SECTION 5

Momentum: Concentrating on Collisions

Section Overview

Students investigate head-on, nearly elastic collisions between two carts in one dimension. In these collisions, one cart is moving and the other is stationary. Students record their observations for carts colliding with equal masses, different masses, and varying initial speeds of the moving cart. Students then apply their observations and analysis to determine information about a stationary cart involved in a collision. From their investigations, students are introduced to the concept of momentum. They then calculate and consider the momentum of various objects.

Background Information

Momentum is a vector quantity describing the motion of an object. Momentum is equal to the mass of an object multiplied by its velocity or $\vec{p} = m\vec{v}$.

The momentum of an object does not change unless a net external force acts on the object. Newton's first law or the law of inertia states that an object at rest will remain at rest, and an object in linear motion will continue its motion, unless acted on by a net force. Another way to state Newton's first law is that the momentum of an object does not change unless a net external force acts on the object, or

If $\vec{F}_{\text{net}} = \vec{0}$, then $\frac{d\vec{p}}{dt} = \vec{0}$.

One reason that momentum is such an important quantity in physics is that the total momentum of any group of objects (a system) remains the same unless external forces act on the objects (the system). This is known as the law of conservation of momentum, which is further discussed in the next section.

A net force changes an object's momentum. Sometimes, Newton's second law is written as

$$\vec{F}_{\text{net}} = \frac{d\vec{p}}{dt} = m\frac{d\vec{v}}{dt} + \frac{d\vec{m}}{dt}v = m\vec{a} + \frac{d\vec{m}}{dt}v.$$

This form is general enough to also account for changes in mass, such as with fuel-burning vehicles. Students will not consider changes in mass during this curriculum.

Photons (quanta of light energy) are massless but have momentum. A photon's momentum is calculated from the relativistic energy expression

$$E = mc^2 = \sqrt{p^2c^2 + m_0^2c^4},$$

and setting the rest mass to zero. This leads to Planck's relationship $p = \frac{E}{c} = \frac{hf}{c} = \frac{h}{\lambda}$, where h is Planck's constant, f is the frequency, c is the speed of light, and λ is the wavelength. Planck's relationship is discussed in another chapter.

Momentum may be referred to as a measure of an object's inertia of motion, or its resistance to change its motion, but as was stated in *Chapter 2*, *Physics in Action*, "Newton explained that an object's **mass** is a measure of its inertia, or tendency to resist a change in motion. Given different masses moving at the same speed, the one with the greatest mass has the greatest inertia." Momentum is dependent on the inertial reference frame it is in, but conservation of momentum is not. Any object moving with a constant velocity appears to be at rest in a reference frame moving with the same velocity. Hence, a ball held in one's hand, while in a vehicle moving at constant speed, is in an inertial reference frame. To the person in the vehicle, the ball appears to be at rest and appears to have a value of zero for its momentum. To an observer on the side of the road, the ball has a momentum equal to the mass of the ball multiplied by its velocity, which would be the same as the velocity of the vehicle. If the passenger in the vehicle holding the ball were in a boxcar with no windows moving at a constant speed, that person would have no idea that he or she was in motion relative to someone on the ground. One of the important rules of physics is that all of the laws of physics must be obeyed in any inertial reference frame. This means that all the concepts of momentum, force, energy, and so on, have to hold true whether the person applying them is in the boxcar moving with a constant velocity, or whether he or she is in a laboratory cart that is not moving relative to the ground below.

