a collision involving a cart fitted with different types of cushions. By analyzing the data, students find the relationship between the force exerted, the time the force acts on the object, and the change in momentum. A class discussion follows on the relationship between impulse and changes in momentum, and how work and energy or impulse and momentum can be used to analyze a collision. Examples using both approaches are presented. Students then apply the concepts of impulse and change in momentum as they create graphs to show how factors involved in collisions, such as force, change for various situations. Students apply the concepts of impulse, conservation of momentum, and the work-energy theorem to solve various problems.

Background Information

A change in momentum only occurs if a net external force acts on an object. During a collision, each object involved in the collision experiences a force from the other object. The amount of force acting on the object at any instant is given by

$$F = \frac{dp}{dt}.$$

The average force acting on the object is given by

$$F = \frac{\Delta p}{\Delta t} = m\frac{\Delta v}{\Delta t},$$

for constant mass. From this equation, one can see that the force needed to change an object's momentum increases as the time involved decreases. For example, if you wish to bring a moving object to rest, it requires more force if you bring it to rest in half a second than if you bring it to rest in one second. This equation is often rearranged and written as $F\Delta t = m\Delta v$.

The quantity $F\Delta t$ is called the impulse. When a vehicle stops and as the stopping time increases, the required force to stop the vehicle decreases. If the stopping time is quite short, as in a collision with a fixed object, the stopping force can be extremely large. For a given velocity, the change in the momentum of the vehicle is the same, regardless of whether the vehicle is stopped over a long time or a short time.

This is very important in designing safety features to protect passengers during a collision, because the goal is to reduce the force acting on the person. Previously, this was discussed using the concepts of the work-energy theorem during the secondary and tertiary collisions, when air bags were reviewed. This section focuses on interpreting the situation using the impulse and change in momentum approach, and by reducing the forces exerted on the passenger by increasing the time required to stop the vehicle, and thus reducing the energy transferred to the passenger. To do this, the vehicle is designed to crumple in order to absorb some of the energy during the collision by increasing the distance the force acts and the time of the collision. These crumple zones allow for deformation of the vehicle during the collision. From the energy approach, some of the initial energy of the vehicle is transferred to deforming the vehicle, leaving less energy to be transferred to the passenger.

Crucial Physics

- Impulse is the change in momentum of an object. An impulse is equal to the net external force acting on an object multiplied by the time that the force acts on the object. A net external force acting on an object causes a change in the object's momentum.
- Stopping an object requires changing its velocity from an initial value to zero. By increasing the amount of time an external force acts on the object, and/or the distance over which the external force acts on the object, the amount of force required to stop the object is reduced.
- For a force vs. time graph, the impulse is equal to the area under the graph, and equal to the object's change in momentum.

Learning Outcomes	Location in the Section	Evidence of Understanding
Design a device that is able to absorb the energy of a collision and reduce the net force on an object in an automobile.	***Investigate*** Part A: Steps 1-5	Students construct "crumple zones," a design feature that reduces the amount of energy and force acting on a cart so that an object in the cart does not fall out during a collision. Students measure the force and velocity of the cart over time during the collision.
Describe collisions and crumple zones in terms of momentum, impulse, and force.	***Investigate*** Part A: Step 5, Part B: Step 7 ***Physics Talk*** ***Physics Essential Questions*** ***Physics to Go*** Questions 1-3, 11	Students analyze data from the cart collisions and find a relationship between impulse and change in momentum. Students read about and participate in a class discussion on crumple zones in terms of change in momentum and impulse, and are able to distinguish this approach from the work-energy approach.
Apply the concept of impulse in the analysis of collisions.	***Physics to Go*** Questions 8-9, 11	Students should apply the concepts discussed in the *Physics Talk* to analyze automobile collisions.
Use a computer's motion probe (sonic ranger) to determine the velocity of moving vehicles.	***Investigate*** Part B: Steps 2-5	Students use a sonic ranger and a computer to measure and graph the velocity of a cart during a collision.
Use a computer's force probe to determine the force exerted during a collision.	***Investigate*** Part B: Steps 2-5	Students use a force probe and a computer to measure and graph the force of a cart during a collision
Compare the change of momentum of a model vehicle before a collision with the impulse applied during a collision.	***Investigate*** Part B: Step 7	Students analyze data and find the relationship between impulse and momentum.
Explore ways of using cushions to increase the time that a force acts during a primary collision.	***Investigate*** Part B: Steps 5-7	Students measure how using different cushions attached to the outside of a cart affect the force and velocity of a cart during a collision.

Section 7 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Dynamics cart	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	
Ruler, metric, in/cm	1 per group	
Meter sticks	1 per group	
AC Ticker tape timer	1 per group	
Wood piece, 1 in. x 2 in. x 2 in.	1 per group	
Self-adhesive Velcro dot (part of variety of cushioning material set)	1 per group	
Cork/cardboard piece, 1/2 in. x 1 in. (part of variety of cushioning material set)	6 per group	
Double-sided tape (to adhere pieces, part of variety of cushioning material set)		
File folders	3 per group	
Tape, masking		6 per group
Ball of string		1 per class
Rubber bands, #64, pack		1 per class
Unlined index card, 3 in. x 5 in., pkg 100		1 per class
Graph paper, pkg of 50		1 per class
Access to a smooth level surface*	1 per group	
Motion detection probeware*		1 per class
MBL or CBL technology to record probeware activity*		1 per class
Stack of books*	1 per group	
Force probeware*		1 per class
Wood block, 4 cm x 4 cm x 3 cm*	1 per group	

*Additional items needed not supplied

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Dynamics cart		1 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 group	
Ruler, metric, in/cm	1 per group	
Meter sticks		1 per class
Wood piece, 1 in. x 2 in. x 2 in.	1 per group	
Self-adhesive Velcro dot (part of variety of cushioning material set)		6 per class
Cork/cardboard piece, 1/2 in. x 1 in. (part of variety of cushioning material set)		6 per class
Double-sided tape (to adhere pieces, part of variety of cushioning material set)		6 per class
File folders	3 per group	
Tape, masking		6 per group
Ball of string		1 per class
Rubber bands, #64, pack		1 per class
Unlined index card, 3 in. x 5 in., pkg 100		1 per class
Graph paper, pkg of 50		1 per class
Access to a smooth level surface*	1 per group	
Motion detection probeware*		1 per class
MBL or CBL technology to record probeware activity*		1 per class
Stack of books*	1 per group	
Force probeware*		1 per class
Wood block, 4 cm x 4 cm x 3 cm*	1 per group	

*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

At least two periods are required to give students time to design and test their crumple-zone designs.

Teacher Preparation

- Consider having students bring in materials to use as cushions for the second part of *Investigate*. Make sure cushion materials that you have tested to compare results are also supplied. Conduct the investigation before class to determine where your students may have difficulties. Decide if you wish to stop students at any step to have a class discussion on the procedure.
- If your materials are limited, use a large-screen monitor or LCD projector to display the data to the class. Prepare a kit for each team consisting of a toy cart and a different cushioning material. Each team can prepare one cart and run it as a demonstration station.
- Try a few sample runs in advance to make sure that the results fall within limits of the available probes. Adjust the height of the ramp accordingly. Demonstrate the operation of the sensors and the software to the class if necessary. Providing materials produces a certain regularity and predictability to the investigation. You may want to present this investigation as a challenge a day in advance. The students are sure to bring some unusual cushioning materials from home.
- When the dynamics carts leave the ramp and travel onto the horizontal surface, a transition surface such as a manila file folder taped to the ramp and the floor or table will smooth the transition.
- A ramp that has a lower incline works better when placing the motion detector at the top of the ramp.
- Place the force probe near the bottom of the ramp so the motion detector will be able to read the velocity up to the point of collision.
- Clear the area being used of all extraneous equipment so the motion detector has a clear image of the moving cart.

Safety Requirements

- Caution the students to keep the collision speeds low to protect the equipment.
- In all collision experiments, goggles are of extra importance.
- Students should wear closed-toe shoes.
- Caution students to keep the cart velocities low to prevent damage to the carts or the force probe.

NOTES

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Copying graphs accurately	***Investigate*** Part B: Steps 4-6	**Augmentation** • It is important that students copy the graphs accurately for comparison. Since students are copying both velocity vs. time and force vs. time graphs, remind students to label the axes carefully. • Model an example of the level of accuracy required to create a graph well enough to use for comparison. • Provide graph paper for students to draw their graphs and then tape into their logs. **Accommodation** • Allow students to print the graphs created by the computer probe programs and tape them into their logs.
Comparing graphs	***Investigate*** Part B: Step 7 ***Physics to Go*** Question 10	**Augmentation** • Some students need help comparing the force vs. time graphs because they do not notice the details that differentiate graphs. Show students a few different graphs and ask them to brainstorm a list of the important details shown by the graphs. The list should include general shape of the graph, slope, axis scales, units, area under the graph, and so on. Ask students to highlight differences on the graph. **Accommodation** • Provide copies of the graphs with differences already highlighted.
Summarizing information in a chart	***Investigate*** Part B: Step 7.d)	**Augmentation** • Summarizing information is a challenge for students who struggle to differentiate the importance of details. • Ask students what information should be included in the summarizing chart. After a list is compiled, ask students if the organization or order of the information is important. For example, since mass and velocity are used to calculate momentum, it would make sense for those values to be included next to each other. It may also be helpful for impulse and change in momentum to be next to each other for comparison.
Using equations and calculations to understand a concept	***Physics Talk***	**Augmentation** • Some students struggle to conceptualize the values that numbers represent and may not be able to independently make sense of these series of calculations. Use this opportunity to review how to calculate changes in velocity, acceleration, force, and momentum. • Model each calculation step-by-step or ask pairs of students to explain the calculations to each other. • Ask students why some of the calculations yield negative values. Explicitly make the connection that vector quantities can be represented with negative numbers because of direction. • Make analogies or provide examples so students can understand what the calculated values represent. How much force is –3000 N? How fast is –15 m/s?

Learning Issue	Reference	Augmentation and Accommodations
Being too literal	***Physics Talk***	**Augmentation** • Students who are very literal thinkers may misunderstand the “small force exerted over a long time” statement. A long time may be several minutes or even hours for some students. Ask students how much time it took for their carts to come to a stop in the *Investigate*. Then ask students how long “a long time” is when comparing crumple zones. **Accommodation** • Some students may need a very concrete example to conceptualize lengths of time. Play music for one second, 10 seconds, 30 seconds, a minute, etc. Then ask students which trial seemed most reasonable in relation to their carts coming to a stop.
Learning essential concepts using equations	***Physics Talk***	**Augmentation** • Direct and inverse relationships help students understand concepts, but the struggle with manipulating fractions often gets in the way of student understanding. For the *Newton's second law explanation* and the *Momentum/impulse explanation*, substitute values in place of the variables to make the relationship more concrete. For example, show students what happens to acceleration if Δt is 10 s, 20 s, or 100 s.