In the *Investigate,* students explore collisions that are nearly elastic (no energy is transferred to the surroundings). For an elastic collision both the kinetic energy and the momentum of the system are conserved quantities. Because these laws must hold true in any inertial reference frame, it is easiest to move into a reference frame where one object is initially at rest. According to the law of conservation of momentum, for elastic collisions, you have the following equation:

$$m_1\vec{v}_{1\text{initial}} + m_2\vec{v}_{2\text{initial}} = m_1\vec{v}_{1\text{final}} + m_2\vec{v}_{2\text{final}}.$$

From the conservation of kinetic energy, you have the following equation:

$$\tfrac{1}{2}m_1v_{1\text{initial}}^2 + \tfrac{1}{2}m_2v_{2\text{initial}}^2 = \tfrac{1}{2}m_1v_{1\text{final}}^2 + \tfrac{1}{2}m_2v_{2\text{final}}^2.$$

In the *Investigate,* the second cart has zero initial speed. Using this condition, you can find the following mathematical relationships for a head-on, elastic collision:

$$v_{1\text{final}} = \frac{m_1 - m_2}{m_1 + m_2}v_{1\text{initial}} \quad \text{and} \quad v_{2\text{final}} = \frac{2m_1}{m_1 + m_2}v_{1\text{initial}}.$$

From these it is easy to see the following:

- if $m_1 = m_2$, then $v_{1\text{final}} = 0$, and $v_{2\text{final}} = v_{1\text{initial}}$.
- if m_1 is much greater than m_2, then $v_{1\text{initial}} \approx v_{1\text{final}}$, and $v_{2\text{final}} \approx 2v_{1\text{initial}}$.
- if m_2 is much greater than m_1, then $v_{1\text{initial}} \approx -v_{1\text{final}}$, and $v_{2\text{final}} \approx 0$.

Crucial Physics

- Momentum is mass multiplied by velocity.
- During a collision, momentum is transferred between colliding objects. The momentum is transferred from an object that initially has a greater magnitude of momentum to an object that initially has a smaller magnitude of momentum. Sometimes this transfer is imperceptible. If the two objects have the same magnitude of momentum, a transfer may occur, resulting in a change of direction or speed of one or both objects.

Learning Outcomes	Location in the Section	Evidence of Understanding
Apply the definition of momentum.	***Physics Talk*** ***Physics Essential Questions*** ***Physics to Go*** Questions 1-7	Students compare and calculate the momentum of different objects.
Conduct analyses of the momentum of pairs of objects in one-dimensional collisions.	***Investigate*** Steps 5 and 6 ***Physics Essential Questions***	Students conclude from analyses of their observations that during collisions between two carts (one at rest), the cart at rest increases its motion when the colliding cart has increased speed or mass, and its motion does not change as much as its mass increases. Students consider how two sets of observations can determine the masses of colliding carts.

NOTES

Section 5 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Dynamics cart	2 per group	
Weight, slotted, 100 g	6 per group	
Scale, electronic, 0-1500 g, 0.01 g readability		1 per class
Tape, masking		6 per group
Access to a smooth level surface*	1 per group	
Spring or loop of thin metal for dynamics cart*	1 per group	

*Additional items needed not supplied

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Dynamics cart	2 per group	
Weight, slotted, 100 g	6 per group	
Scale, electronic, 0-1500 g, 0.01 g readability		1 per class
Tape, masking		6 per group
Access to a smooth level surface*	1 per group	
Spring or loop of thin metal for dynamics cart*	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

Allow one period for the students to investigate the collisions.

Teacher Preparation

- Obtain dynamics carts with a spring mounted to one end to allow elastic collisions. If carts with springs are unavailable, a spring can be made from “strap steel” from a lumberyard. This is scrap metal that is used to hold bundles of wood together. When attached firmly to the sides of a cart and allowed to extend over the front, it makes an excellent spring.
- Caution the students to keep the collision speeds for the carts low and that care must be taken so that the carts are lined up properly to have a direct hit on the spring between the carts.
- During the collision between the small-mass cart and the large-mass cart, the small-mass cart may travel much faster than the large-mass cart. The students should be prepared to catch the small-mass cart quickly so that it doesn’t fall on the floor.
- Decide where students should conduct the investigation. A long-level area clear of obstructions is needed for each group. To prevent carts from falling, consider using the floor.
- 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.

Safety Requirements

- In all collision experiments, goggles are of extra importance. Closed-toe shoes are also advised.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Describing collisions	***Investigate*** Steps 2-7	**Augmentation** • Students often have difficulty writing subjective observations with enough detail to be used for meaningful comparisons. They write phrases such as “It moved.” Explicitly teach students how to describe motion in detail. • Provide structured activities to practice describing motion. Jump into the air and ask students to describe the motion. Show video clips of animals and/or athletes jumping and ask students to describe the motion. Students will understand that saying, “It jumped,” is an ineffective way to describe this motion. Then students can make a list of words they have used to effectively describe motion. **Accommodation** • Provide students with a list of words that describe motion including forward, backward, fast, slow, moving cart, target cart, and so on.
Understanding essential concepts	***Physics Talk***	**Augmentation** • Many students can conceptualize that a large moving object can cause damage because of its momentum, but they really struggle to conceptualize the idea that very small objects that are moving very fast can also have a lot of momentum and cause damage. Show an Internet video clip of a sandblaster at work.
Understanding vectors	***Physics Words***	**Augmentation** • Without frequent review, students often forget the difference between scalar and vector quantities. Review the meaning of *scalar* and *vector*. Add *momentum* to the scalar/vector list created during *Chapter 1, Section 4*. • If students created a list of words to describe motion earlier in this section, explicitly make the connection that describing motion usually involves using a direction (vector).

Strategies for Students with Limited English-Language Proficiency

Point out new vocabulary words in context and practice using the words as much as possible throughout the section. As you work through the section, have students write the terms in their *Active Physics* logs and add the definitions in their own words.

absolute masses	obstructions
circumstances	pedestrian
disastrous	relative masses
elastic collision	stationary
enormous	transfer of momentum

Consider giving students a cloze activity when you reach the end of the section. Cloze activities are useful tools for summarizing material and for giving English-language learners opportunities to practice writing complete sentences using science vocabulary. Cloze activities are most effective when used frequently, to build students' abilities with more complex sentences.

Ask students to give you sentences describing what they did in the section, telling what important lessons they learned. Their comments should include the vocabulary words listed above. You may wish to offer a first sentence as an example. For instance, "You investigated momentum in collisions between two carts of different masses and different velocities." Write simple sentences, and work them into paragraphs. Some sentences should compare and contrast the transfer of momentum in the different collisions studied. Model using a topic sentence, supporting statements, and a closing sentence. Model the process of editing, in which students make corrections that improve the sentences.