NOTES

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Vocabulary	***What Do You Think?***	To help students understand the word "crumple," crumple a piece of paper in your hands.
Following complex procedures	***Investigate***	Break down the *Investigate* into smaller chunks that allow students to comprehend each portion of the investigation before moving on to the next one. This approach will allow students to get acquainted with the apparatus, get comfortable following the procedures outlined within each step, and to internalize new concepts that are introduced. Lead a brief class discussion after each step to allow students the opportunity to demonstrate acquired knowledge and understanding.
Following directions Vocabulary comprehension	***Investigate*** Part A: Step 2 Part B: Steps 1.a), 2, 4.b), 5	To properly follow each direction, ELL students may need help with some of the vocabulary, such as "disturbing," "detector," "barrier," "transparency," and "coasting."
Understanding concepts	***Investigate*** Part B: Step 3	Hold a class discussion to determine what your students know about sound waves and reflection. Give them a brief tutorial on how a sonic ranger works, geared toward their level of understanding.
Understanding concepts Vocabulary comprehension	***Physics Talk***	When students encounter the term "impulse," be sure they understand that it means a change in momentum. Also, help them grasp that the two factors that affect impulse—force and time—are inversely proportional. For the same collision, a small force exerted over a long time produces the same change in momentum (the same impulse) as a large force exerted over a short time.
Comprehension	***Physics Talk*** ***Active Physics Plus***	Students may benefit from an oral representation of tables and graphs. When students look at the graphs, ask them which graph represents the collision that likely would have caused less injury. Make sure students correctly interpret the labels on the graph axes before proceeding. Be sure they correctly identify the graph showing less force over a longer time, and allow students time to discuss reasons for their choices.
Vocabulary comprehension	***Reflecting on the Section and the Challenge***	Students need to know that they must give a rationale for the design decisions they have made when they have completed and are demonstrating their safety devices. That is, they need to provide reasons for going with the design they chose, and the reasons must be based on sound physics principles.
Applying concepts	***Physics to Go*** Step 4	Hold a class discussion to address this question. Students should be able to deduce that bending your knees when landing from a jump increases the time during which the landing force is applied, thereby reducing the amount of force on your legs.

NOTES

SECTION 7

Teaching Suggestions and Sample Answers

What Do You See?

Have students describe the illustration in the student text. Discuss how students think the illustration connects to the title of the section and the *Learning Outcomes*. Ask them what in the illustration might be a device capable of absorbing the energy of a collision or reducing the net force of the collision, or where such a device could be. Consider using an overhead of the illustration as a focal point for the discussion.

What Do You Think?

Describe to the class what a crumple zone is using the information in the student text. Ask what part of the vehicle in the image they think is the crumple zone and why. Ask students to record in their logs their responses to the *What Do You Think?* question. Have a class discussion on students' ideas. Record misconceptions and make sure they are addressed at appropriate times during the section. Focus on the responses that provide a chance for you to get the class engaged in a discussion of reducing the energy transferred to the passengers, and reducing the force acting on the passengers.

Investigate

If you decide to guide students through some of the steps during the *Investigate*, let them know at which step they should stop. Otherwise, have a discussion on the *Investigate* steps, and let them begin and complete the *Investigate*. Let them know what guidelines they should follow for time, space, and materials. Demonstrate how to use the force and velocity probes before Part B.

What Do You Think?

A Physicist's Response

Crumple zones are very important because they reduce the amount of energy transferred to passengers in a vehicle during a collision, and the amount of force acting on the passengers during the collision. It is important to realize that crumple zones must follow conservation of momentum and conservation of energy. The momentum change of the vehicle for a given speed is the same, as is the change in kinetic energy. By increasing the time of the collision and the distance over which the collision occurs, one can reduce the amount of force needed to stop the vehicle. This also reduces the amount of force that acts on the passenger. From the energy approach, energy is needed to deform an object, and if the object is permanently deformed, that energy cannot be retrieved and transferred to the passenger. Energy is also transformed into heat energy when deformation occurs. Because of this, it is important to design crumple zones that will permanently deform and will absorb the energy of the collision. Very rigid objects and very elastic objects do not do this well.

Crumple zones are built not only on vehicles but also around areas where collisions are likely to occur or where collisions could cause other danger. Examples include canisters of sand near roadwork or bridge supports, and railings along bridges.

Students' Prior Conceptions

This section is all about making connections and refining the engineering model to protect the egg in the cart for the *Chapter Challenge*. Placing a visual that emphasizes the two elements of impulse, force and change in time, as large and/or small icons, is a simple anchoring activity for student understanding. Following this with a second visual that connects impulse to change in momentum reinforces the *Physics Talk*: "You can get an identical change in momentum with a large force over a short time or a small force over a longer time." A welcome strategy for students is to encourage them to make a small 'comic' poster to illustrate the connection shown at the right:

$$\text{Impulse} = \mathbf{F} \times \Delta t \qquad \text{Impulse = change in momentum}$$

$$\mathbf{F} \times \Delta t = m \times \Delta v$$

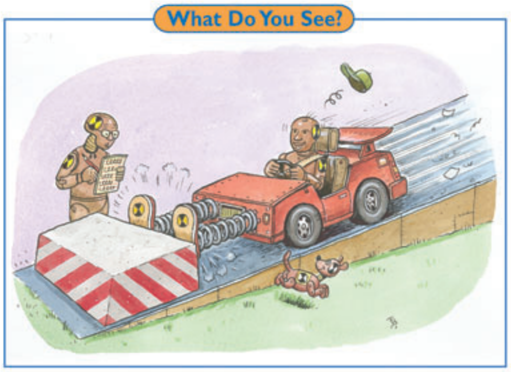
or,

$$\text{Impulse} = F \times \mathbf{\Delta t} \qquad \text{Impulse = change in momentum}$$

$$F \times \mathbf{\Delta t} = m \times \Delta v$$

Section 7 Impulse and Changes in Momentum: Crumple Zone

What Do You See?



Learning Outcomes

In this section, you will

- **Design** a device that is able to absorb the energy of a collision and reduce the net force on an object in an automobile.
- **Describe** collisions and crumple zones in terms of momentum, impulse, and force.
- **Apply** the concept of impulse in the analysis of collisions.
- **Use** a computer's motion probe (sonic ranger) to determine the velocity of moving vehicles.
- **Use** a computer's force probe to determine the force exerted during a collision.
- **Compare** the change of momentum of a model vehicle before a collision with the impulse applied during a collision.
- **Explore** ways of using cushions to increase the time that a force acts during a primary collision.

What Do You Think?

When an automobile collides with a wall and is brought to a stop, all of the energy of motion that the automobile had has to go somewhere. Also, a force must act to stop the automobile, and any passengers inside. Automotive engineers design something called a crumple zone to absorb the energy of the collision and to lessen the force on the passengers. (*A crumple zone is part of the body of an automobile that compresses during an impact.*)

- What are some of the factors that automobile designers and engineers must consider when designing a crumple zone as a safety feature?

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

Teaching Tip

If you decide to do Part B of this *Investigate* as a class demonstration, be sure to have the students still do Part A. Otherwise, the students may not grasp that allowing the front of the cart to crumple will decrease the force exerted, and this will allow them to test several designs.

Part A: Designing a Crumple Zone

Teaching Tip

Some students may choose to use all of the material available for the crumple zone, and others only part of the material. Let them determine and test their own designs, but put a time limit on the investigation.

1.

Students should work in groups. Allow students to design their crumple zones in whatever manner they choose and allow them to test their design and change it using the *Engineering Design Cycle*.

2.–3.

Students test and revise their designs as necessary. Check that students are following the guidelines.

1. **Collision severity is the same for both automobiles involved in a head-on collision.** Measurement of impulse and momentum to identify the forces involved in the collision and attesting to the equal and opposite nature of those forces serves as a tool for students to organize their knowledge of crumple zones. They learn to assess the severity of the collision by considering the time through which the force acts. Crumple zones allow for more time for the stopping force to act. This observation expands students' conception of work when they associate the force of impact with the distance over which that force is applied. The work done has a consistent value but the change in distance reduces the impact of the force. Energy lost equals work done, and work is force applied multiplied by the distance over which the force is applied.
2. **Students do not recognize the importance of the time factor involved with the concept of impulse.** As students model the work required to stop an object, they become more aware of the change in distance required to stop an object and the time required for the force to act over this distance. This triggers the association with time being critical in the design of safety restraints, and how it relates to the change in the motion and the momentum of the object. As impulse is mathematically related to the change in motion, students will reason about the time required to stop more correctly.

CHAPTER 3

4.

Students should describe why the tape does not keep the block on the cart in terms of Newton's laws. The tape does not apply a net force acting against the direction of motion of the block to stop its motion. Rather, the tape applies a force toward the pivot point on the block when the block tries to continue its forward motion (due to Newton's first law), causing the block to tip forward. If the tape breaks free, the block will continue its motion until a force acts on it.

5.

Students should demonstrate their designs and record their thinking and data.

Before beginning Part B, demonstrate how to open the software and use the probes.

Part B: Cushioning Collisions (Computer Analysis)

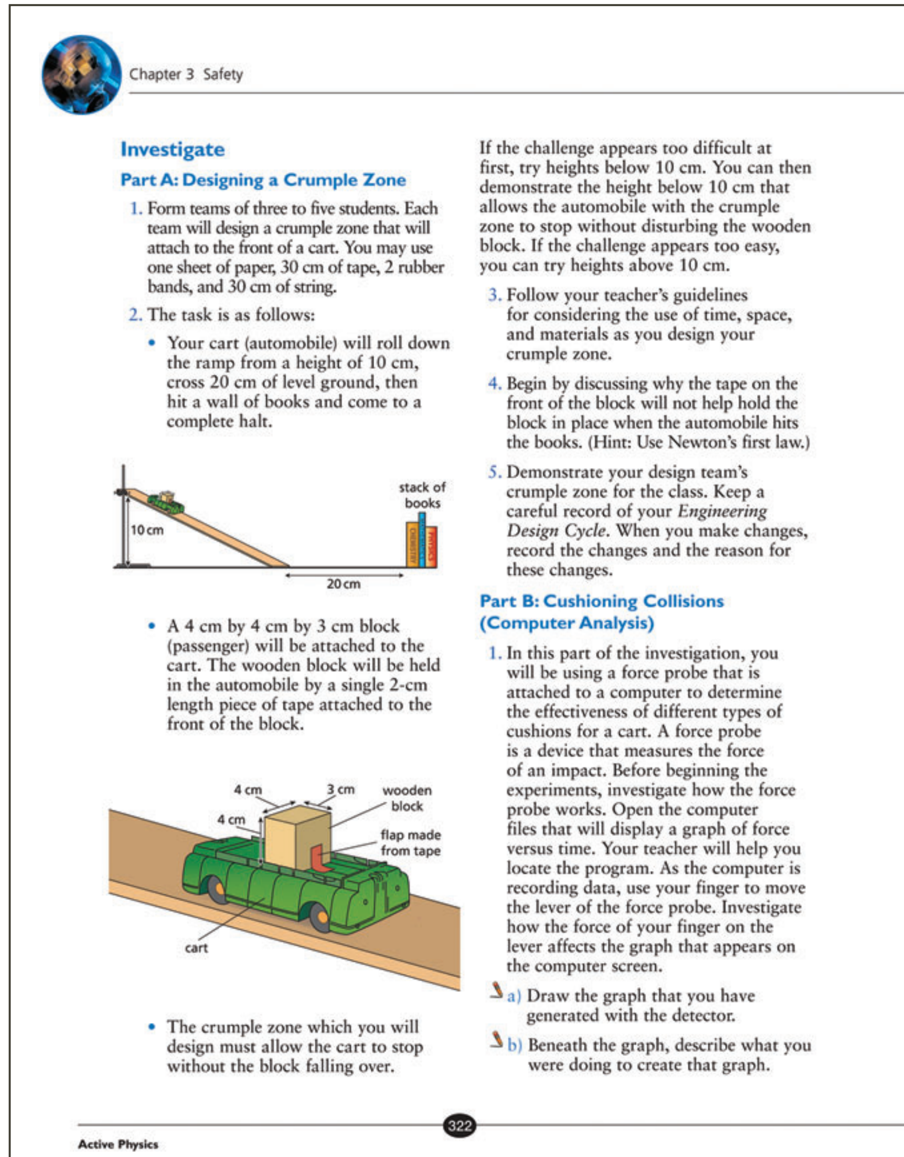
> **Teaching Tip**
>
> You may choose to do Part B as a demonstration due to time or equipment considerations. If you do, demonstrate to the students how the apparatus works prior to testing the various cushioning materials. You can also choose one of the class's crumple designs to compare to other cushioning material.