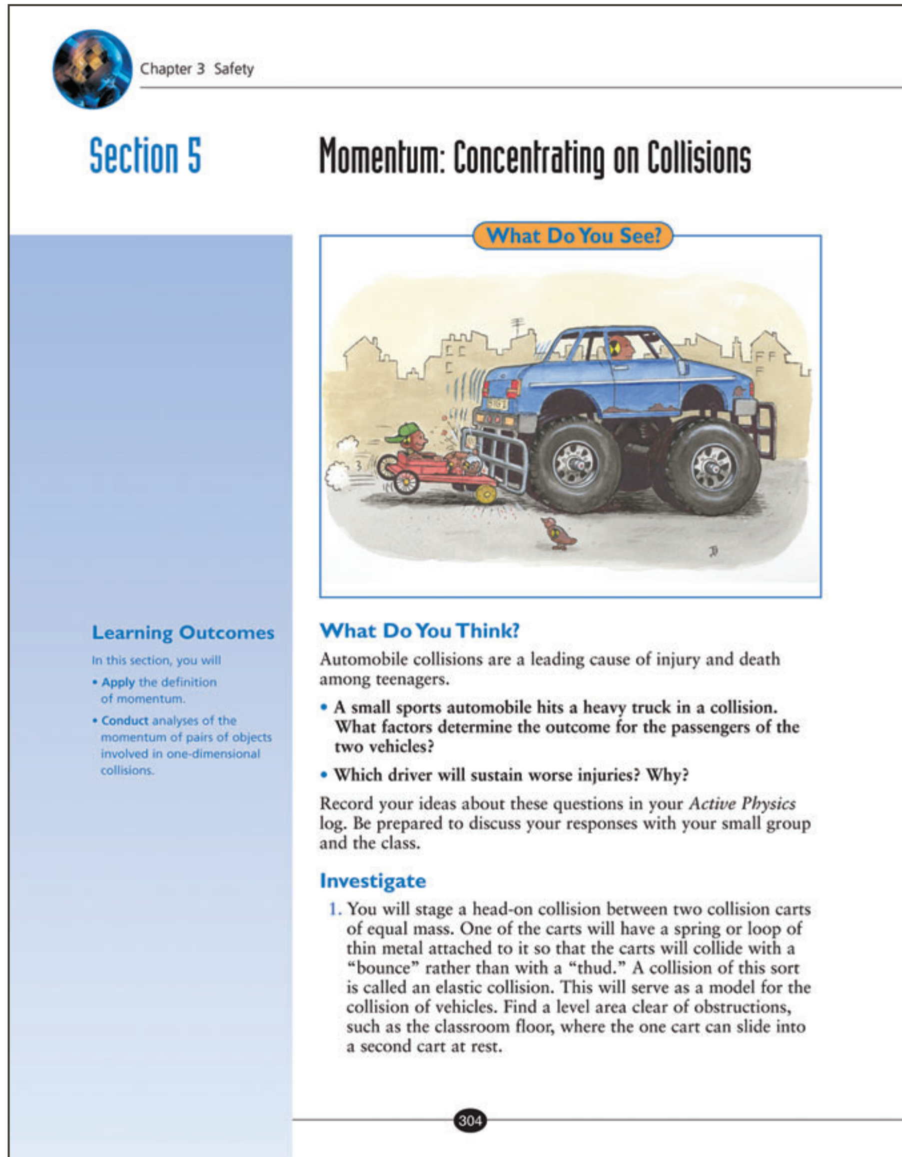
There are many types of collisions covered in this section, so you will likely end up with a few paragraphs. Once the paragraphs are complete and students agree that these paragraphs accurately summarize what they did and learned, have the students copy them down. Explain that there will be a brief quiz on the paragraphs the next day at the beginning of class. The quiz will consist of the same paragraphs they wrote down, but with blanks where several terms were. The students will need to fill in the blanks with the terms that are missing. Tell students how the quiz will be graded. Prepare this quiz by keying in the paragraphs and then going back and removing every vocabulary term and replacing it with a blank. Choose a variety of words to leave out—nouns, verbs, adjectives, and so on. These terms can be science content words, but they do not have to be. Score the quiz by allotting two points for every blank: one point for the correct term or word (or perhaps another word with the correct meaning), and a second point for the correct spelling of that term or word.

SECTION 5

Teaching Suggestions and Sample Answers

What Do You See?

Have students consider the illustration and the title of the section. Use an overhead of the illustration to help focus the discussion. Ask students to describe the illustration and what they think is happening. Ask them what physics ideas they think pertain to the situation and how they might be useful. This elicitation helps to get students' initial ideas and provides a focus for the science content.



Chapter 3 Safety

Section 5 Momentum: Concentrating on Collisions

What Do You See?

Learning Outcomes

In this section, you will

- **Apply** the definition of momentum.
- **Conduct** analyses of the momentum of pairs of objects involved in one-dimensional collisions.

What Do You Think?

Automobile collisions are a leading cause of injury and death among teenagers.

- **A small sports automobile hits a heavy truck in a collision. What factors determine the outcome for the passengers of the two vehicles?**
- **Which driver will sustain worse injuries? Why?**

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

1. You will stage a head-on collision between two collision carts of equal mass. One of the carts will have a spring or loop of thin metal attached to it so that the carts will collide with a "bounce" rather than with a "thud." A collision of this sort is called an elastic collision. This will serve as a model for the collision of vehicles. Find a level area clear of obstructions, such as the classroom floor, where the one cart can slide into a second cart at rest.

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Students' Prior Conceptions

Being able to identify the momentum for each object involved in a collision both before and after the impact is an overriding strategy and an analytical tool that must be developed by the students during this section. The simple dictum "momentum before is equal to the momentum after" followed by verbal and/or mathematical statements identifying the mass and the velocity of each object should be included when students analyze what happens during collisions. Remind them that velocity is a vector and the vector nature of momentum is important in describing collisions. Exploring the transfer of energy during these interactions serves as a ladder for student cognition.

1. **Students have difficulty appreciating that all collisions involve equal forces acting on the separate bodies in opposite directions.** Provide opportunities for students to investigate and analyze collisions and ask them questions to ascertain their understanding through all of the sections embedded in *Chapter 3*.
2. **Higher impact speed causes more severe distortions than collisions with lower impact velocities.** This interpretation of prior student knowledge appears throughout this chapter. In this section, you may find it useful to evaluate the student engineering designs that mitigate the effects of a high speed collision to check that a shift in

What Do You Think?

Ask students to record their responses in their *Active Physics* logs, then have them discuss it with their group members to come up with their best group response. Have a class discussion on each group's ideas and record these ideas. Refer to these initial ideas during the section.

The concept of momentum is introduced later in this section. It is not expected that students will apply this concept in their supporting reasons; however, students can try to use reasoning based on the work-energy theorem as they did in the previous section to describe their ideas. They should incorporate the idea that as energy transferred to a passenger increases the likelihood of sustaining an injury increases.

What Do You Think?

A Physicist's Response

The factors that determine the outcome for the passengers of the two vehicles are the mass of each vehicle, the initial velocities of the two vehicles, and the safety features of each vehicle. The faster the vehicles are moving toward each other, and the more massive they are, the more energy they each have to transfer to the other vehicle. This results in more energy being transferred to the passengers in the other vehicle when they collide and increases risk of injury.

Trucks have more mass than small sports cars, so if they are traveling at the same speed toward each other, or even if the truck is traveling at a slightly lower speed than the sports car, the truck will have more energy than the sports car and will transfer more energy to the sports car during the crash. Because more energy will be transferred to the sports car than the truck, the passengers in the sports car are more likely to be injured than the passengers in the truck. Since the sports car does not have a lot of mass, it doesn't take much force to change its motion. Not as much work is required to move the sports car as is needed to move the truck, allowing more energy to be transferred to the passengers. For the very massive truck, most of the energy would go into stopping the truck or changing its motion, and not as much energy would be transferred to moving the passengers. However, serious injuries could still occur for the passengers in the truck.

In general, more massive vehicles are safer for passengers, but in practice, more massive vehicles may not be safer for passengers depending on their structure, the safety features that have been added, and the type of collision. Scientists use a physical quantity known as momentum to analyze collisions. The momentum is given by the mass multiplied by the velocity. Scientists consider how momentum changes from before a collision to after the collision. As the change in momentum increases, the chance of sustaining injury increases, as does the severity of the injury.

student understanding is occurring. Ensure that mass of colliding objects is also considered while students explain momentum and impact velocities.

3. **Students believe that backward momentum or recoil is less than forward momentum in a collision.** Applying the theory of the conservation of momentum, and measuring the mass and velocity of two objects that separate from each other after a collision in which the objects move in opposite directions facilitates students' assessment of forward momentum. They are able recognize the equality of recoil in an action-reaction situation.