1.a)

Students should sketch the force vs. time graph that is produced by pushing back and forth gently on the force probe.

1.b)

Students should record their actions that made the force vs. time graph. They should note particularly whether pushing on the probe gave a positive or negative reading.



Chapter 3 Safety

Investigate

Part A: Designing a Crumple Zone

1. Form teams of three to five students. Each team will design a crumple zone that will attach to the front of a cart. You may use one sheet of paper, 30 cm of tape, 2 rubber bands, and 30 cm of string.
2. The task is as follows:
   - Your cart (automobile) will roll down the ramp from a height of 10 cm, cross 20 cm of level ground, then hit a wall of books and come to a complete halt.

   - A 4 cm by 4 cm by 3 cm block (passenger) will be attached to the cart. The wooden block will be held in the automobile by a single 2-cm length piece of tape attached to the front of the block.

   - The crumple zone which you will design must allow the cart to stop without the block falling over.

If the challenge appears too difficult at first, try heights below 10 cm. You can then demonstrate the height below 10 cm that allows the automobile with the crumple zone to stop without disturbing the wooden block. If the challenge appears too easy, you can try heights above 10 cm.

3. Follow your teacher's guidelines for considering the use of time, space, and materials as you design your crumple zone.
4. Begin by discussing why the tape on the front of the block will not help hold the block in place when the automobile hits the books. (Hint: Use Newton's first law.)
5. Demonstrate your design team's crumple zone for the class. Keep a careful record of your *Engineering Design Cycle*. When you make changes, record the changes and the reason for these changes.

Part B: Cushioning Collisions (Computer Analysis)

1. In this part of the investigation, you will be using a force probe that is attached to a computer to determine the effectiveness of different types of cushions for a cart. A force probe is a device that measures the force of an impact. Before beginning the experiments, investigate how the force probe works. Open the computer files that will display a graph of force versus time. Your teacher will help you locate the program. As the computer is recording data, use your finger to move the lever of the force probe. Investigate how the force of your finger on the lever affects the graph that appears on the computer screen.
   a) Draw the graph that you have generated with the detector.
   b) Beneath the graph, describe what you were doing to create that graph.

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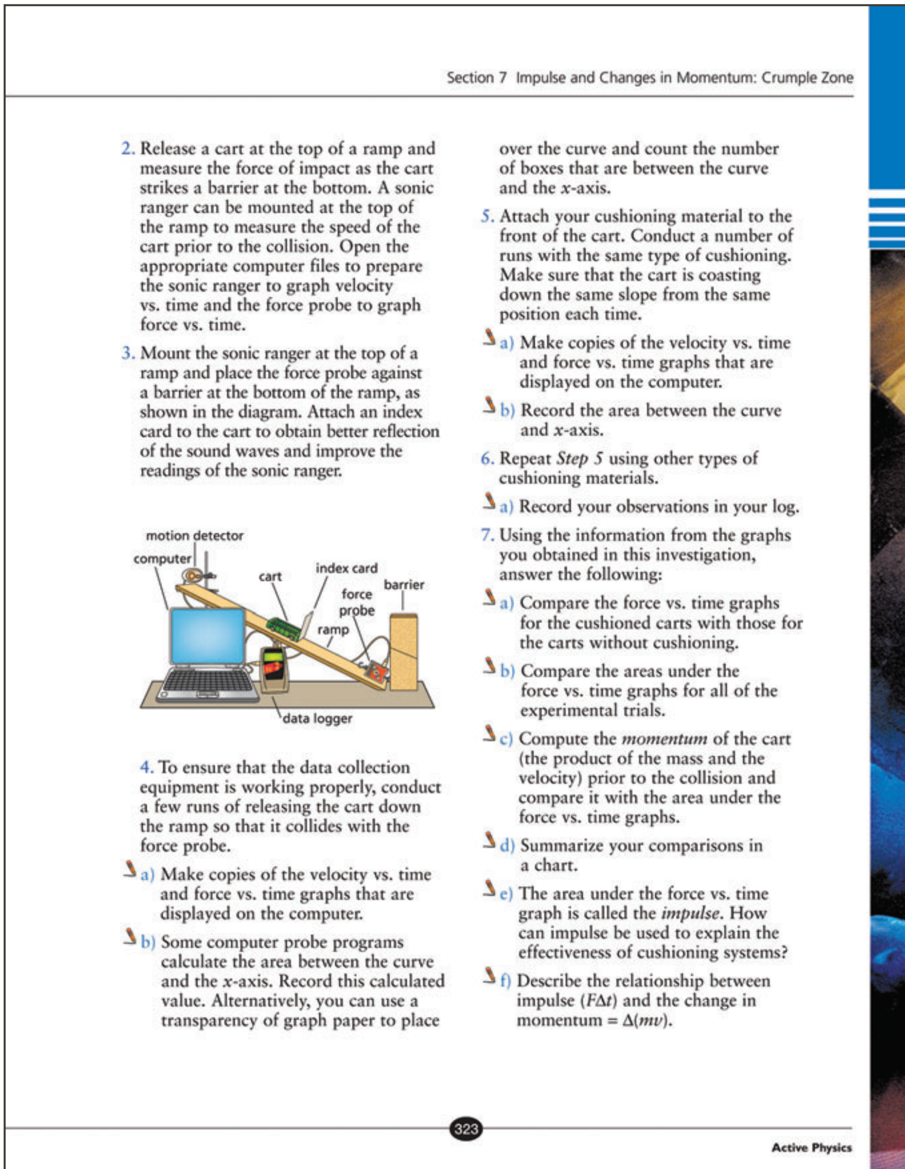
> **Teaching Tip**
>
> If a force probe is not available, a substitute setup can be constructed as follows. In place of the force probe, fill a paper tube, such as that from a roll of paper towels or toilet paper with modeling clay. Insert a sharpened pencil about 1 in. deep into the clay along the axis of the tube. When the cart comes down the ramp, the tube should be aligned so that the center of the cart strikes the end of the pencil perpendicularly, pushing the pencil into the clay. How far the pencil pierces the clay is a measure of the force exerted. After each trial, repair the clay in the tube, and place the pencil back into the tube at the 1-in. depth. Of course, this does not allow you to show that the area under a force vs. time graph equals the change in momentum, but it does give a relative measure of the force. If you assume depth of travel is also proportional to the time required to stop the cart, approximate results may be obtained for $F\Delta t = m\Delta v$. Numerous demonstrations illustrating the change in momentum relationship can be found online.



2. Release a cart at the top of a ramp and measure the force of impact as the cart strikes a barrier at the bottom. A sonic ranger can be mounted at the top of the ramp to measure the speed of the cart prior to the collision. Open the appropriate computer files to prepare the sonic ranger to graph velocity vs. time and the force probe to graph force vs. time.

3. Mount the sonic ranger at the top of a ramp and place the force probe against a barrier at the bottom of the ramp, as shown in the diagram. Attach an index card to the cart to obtain better reflection of the sound waves and improve the readings of the sonic ranger.

motion detector
computer
cart
index card
force probe
barrier
ramp
data logger

4. To ensure that the data collection equipment is working properly, conduct a few runs of releasing the cart down the ramp so that it collides with the force probe.

a) Make copies of the velocity vs. time and force vs. time graphs that are displayed on the computer.

b) Some computer probe programs calculate the area between the curve and the x-axis. Record this calculated value. Alternatively, you can use a transparency of graph paper to place over the curve and count the number of boxes that are between the curve and the x-axis.

5. Attach your cushioning material to the front of the cart. Conduct a number of runs with the same type of cushioning. Make sure that the cart is coasting down the same slope from the same position each time.

a) Make copies of the velocity vs. time and force vs. time graphs that are displayed on the computer.

b) Record the area between the curve and x-axis.

6. Repeat *Step 5* using other types of cushioning materials.

a) Record your observations in your log.

7. Using the information from the graphs you obtained in this investigation, answer the following:

a) Compare the force vs. time graphs for the cushioned carts with those for the carts without cushioning.

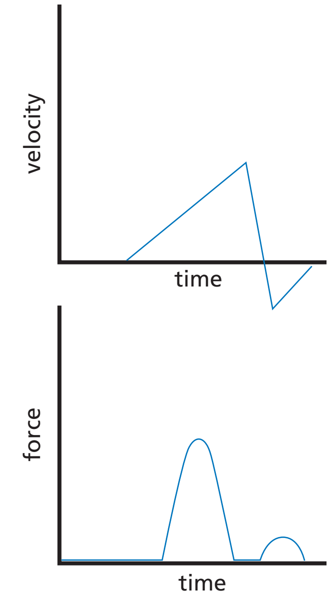
b) Compare the areas under the force vs. time graphs for all of the experimental trials.

c) Compute the ***momentum*** of the cart (the product of the mass and the velocity) prior to the collision and compare it with the area under the force vs. time graphs.

d) Summarize your comparisons in a chart.

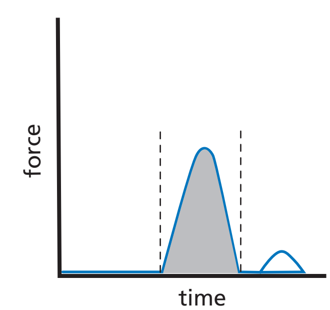
e) The area under the force vs. time graph is called the ***impulse***. How can impulse be used to explain the effectiveness of cushioning systems?

f) Describe the relationship between impulse ($F\Delta t$) and the change in momentum = $\Delta(mv)$.



4.b)

Students compute the area under the curve and record the value for the force vs. time graph. Force vs. time graphs with the area under the graph computed should appear similar to the graph shown below.



2.

Students set up equipment and computer files.

3.

Check that students have adjusted the equipment to obtain good signals with the sonic ranger.

4.

The students should take several trials before actually testing their crumple zones to ensure the computer-generated graphs are reasonable (see the following sample graphs). Good velocity vs. time and force vs. time graphs are shown.

4.a)

Students should make copies of the velocity vs. time and the force vs. time graphs.

3-7a Blackline Master

5.a)

Students take data on force vs. time and velocity vs. time. If the cushioning material is working well, the force vs. time graph should be stretched out in the horizontal direction (the time axis) with a lower maximum value for the force. The velocity vs. time graph should have a lower slope indicating a smaller

CHAPTER 3

negative acceleration.

5.b)

Students record the area under the force vs. time graph as shown in *4.b)*. The area under the curve should remain approximately the same if the carts strike the probe with the same speed and come to rest without rebound.

6.a)

Have students try several other types of cushion materials and record values and graphs for these other types of cushion material.

7.a)

Students' data will vary. Students should observe that the force is greater on the collision without cushioning.

7.b)

Students should describe the similarities and differences between the areas under the force vs. time graphs for all the graphs. If the speeds before the collisions are the same, then the areas under the graphs are the same.

7.c)

The mass multiplied by the velocity just before the collision is roughly equal to the area under the force vs. time graphs. The relevant velocity is the velocity at impact, which should be the highest value recorded by the sonic ranger. The area under the graph should equal the change in momentum of the cart because the final momentum is zero. Student answers may vary due to calculation and measurement errors.

7.d)

Students summarize and record their comparisons.

7.e)

The impulse is equal to the change in momentum, and is therefore, related to the mass and the velocity of the cart. Depending on the cushioning, there will be an increase in the time, with the impulse remaining constant; thus, the force acting on the cart and individuals inside will be less.

7.f)

Students' responses should indicate that impulse equals the change in momentum.

NOTES

NOTES

Physics Talk

This *Physics Talk* discusses how force, time, and the change in momentum are related. There is also a discussion on the two approaches used to explain a collision, which are the work and energy approach, and the impulse and momentum approach. Check students' understanding on the factors that play a role in collisions and safety devices.

Have a discussion on how the work-energy theorem applies to students' crumple zones using the information in the student text. Remind the class that the physics is the same as that used when describing air bags. Discuss how the amount of time in which a collision occurs affects the amount of force involved in changing the colliding objects' combined momentum, and how the impulse is equal to the change in momentum.

Go through the derivation in the student text of calculating the force if the change in momentum is known. Discuss how this connects with Newton's second law and show students how the change in momentum over time is equal to the force acting on the object. Let students know that the change in momentum is called the impulse and that it is equal to the force acting on the object multiplied by the time the force acts on the object.

Make connections with students' observations in the *Investigate* and with everyday experiences, such as falling on concrete versus grass, or falling on the floor versus falling on a trampoline or bed. Emphasize that as the time to change the momentum decreases, the force increases. Ask students to provide examples.

As the example of the 50-kg mass is discussed with the class, point out how the force required to stop the object changes as the time of the collision changes. Emphasize that the change in momentum is always equal to the impulse. Describe how the type of surface the object collides with changes the collision time, making connections to the example of the grass and concrete, as well as students' observations from the *Investigate*.

Discuss how crumple zones reduce the force acting on a passenger and the energy transferred to the passenger. Emphasize to students that they can use the work and energy approach (increase the distance over which the force acts) or

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Chapter 3 Safety

Physics Talk

FORCES AFFECTING COLLISIONS

By examining the different crumple zones designed by other teams in your class, you can get an insight into the physics of collisions. Probably no team just used the flat sheet of paper. Most teams tried to fold the paper in specific ways. It seemed the goal was to have a "softer" collision rather than have the cart hit the wall without any crumple zone.

By trying to make a "softer" collision, you may have used the physics of work and change in kinetic energy.

$$W = F \cdot d = \Delta KE$$

In this case, as in the air bag, you wanted to decrease the force by increasing the distance to stop the automobile. The work done on the cart then reduced the kinetic energy of the cart.

Impulse and Changes in Momentum

There is an equivalent way of describing the physics of a collision. Rather than focusing on the distance that the force acts, you can look at the amount of time that the force acts. By maximizing the time, you can minimize the force. When creating the crumple zone, you increased the time and thereby minimized the force.

It takes an unbalanced, opposing force to stop a moving automobile. Newton's second law of motion, $F = ma$, lets you find out how much force is required to stop any automobile of any mass with a corresponding *acceleration* (or change in speed with respect to time). For example, if a 1000-kg automobile accelerates at $-2\ \text{m/s}^2$, then the force required is

$$F = ma = (1000\ \text{kg})(-2\ \text{m/s}^2) = -2000\ \text{N}$$

Notice that the acceleration is negative because the automobile's **velocity** decreased. Also, notice that the force is negative to indicate that it produces a negative acceleration as it slows the automobile down to a stop.

The overall idea can be shown using a concept map seen at the top of the next page.

Physics Words

velocity: speed in a given direction; displacement divided by the time interval; velocity is a vector quantity; it has magnitude and direction.

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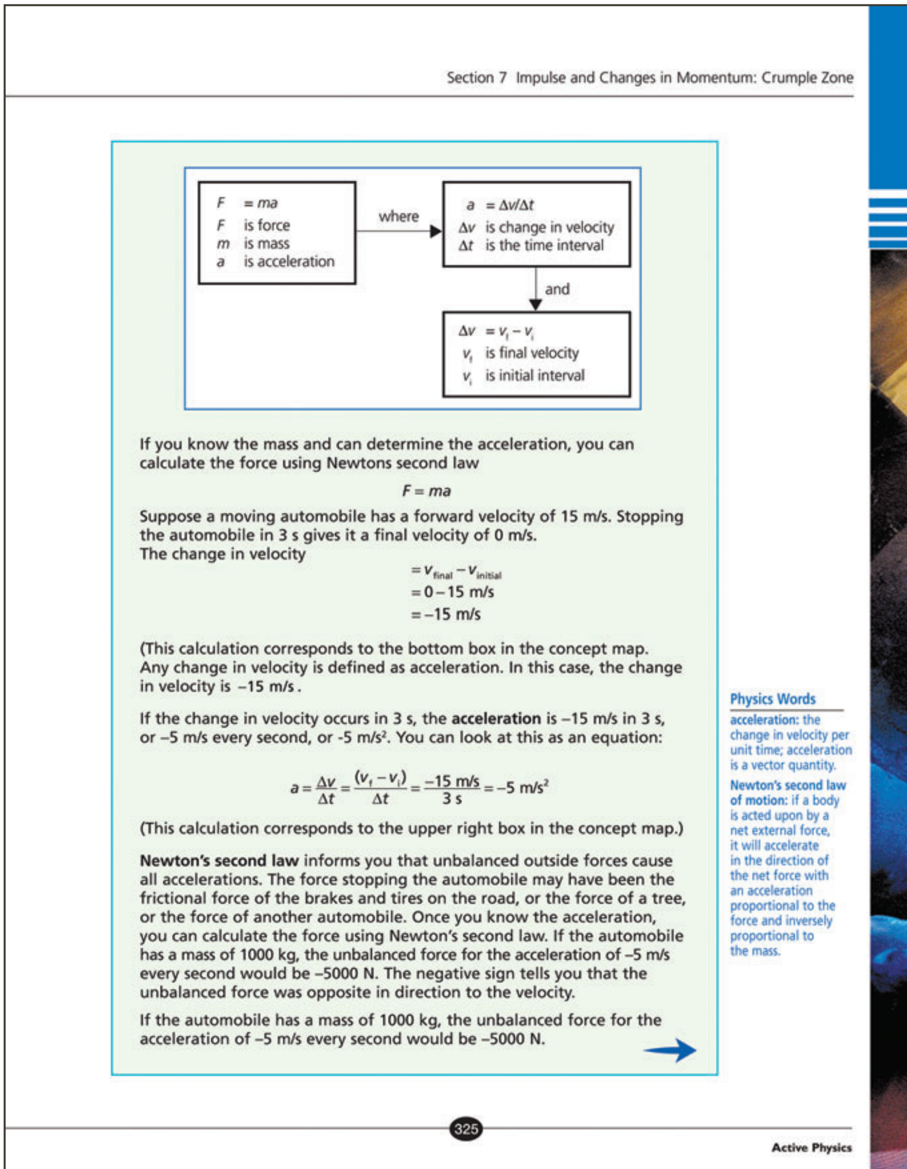
Active Physics


Section 7 Impulse and Changes in Momentum: Crumple Zone

$F = ma$
F is force
m is mass
a is acceleration

where

$a = \Delta v / \Delta t$
Δv is change in velocity
Δt is the time interval

and

$\Delta v = v_f - v_i$
v_f is final velocity
v_i is initial interval

If you know the mass and can determine the acceleration, you can calculate the force using Newtons second law

$$F = ma$$

Suppose a moving automobile has a forward velocity of 15 m/s. Stopping the automobile in 3 s gives it a final velocity of 0 m/s.
The change in velocity

$$= v_{final} - v_{initial}$$
$$= 0 - 15 \text{ m/s}$$
$$= -15 \text{ m/s}$$

(This calculation corresponds to the bottom box in the concept map. Any change in velocity is defined as acceleration. In this case, the change in velocity is –15 m/s.

If the change in velocity occurs in 3 s, the **acceleration** is –15 m/s in 3 s, or –5 m/s every second, or -5 m/s². You can look at this as an equation:

$$a = \frac{\Delta v}{\Delta t} = \frac{(v_f - v_i)}{\Delta t} = \frac{-15 \text{ m/s}}{3 \text{ s}} = -5 \text{ m/s}^2$$

(This calculation corresponds to the upper right box in the concept map.)

Newton's second law informs you that unbalanced outside forces cause all accelerations. The force stopping the automobile may have been the frictional force of the brakes and tires on the road, or the force of a tree, or the force of another automobile. Once you know the acceleration, you can calculate the force using Newton's second law. If the automobile has a mass of 1000 kg, the unbalanced force for the acceleration of –5 m/s every second would be –5000 N. The negative sign tells you that the unbalanced force was opposite in direction to the velocity.

If the automobile has a mass of 1000 kg, the unbalanced force for the acceleration of –5 m/s every second would be –5000 N.

Physics Words

acceleration: the change in velocity per unit time; acceleration is a vector quantity.

Newton's second law of motion: if a body is acted upon by a net external force, it will accelerate in the direction of the net force with an acceleration proportional to the force and inversely proportional to the mass.

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Active Physics

the impulse and momentum approach (increase the time during which the force acts) when analyzing and discussing collisions. In physics, there are two fundamental approaches to describing phenomena: the force approach and the energy approach. The force approach is dependent on direction, however, the energy approach is not.

Discuss how crumple zones reduce the force acting on a passenger and the energy transferred to the passenger, but no matter what the change in momentum of the vehicle is, the total momentum is always conserved. Ask students to describe how it can be that a cart can change its momentum and yet the total momentum is conserved.

3-7b Blackline Master

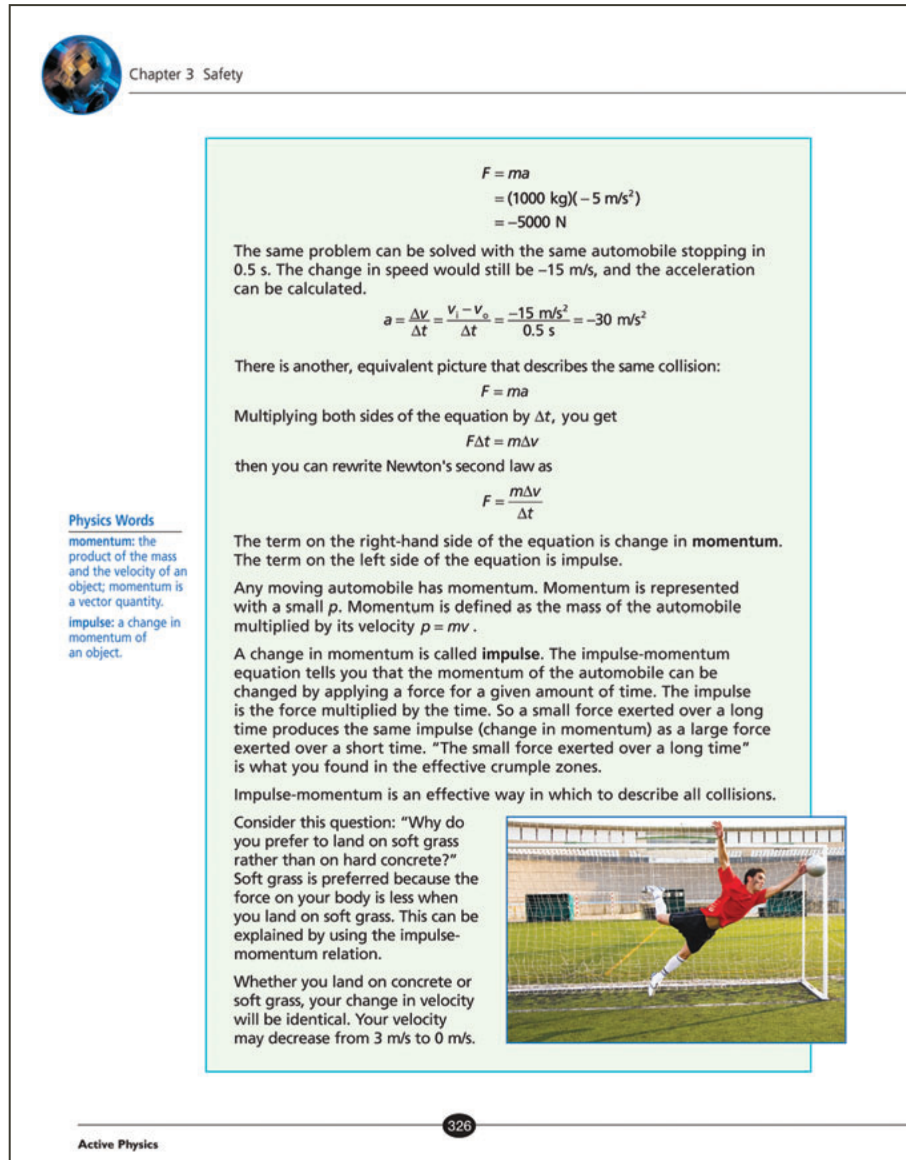
Sometimes students have difficulty remembering that momentum is a vector quantity. Ask students if momentum is conserved when two objects of equal mass move toward each other with equal speeds, collide, and come to rest. In this case, both objects initially had momentum and finally do not. Emphasize that the total momentum of the two objects before the collision is equal to the total momentum after the collision. It is zero before and zero after, and it is extremely important to consider the direction when they add together the momentums of each individual cart.

Then ask students to describe what happens when two carts of the same mass are connected together with a compressed spring between them. They are at rest initially, and then they are released from each other. Note that this collision is sometimes called an explosion. Students should describe both carts initially having no momentum, and finally, each cart has momentum, but the total momentum is zero initially and finally.

CHAPTER 3

Return to the collision with a cushion and ask students to describe what happens to the momentum during the collision with the cushion, and how the momentum can be conserved in the collision but changed by a cushion. Ask students to describe what happens to the momentum of the cushion and the energy transferred to it; the momentum of the cart and the energy transferred to it; and the momentum of the force probe and the energy transferred to it. Then, describe what occurs as the cart with the cushion collides with the force probe, using the information in the student text.

Remind students that another approach is the work energy approach, and that the change in kinetic energy of the carts for both cushions was the same. This means that the work done on the cart was the same for the hard cushion and the soft cushion. The forces and distances over which they acted were different, but the work done was the same. Review and summarize how the change of momentum equals the impulse. Review and summarize how the change of kinetic energy equals the work.


Chapter 3 Safety

$$F = ma$$
$$= (1000\ \text{kg})(-5\ \text{m/s}^2)$$
$$= -5000\ \text{N}$$

The same problem can be solved with the same automobile stopping in 0.5 s. The change in speed would still be –15 m/s, and the acceleration can be calculated.

$$a = \frac{\Delta v}{\Delta t} = \frac{v_1 - v_0}{\Delta t} = \frac{-15\ \text{m/s}^2}{0.5\ \text{s}} = -30\ \text{m/s}^2$$

There is another, equivalent picture that describes the same collision:

$$F = ma$$

Multiplying both sides of the equation by Δt, you get

$$F\Delta t = m\Delta v$$

then you can rewrite Newton's second law as

$$F = \frac{m\Delta v}{\Delta t}$$

The term on the right-hand side of the equation is change in **momentum**. The term on the left side of the equation is impulse.

Any moving automobile has momentum. Momentum is represented with a small p. Momentum is defined as the mass of the automobile multiplied by its velocity $p = mv$.

A change in momentum is called **impulse**. The impulse-momentum equation tells you that the momentum of the automobile can be changed by applying a force for a given amount of time. The impulse is the force multiplied by the time. So a small force exerted over a long time produces the same impulse (change in momentum) as a large force exerted over a short time. "The small force exerted over a long time" is what you found in the effective crumple zones.

Impulse-momentum is an effective way in which to describe all collisions.

Consider this question: "Why do you prefer to land on soft grass rather than on hard concrete?" Soft grass is preferred because the force on your body is less when you land on soft grass. This can be explained by using the impulse-momentum relation.

Whether you land on concrete or soft grass, your change in velocity will be identical. Your velocity may decrease from 3 m/s to 0 m/s.

Physics Words

momentum: the product of the mass and the velocity of an object; momentum is a vector quantity.

impulse: a change in momentum of an object.

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Section 7 Impulse and Changes in Momentum: Crumple Zone

On concrete, this change occurs very fast, while on soft grass this change occurs in a longer period of time. Your acceleration on soft grass is smaller because the change in velocity occurred in a longer period of time.

$$a = \frac{\Delta v}{\Delta t}$$

When the change in the period of time gets larger, the denominator of the fraction gets larger and the value of the acceleration gets smaller.

When landing on grass, Newton's second law then tells you that the force must be smaller because the acceleration is smaller for an identical mass, $F = ma$. Smaller acceleration on grass requires a smaller force. Smaller forces are easier on your body and that is why you prefer to land on soft grass.

Change in value of momentum $\Delta p = \Delta mv$	Force F	Change in time Δt	Impulse $F\Delta t$
150 kg • m/s	50 N	3 s	150 N/s (150 kg • m/s)
150 kg • m/s	150 N	1 s	150 N/s (150 kg • m/s)
150 kg • m/s	15,000 N	0.01 s	150 N/s (150 kg • m/s)

You can get this change in momentum with a large force over a short time or a small force over a longer time.

If your mass is 50 kg, the amount of your change in momentum will be 150 kg • m/s when you decrease your velocity from 3 m/s to 0 m/s. There are many forces and associated times that can give this change in the value of the momentum.

If you could land on a surface that requires 3 s to stop, it will only require 50 N. A more realistic time of 1 s to stop will require a larger force of 150 N. A hard surface that brings you to a stop in 0.01 s requires a much larger force of 15,000 N.

On concrete, this change in the value of the momentum occurs very fast (a short time) and requires a large force. It hurts. On soft grass this change in the value of the momentum occurs in a longer time and requires a small force that is less painful and is preferred.

Notice that in the chart above, the change in momentum is always equal to the impulse.

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Chapter 3 Safety

"Work and Energy" or "Impulse and Momentum"

The effective crumple zone decreases the force on the passenger. Using the work-energy theorem the force can be minimized by increasing the distance required to stop. Using the impulse-momentum theorem, the force can be minimized by increasing the time required.

As a physics student, it is your job to decide which of these two approaches is best for explaining a particular collision.

$$W = Fd = \Delta KE$$

or

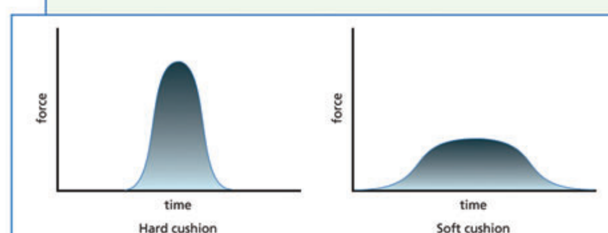
$$F\Delta t = \Delta p$$

Both show that the force can be minimized. In work-energy, force is minimized by an increase in impact distance. In impulse-momentum, force is minimized by an increase in impact time.

Conserving Momentum

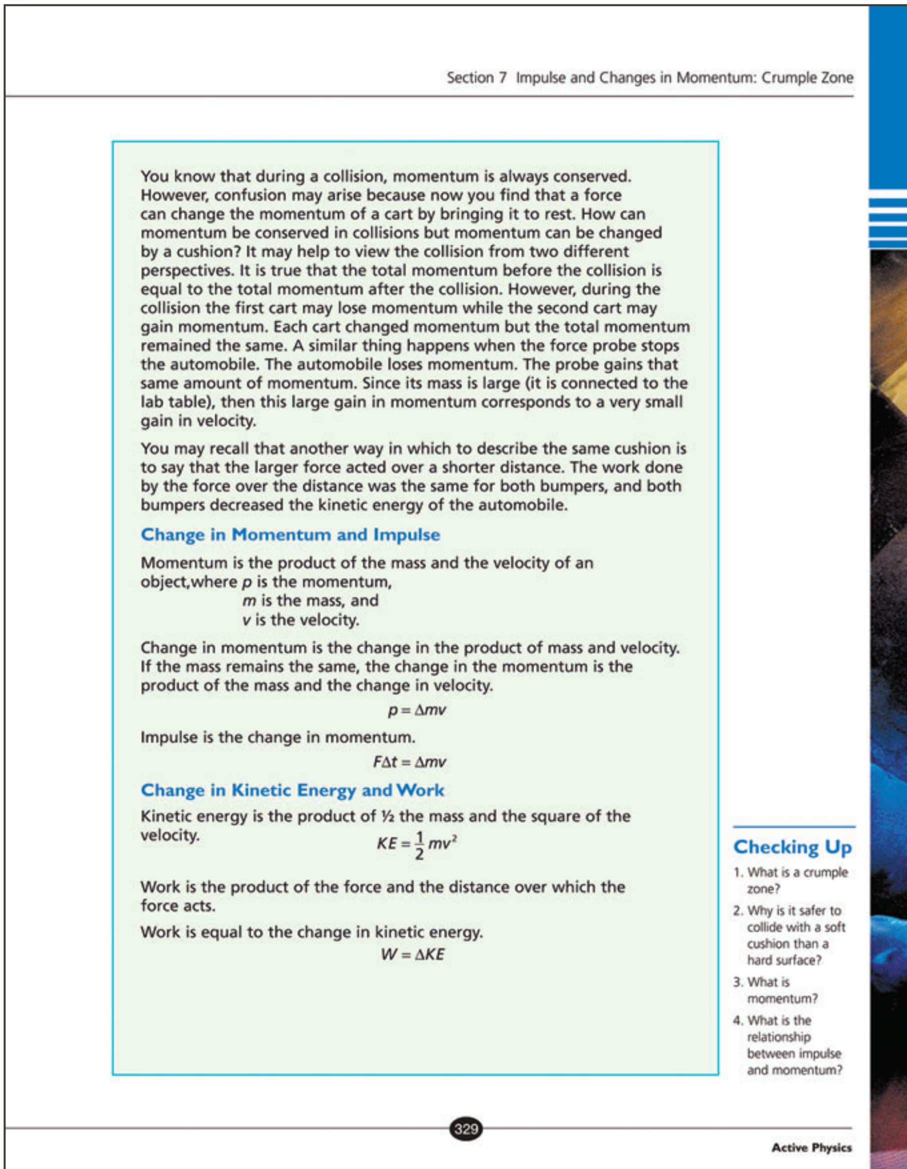
In *Part B* of the *Investigate*, a moving cart was brought to rest. The moving cart had momentum. The force probe was able to record the force that was applied to the cart over time to stop the cart. This force over time changed the momentum of the cart.

The force vs. time graphs for two carts with the same initial momentum are sketched below.



As you can see, the cart with the hard cushion had a larger force acting over a shorter time than the cart with the soft cushion. For the safety of passengers, a small force over a long time is what is needed.

Designing a safety device for an automobile is often determined by finding ways to decrease the force and increase the time during an impact. The change in momentum of a cart or an automobile can be identical, but a smaller force over a larger time will be safer.



You know that during a collision, momentum is always conserved. However, confusion may arise because now you find that a force can change the momentum of a cart by bringing it to rest. How can momentum be conserved in collisions but momentum can be changed by a cushion? It may help to view the collision from two different perspectives. It is true that the total momentum before the collision is equal to the total momentum after the collision. However, during the collision the first cart may lose momentum while the second cart may gain momentum. Each cart changed momentum but the total momentum remained the same. A similar thing happens when the force probe stops the automobile. The automobile loses momentum. The probe gains that same amount of momentum. Since its mass is large (it is connected to the lab table), then this large gain in momentum corresponds to a very small gain in velocity.

You may recall that another way in which to describe the same cushion is to say that the larger force acted over a shorter distance. The work done by the force over the distance was the same for both bumpers, and both bumpers decreased the kinetic energy of the automobile.

Change in Momentum and Impulse

Momentum is the product of the mass and the velocity of an object,where p is the momentum,
m is the mass, and
v is the velocity.

Change in momentum is the change in the product of mass and velocity. If the mass remains the same, the change in the momentum is the product of the mass and the change in velocity.

$$p = \Delta mv$$

Impulse is the change in momentum.

$$F\Delta t = \Delta mv$$

Change in Kinetic Energy and Work

Kinetic energy is the product of ½ the mass and the square of the velocity.

$$KE = \frac{1}{2}mv^2$$

Work is the product of the force and the distance over which the force acts.

Work is equal to the change in kinetic energy.

$$W = \Delta KE$$

Checking Up

1. What is a crumple zone?
2. Why is it safer to collide with a soft cushion than a hard surface?
3. What is momentum?
4. What is the relationship between impulse and momentum?

Checking Up

1.

A crumple zone is a part of a vehicle that compresses during impact to reduce the amount of force acting on passengers during a collision, and it reduces the amount of energy transferred to passengers during collisions.

2.

The softer cushion reduces the force of impact by increasing the time of the collision and the distance over which the force acts.

3.

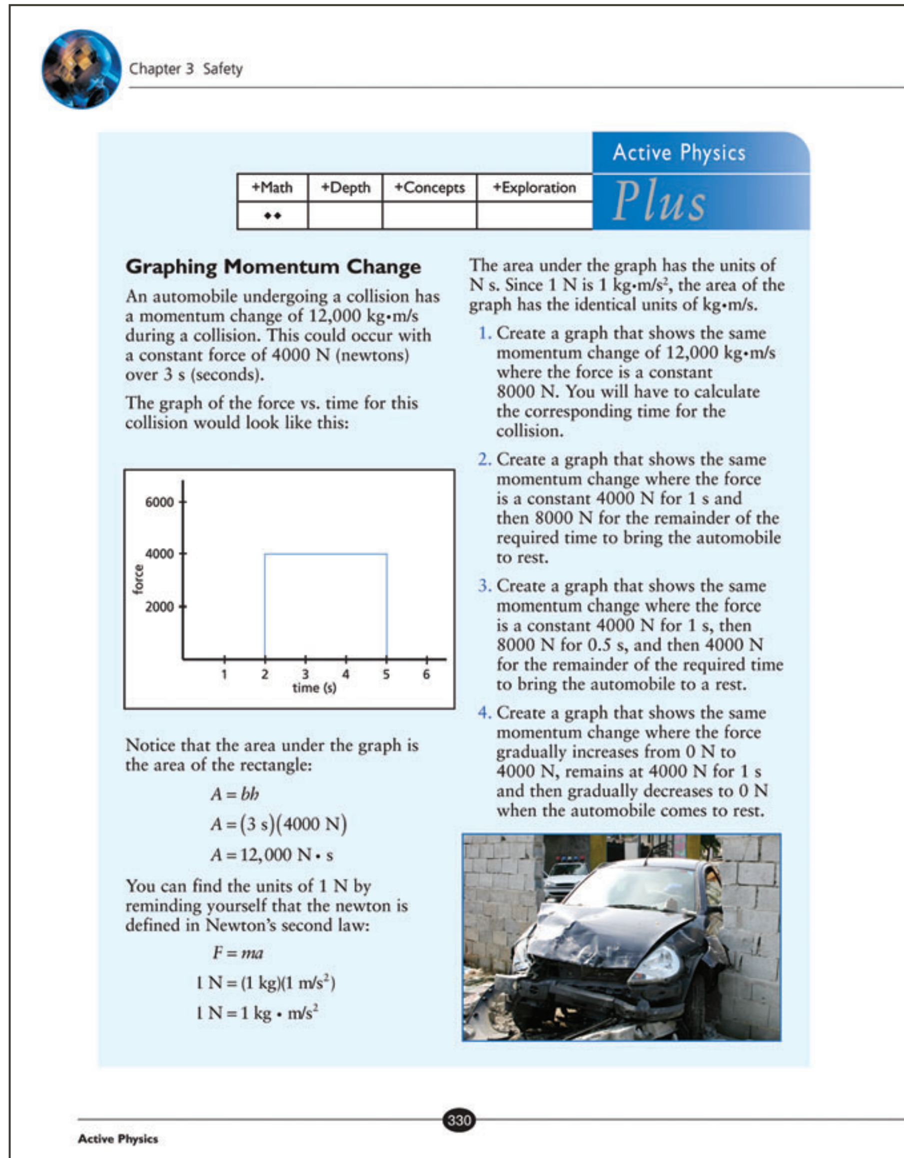
Momentum is the product of the mass and the velocity of an object, and it is a vector quantity.

4.

The impulse on an object is equal to the change in momentum of the object, which is equal to the net external force acting on the object multiplied by the time this force acts on the object.

Active Physics Plus

This *Active Physics Plus* provides an opportunity for students to apply the concepts presented in this section in a more mathematical context.



Chapter 3 Safety

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
◆◆			

Graphing Momentum Change

An automobile undergoing a collision has a momentum change of 12,000 kg•m/s during a collision. This could occur with a constant force of 4000 N (newtons) over 3 s (seconds).

The graph of the force vs. time for this collision would look like this:

Notice that the area under the graph is the area of the rectangle:

$$A = bh$$
$$A = (3\ \text{s})(4000\ \text{N})$$
$$A = 12{,}000\ \text{N} \cdot \text{s}$$

You can find the units of 1 N by reminding yourself that the newton is defined in Newton's second law:

$$F = ma$$
$$1\ \text{N} = (1\ \text{kg})(1\ \text{m/s}^2)$$
$$1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$$

The area under the graph has the units of N s. Since 1 N is 1 kg•m/s^2, the area of the graph has the identical units of kg•m/s.

1. Create a graph that shows the same momentum change of 12,000 kg•m/s where the force is a constant 8000 N. You will have to calculate the corresponding time for the collision.
2. Create a graph that shows the same momentum change where the force is a constant 4000 N for 1 s and then 8000 N for the remainder of the required time to bring the automobile to rest.
3. Create a graph that shows the same momentum change where the force is a constant 4000 N for 1 s, then 8000 N for 0.5 s, and then 4000 N for the remainder of the required time to bring the automobile to a rest.
4. Create a graph that shows the same momentum change where the force gradually increases from 0 N to 4000 N, remains at 4000 N for 1 s and then gradually decreases to 0 N when the automobile comes to rest.

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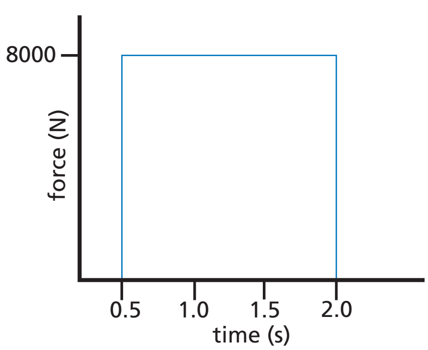
1.

Students should calculate the time involved for changing the momentum by 12,000 kg · m/s using a force of 8000 N.

$$F\Delta t = \Delta p$$

$$\Delta t = \frac{\Delta p}{F} = \frac{12{,}000\ \text{kg} \cdot \text{m/s}}{8000\ \text{N}} = 1.5\ \text{s}.$$

Students should construct a graph that shows the force versus time similar to the graph shown below. The initial value of time is not important, but the time over which the force is applied is, and it should be 1.5 s.



Show students that the area under the curve for this graph is equal to the base (the time interval or 1.5 s) multiplied by the height (the force or 8000 N) and this is equal to the change in momentum.

Area = (base)(height) = ΔtF = (1.5 s)(8000 N) = 12,000 kg · m/s.

2.

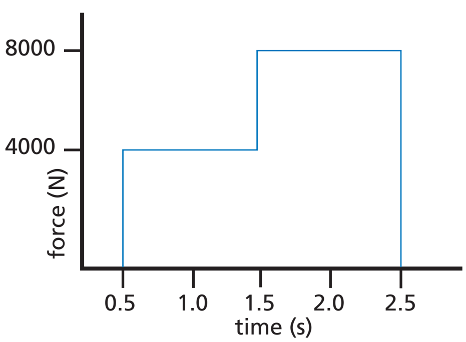
Students should find the time needed for the second interval.

For the first interval a 4000 N force acts on the object for 1 s. This changes the momentum by $\Delta p = F\Delta t = (4000\ \text{N})(1\ \text{s}) = 4000\ \text{N} \cdot \text{s}$.

For the vehicle to stop, the momentum has to change a total of 12,000 kg · m/s. Therefore, the second force needs to be applied long enough to reduce the momentum by an additional 12,000 kg · m/s – 4000 kg · m/s = 8000 kg · m/s.

This means the 8000 N force should be applied for an additional time of

$$\Delta t = \frac{\Delta p}{F} = \frac{8000 \text{ kg} \cdot \text{m/s}}{8000 \text{ N}} = 1 \text{ s}.$$



Have students check that the area under the curve (the sum of areas of the two rectangles formed) is equal to the total change in momentum.

3.

For the first interval a 4000 N force acts on the object for 1 s. This changes the momentum by

$\Delta p = F\Delta t = (4000 \text{ N})(1 \text{ s}) =$

$4000 \text{ N} \cdot \text{s}$.

During the second interval an 8000 N force acts on the object for 0.5 s. This changes the momentum by

$\Delta p = F\Delta t = (8000 \text{ N})(0.5 \text{ s}) =$

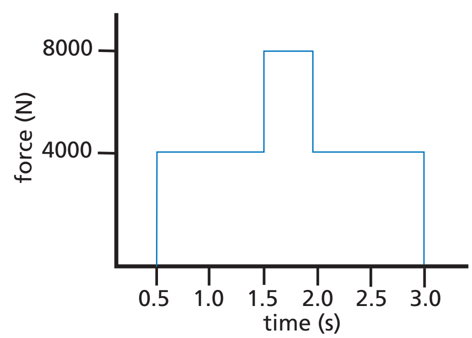
$4000 \text{ N} \cdot \text{s}$.

For the vehicle to stop, the momentum has to change a total of 12,000 kg · m/s. Therefore, the third force needs to be applied long enough to reduce the momentum by an additional

12,000 kg · m/s – 4000 kg · m/s – 4000 kg · m/s = 4000 kg · m/s.

This means the third applied force of 4000 N force should be applied for an additional

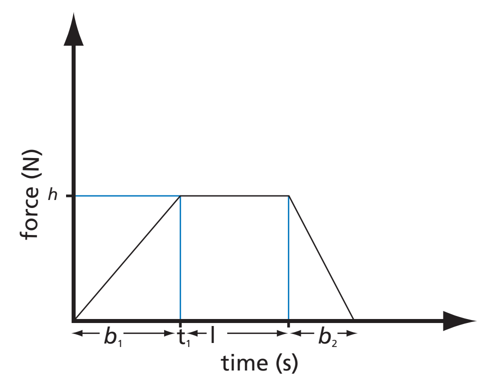
$$\Delta t = \frac{\Delta p}{F} = \frac{4000 \text{ kg} \cdot \text{m/s}}{4000 \text{ N}} = 1 \text{ s}.$$



Have students check that the area under the curve (the sum of areas of the three rectangles formed) is equal to the total change in momentum.

4.

If students are having difficulty starting, point out that this problem should be solved in three parts and have them find the area under the curve. They can do this by constructing a graph and figuring out the areas under each part of the curve. For the first and last parts of the curve, the area of a triangle ($A = \frac{1}{2}bh$) should be calculated. The middle part forms the area of a rectangle ($A = l \times h$). The total area under the curve is equal to the change in momentum or 12,000 N · s. This can be found by adding the area under each part of the curve, or the area of the two triangles plus the area of the rectangle. Help students to visualize this by showing them a graph similar to the one below. Note that the two triangles may be the same or different depending on how the gradually changing forces are shown.



The simplest is the middle part in which a 4000 N force is applied for 1 s. This corresponds to a rectangle of height 4000 N and time 1 s on the graph. This force changed the momentum by

$\Delta p = F\Delta t = (4000 \text{ N})(1 \text{ s}) =$

$4000 \text{ N} \cdot \text{s}$.

An area of 4000 N·s is under this part of the curve.

NOTES

CHAPTER 3

The remaining two sections must add up with the middle section to account for the total change in momentum of 12,000 N. Therefore, together they need to reduce the momentum by 8000 N. If you assume that each gradual force reduces the momentum equally, then the first gradually applied force must reduce the momentum by 4000 N · s, as does the last. This can be found by using the relationship for the area of the triangle

$A = \frac{1}{2}bh$

$\Delta p_{\text{first part}} = \frac{1}{2}(t_1)(4000\ \text{N})$

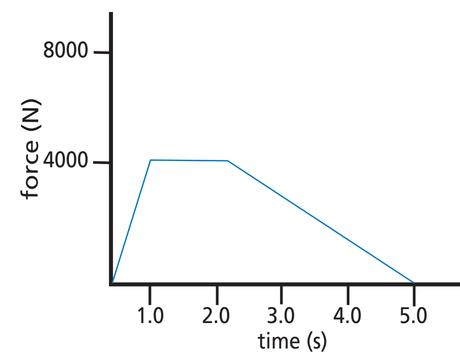
$4000\ \text{N} \cdot \text{s} = (2000\ \text{N})t_1$

$t_1 = 2\ \text{s}.$

This means that the gradually increasing force must increase from 0 to 4000 N over a time period that needs to be calculated by figuring out the area under the curve, which is equal to the change in momentum during the time it is applied. This time is 2 s. An equal area will be needed for the gradually decreasing force applied in the last part, and an equal amount of time.

Point out that if the time the force is applied increases, the area under the curve increases, and if the time it is applied decreases, the area under the curve decreases.

The following image is for a more general case in which the two gradually changing forces applied are not changing equally. As long as the total area under the curve (the sum of the two triangles and the rectangle) are equal to the total change in momentum, then the curve correctly depicts a physical solution.



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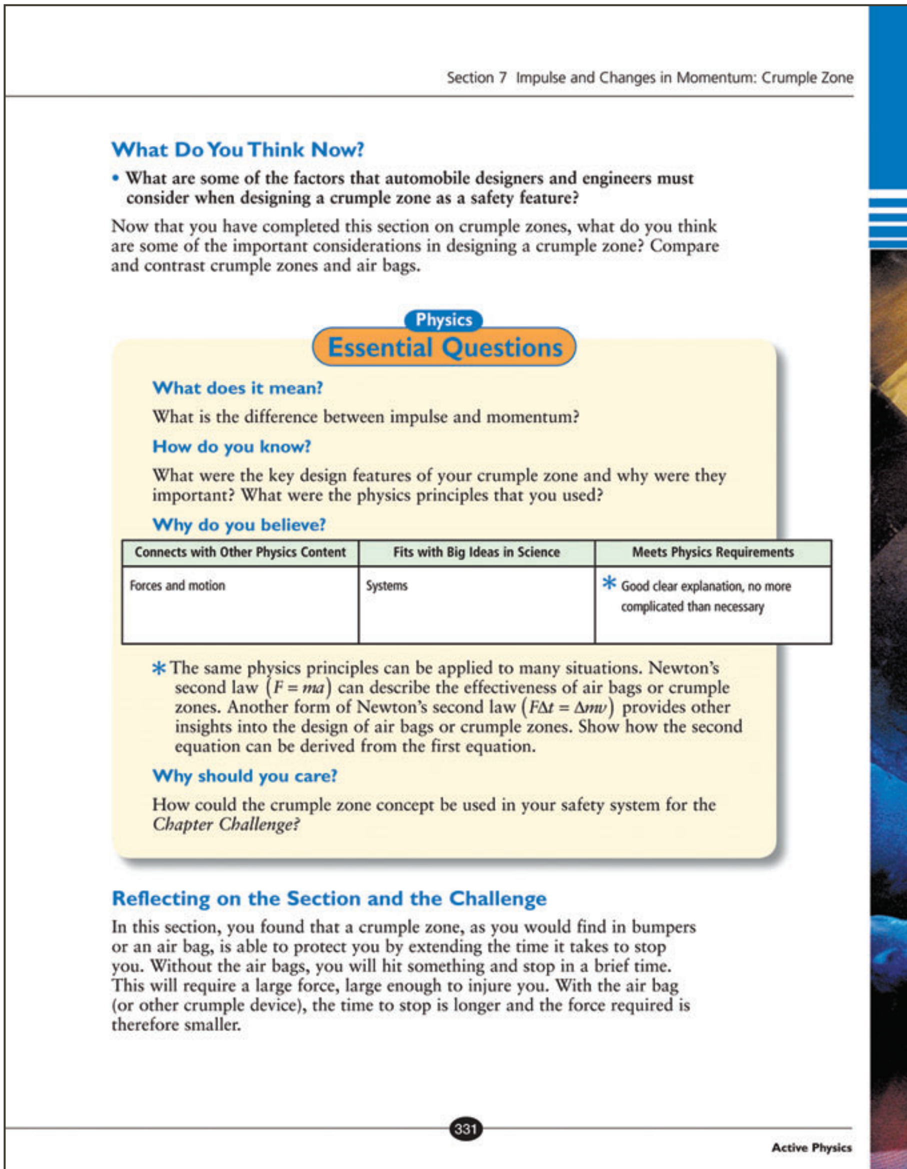

Section 7 Impulse and Changes in Momentum: Crumple Zone

What Do You Think Now?

- **What are some of the factors that automobile designers and engineers must consider when designing a crumple zone as a safety feature?**

Now that you have completed this section on crumple zones, what do you think are some of the important considerations in designing a crumple zone? Compare and contrast crumple zones and air bags.

Physics

Essential Questions

What does it mean?

What is the difference between impulse and momentum?

How do you know?

What were the key design features of your crumple zone and why were they important? What were the physics principles that you used?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Forces and motion	Systems	* Good clear explanation, no more complicated than necessary

* The same physics principles can be applied to many situations. Newton's second law $(F = ma)$ can describe the effectiveness of air bags or crumple zones. Another form of Newton's second law $(F\Delta t = \Delta mv)$ provides other insights into the design of air bags or crumple zones. Show how the second equation can be derived from the first equation.

Why should you care?

How could the crumple zone concept be used in your safety system for the *Chapter Challenge?*

Reflecting on the Section and the Challenge

In this section, you found that a crumple zone, as you would find in bumpers or an air bag, is able to protect you by extending the time it takes to stop you. Without the air bags, you will hit something and stop in a brief time. This will require a large force, large enough to injure you. With the air bag (or other crumple device), the time to stop is longer and the force required is therefore smaller.

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What Do You Think Now?

Ask students to review the previous answers to the *What Do You Think?* question. Ask students how they would answer this question now and survey the class for how many students changed their ideas. Point out that scientists often change their ideas as they gather more information. Consider discussing the information in *A Physicist's Response*.

Reflecting on the Section and the Challenge

Using the information in the student text, review crumple zones and the idea of reducing the force acting on passengers and energy transferred to passengers by having a smaller force act during a greater time during a collision, or having the force act over a greater distance. Emphasize that the crumple device reduces the amount of energy transferred to the passenger because more energy is transformed to heat

Physics Essential Questions

What does it mean?

Impulse and momentum will have the same mathematical value. Impulse is equal to the change in momentum. Impulse is the product of force and time. Momentum is the product of mass and velocity.

How do you know?

Students' crumple zones reduced the amount of force acting on passengers, and the energy transferred to passengers during a collision. Crumple zones decrease the impact felt by passengers during a crash by reducing the force needed to stop a vehicle.

Why do you believe?

For constant mass

$F = ma$

$F = m\dfrac{\Delta v}{\Delta t}$

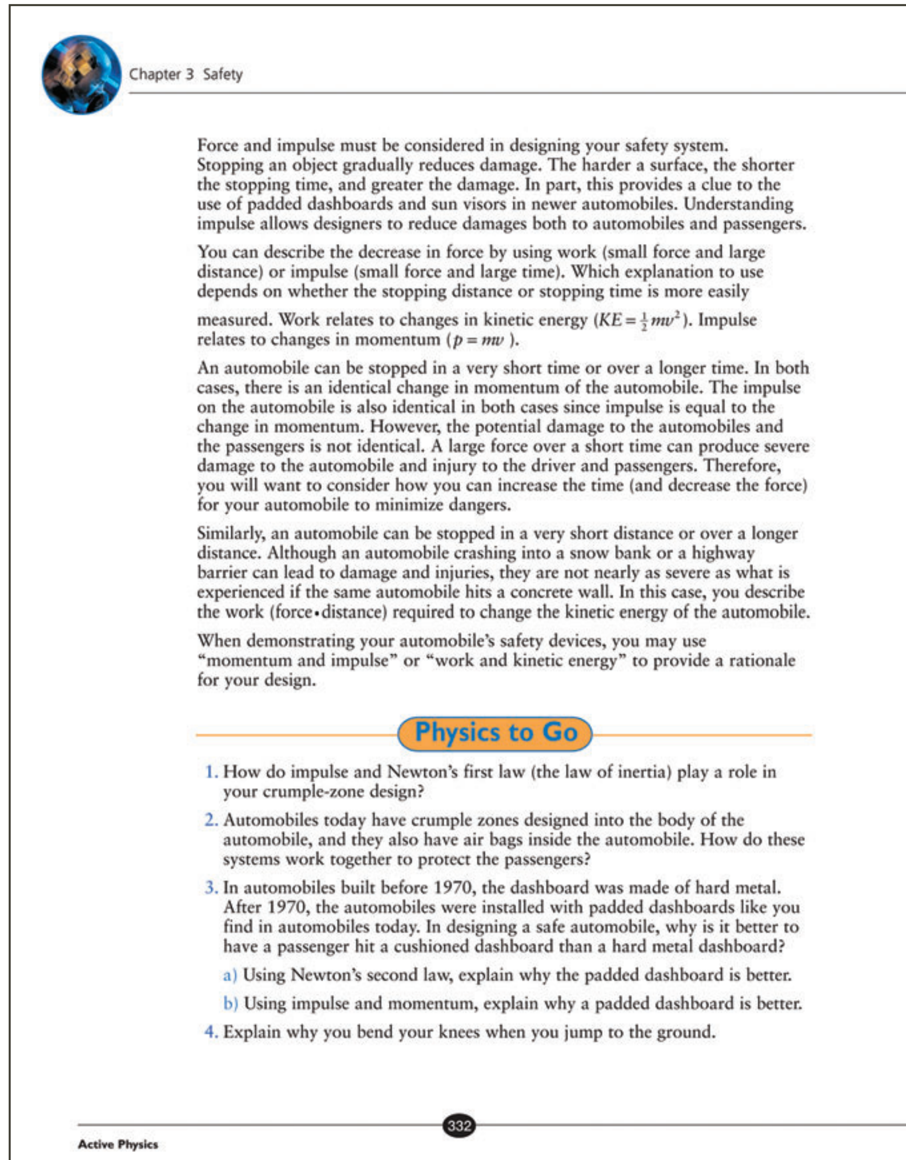
$F\Delta t = m\Delta v = \Delta p$

Why should you care?

If an object is going to crash, adding a crumple zone will increase the time of the crash and decrease the force exerted during the crash.

CHAPTER 3

energy or energy of deformation during the “crumpling.” Remind students that the impulse-momentum and work-energy concepts are important to keep in mind for the *Chapter Challenge*, and that they should consider these concepts as they design their prototype and construct their explanations.



Chapter 3 Safety

Force and impulse must be considered in designing your safety system. Stopping an object gradually reduces damage. The harder a surface, the shorter the stopping time, and greater the damage. In part, this provides a clue to the use of padded dashboards and sun visors in newer automobiles. Understanding impulse allows designers to reduce damages both to automobiles and passengers.

You can describe the decrease in force by using work (small force and large distance) or impulse (small force and large time). Which explanation to use depends on whether the stopping distance or stopping time is more easily measured. Work relates to changes in kinetic energy ($KE = \frac{1}{2}mv^2$). Impulse relates to changes in momentum ($p = mv$).

An automobile can be stopped in a very short time or over a longer time. In both cases, there is an identical change in momentum of the automobile. The impulse on the automobile is also identical in both cases since impulse is equal to the change in momentum. However, the potential damage to the automobiles and the passengers is not identical. A large force over a short time can produce severe damage to the automobile and injury to the driver and passengers. Therefore, you will want to consider how you can increase the time (and decrease the force) for your automobile to minimize dangers.

Similarly, an automobile can be stopped in a very short distance or over a longer distance. Although an automobile crashing into a snow bank or a highway barrier can lead to damage and injuries, they are not nearly as severe as what is experienced if the same automobile hits a concrete wall. In this case, you describe the work (force•distance) required to change the kinetic energy of the automobile.

When demonstrating your automobile's safety devices, you may use “momentum and impulse” or “work and kinetic energy” to provide a rationale for your design.

Physics to Go

1. How do impulse and Newton's first law (the law of inertia) play a role in your crumple-zone design?
2. Automobiles today have crumple zones designed into the body of the automobile, and they also have air bags inside the automobile. How do these systems work together to protect the passengers?
3. In automobiles built before 1970, the dashboard was made of hard metal. After 1970, the automobiles were installed with padded dashboards like you find in automobiles today. In designing a safe automobile, why is it better to have a passenger hit a cushioned dashboard than a hard metal dashboard?
   a) Using Newton's second law, explain why the padded dashboard is better.
   b) Using impulse and momentum, explain why a padded dashboard is better.
4. Explain why you bend your knees when you jump to the ground.

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Physics to Go

1.

Students should describe how Newton’s first law, as an object in motion, keeps its motion unless acted upon by a force. Before a collision, the vehicle and its occupants will keep their motion. During a collision, a force is needed to reduce both the vehicle’s momentum and that of the occupants to zero. Students should describe how their crumple zone is designed to reduce the amount of force acting on passengers, and energy transferred to passengers during a collision. Then they should explain that the crumple zone increases the amount of time of the collision, but is designed to increase it by “safely” crumpling a part of the vehicle. This reduces the force needed to stop the vehicle. Hence, the impact the occupants feel is also less.

2.

Both the crumple zone and the air bag increase the stopping time of a passenger in a collision. The crumple zone increases the time for the automobile to stop, and the air bag increases the time for the passenger inside the vehicle to stop. The crumple zones reduce the amount of force acting on the vehicle during the collision and on the passenger. They also dissipate energy. The air bags further reduce the amount of force acting on the passenger during a collision and dissipate energy.

3.a)

With a padded dashboard, the increased stopping time means the acceleration is reduced, since the change in velocity is the same, but the time is longer. Using Newton’s second law of motion, $F = ma$ means the force is lower if the acceleration is less.

3.b)

Because change in momentum is the same in both cases (the mass, and initial and final velocities, are the same), as the stopping time is increased through the use of a padded dashboard, the required stopping force decreases.

Section 7 Impulse and Changes in Momentum: Crumple Zone

5. Helmets are designed to protect cyclists. How would the designers of helmets make use of the concept of impulse to improve their effectiveness?

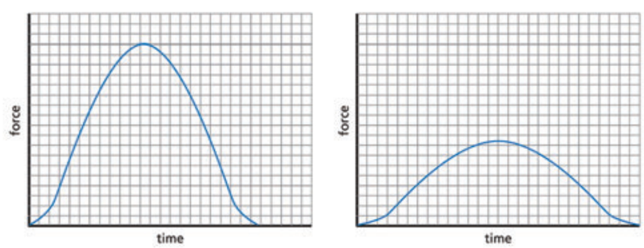
6. An automobile has a mass of 1200 kg and an initial velocity of 10 m/s (about 20 mi/h). Calculate the change in momentum required to do the following:
   a) Bring it to rest
   b) Slow it to 5 m/s (approximately 10 mi/h)

7. If the braking force for an automobile is 10,000 N, calculate the impulse if the brake is applied for 1.2 s (seconds). If the automobile has a mass of 1200 kg, what is the change in velocity of the automobile over this 1.2 s time interval?

8. A 1500-kg automobile, traveling at 5.0 m/s after braking, strikes a power pole and comes to a full stop in 0.1 s. Calculate the force exerted by the power pole and brakes required to stop the automobile.

9. For the automobile described in *Question 8*, explain why a breakaway pole that brings the automobile to rest after 2.8 s is safer than the conventional power pole.

10. Compare and contrast the two force vs. time graphs shown below.



11. ***Preparing for the Chapter Challenge***

    How can your safety device reduce the force experienced during an impulse? What features of your device increase the stopping time for the passenger? Record a description of how these features work in terms of impulse and momentum.

4.

Bending your knees when you land on the ground increases the stopping time as you collide with the ground, and therefore, the stopping force exerted on you by the ground is decreased.

5.

Helmets use cushioning materials that lengthen the time of impact and thus, decrease the force of impact. Note that helmets are designed to break and should not be used again after an accident. A rigid, unbreakable helmet would be useless.

6.a)

$\Delta p = p_{\text{final}} - p_{\text{initial}} =$

$mv_{\text{final}} - mv_{\text{initial}} =$

$12{,}000\ \text{kg}(0) - 12{,}000\ \text{kg}(10\ \text{m/s}) =$

$-120{,}000\ \text{kg}\cdot\text{m/s}.$

6.b)

$\Delta p = p_{\text{final}} - p_{\text{initial}} =$

$mv_{\text{final}} - mv_{\text{initial}} = m\left(v_{\text{final}} - v_{\text{initial}}\right) =$

$12{,}000\ \text{kg}\left(5\ \text{m/s} - 10\ \text{m/s}\right) =$

$-60{,}000\ \text{kg}\cdot\text{m/s}.$

7.

Students should use the impulse-momentum concepts. Here the direction of motion of the vehicle is taken as positive. This means the force acts on the vehicle in the negative direction. Consider asking students what direction the force acts relative to the motion of the vehicle.

$\Delta p = F\Delta t$

$m\Delta v = (-10{,}000\ \text{N})(1.2\ \text{s})$

$(1200\ \text{kg})\Delta v = -12{,}000\ \text{N}\cdot\text{s}$

$\Delta v = -10\ \text{m/s}.$

CHAPTER 3

8.

Using the impulse-momentum concepts,

$F\Delta t = \Delta p$

$F\Delta t = m\Delta v = (1500 \text{ kg})(-5 \text{ m/s})$

$F(0.1 \text{ s}) = (-7500 \text{ kg} \cdot \text{m/s})$

$F = (-75{,}000 \text{ N})$

The negative sign indicates that the force acts opposite to the automobile's direction of motion. Consider asking students the direction of the force relative to the direction of the automobile.

9.

Increasing the time of the collision decreases the force exerted on the vehicle during the collision, even though the change in momentum is the same. This can be verified by calculating the value of the force for this collision.

$F\Delta t = \Delta p$

$F\Delta t = m\Delta v = (1500 \text{ kg})(-5 \text{ m/s})$

$F(2.8 \text{ s}) = (-7500 \text{ kg} \cdot \text{m/s})$

$F = (-2700 \text{ N})$

10.

Students should use the impulse-momentum ideas in their comparison. They should point out that the first graph has a greater force over a shorter time period. The second graph has a smaller force over a longer period of time, and that the area under each graph is equal to the impulse or change in momentum.

11.

Preparing for the Chapter Challenge

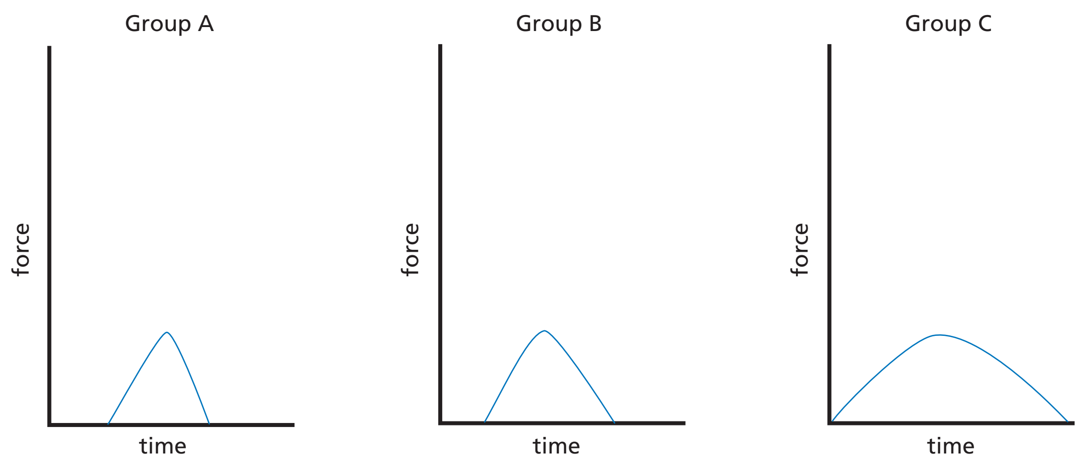
Students should develop a description of their safety device, and explain how it will increase stopping time and decrease stopping force to provide the impulse required to stop an automobile. Students should realize that the impulse required to stop the vehicle will be the same since the vehicle's mass and initial velocity are not changing. Their safety device is concerned with decreasing the force required, not the impulse.

NOTES

SECTION 7 QUIZ

3-7c **Blackline Master**

1. Three groups of students are testing their designs for cushioning collisions and obtain the force vs. time graphs shown below. If the areas under all three graphs are equal, which group's design worked best at cushioning the collision?



a) Group A
b) Group B
c) Group C
d) All three groups were equal

2. In *Question 1*, which group's cart had the greatest change in momentum when the three carts struck the force probe?

a) Group A
b) Group B
c) Group C
d) All three carts were equal

3. A student drops two eggs of equal mass simultaneously from the same height. Egg A lands on the tile floor and breaks. Egg B lands intact without bouncing on a foam pad lying on the floor. Compared to the impulse exerted to stop egg A as it lands on the tile floor, the impulse exerted to stop egg B is

a) less.
b) greater.
c) the same.

4. In an automobile collision, a 44-kg passenger moving at 15 m/s is brought to rest by an air bag in 0.10 s. What is the average force the air bag exerts on the passenger?

a) 440 N
b) 4400 N
c) 660 N
d) 6600 N

5. A 1.0-kg mass changes speed from 2.0 m/s to 5.0 m/s. What is the mass's change in momentum?

a) 9.0 kg · m/s
b) 21 kg · m/s
c) 3.0 kg · m/s
d) 29 kg · m/s

SECTION 7 QUIZ ANSWERS

1. c) Group C
2. d) All three carts were equal
3. c) the same.
4. d) 6600 N
5. c) 3.0 kg · m/s

NOTES

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