Investigate

If you decided to have a discussion during the *Investigate* to guide the students through some of the steps, then let them know now at which step they should stop. Otherwise, have a discussion on the *Investigate* steps and let students begin and complete it. Let students know that the collisions they will be investigating are almost elastic collisions. Perfectly elastic collisions only occur on the molecular level. All other collisions will lose some energy to things such as sound and heat. Emphasize to students that in an elastic collision, the kinetic energy of the colliding objects before the collision is equal to the kinetic energy of the colliding objects after the collision. This means that no energy is transferred to the surroundings and no energy is used to permanently deform either object.

Teaching Tip

Using carts with springs actually reduces the force of the carts on the occupants because the springs lengthen the time that the carts interact. This has no effect on the momentum principles being studied.

Teaching Tip

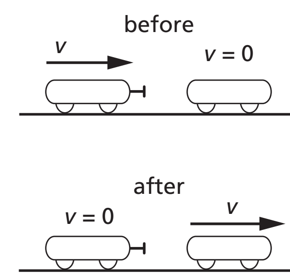
Students should use carts that are in good condition with very low friction. If much friction is present, the carts will slow down immediately after the collision. Have students make their observations for just before, during, and just after the collision.

1.

Student groups should set up the materials and practice a head-on elastic collision between a moving cart and a stationary cart.

2.a)

Students should observe that when the two carts of equal mass have a head-on, elastic collision, the first cart should stop after the collision (or nearly so), and the second cart should leave with a speed equal to that of the moving cart before the collision. Students should record their observations in their log and construct a diagram similar to the following.



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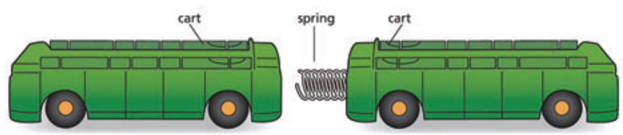


2. Give one cart a small push so that it collides with the second cart. Observe the collision of the moving cart and the target cart.
   a) Record the results in your log. Use a diagram and words to describe what happened to each cart.
3. Repeat the type of collision you just conducted, but this time give the moving cart a larger push so that it hits the target cart with a greater speed.
   a) Describe the results in your log.
   b) How did the results of the collision change from the first time?
   c) Identify a real-life situation that this collision could represent.
4. Double the mass of each cart. Repeat this set of experiments with the two large-mass carts. Compare and contrast the large-mass cart collisions with the small-mass cart collisions.
5. Stage another collision between a stationary small-mass cart and a moving large-mass cart.
   a) Record your observations.
   b) Identify a similar situation in real life, in your log.
   c) Are there any changes in your observations if you increase the speed of the small-mass cart?
6. Stage another collision between a stationary large-mass cart and a moving small-mass cart.
   a) Record your observations.
   b) Identify a similar situation in real life, in your log.
   c) Are there any changes in your observations if you increase the speed of the large-mass cart?
7. You have made observations of what happens when a massive cart hits a less-massive cart. You have also made observations of what happens when the less-massive cart hits the massive cart. Using your observations, conduct an experiment to determine the relative mass of a "mystery" cart of unknown mass compared to a massive cart by staging collisions between them.
   a) Which cart has the greater mass? Describe what you did to decide upon your answer.
   b) Use a scale or balance to check your result. Comment on how well observing collisions between the carts worked as a method of comparing their masses.

3.a)

Students' descriptions and diagrams should indicate that the results are similar to those in *Step 2*, except with a larger incoming and outgoing velocity.

3.b)

Students' responses should note that the outgoing velocity of the target cart would be higher.

3.c)

Students might identify this collision as similar to a rear-end collision between two automobiles of approximately equal mass.

4.

Students observe results like they observed in *Step 3*. The incoming mass should stop, and the target mass moves off with a velocity equal to that of the incoming cart. Similarities in the two collisions would be that in both cases, the moving cart came to rest (or almost to rest) while the target cart moved off with a speed almost equal to that of the moving cart before the collision. Also, in both cases, the target cart continued forward in the same direction as the moving cart was traveling before the collision.

Differences could include the difference in speed between the carts in the two different collisions before and after. The target cart in the second collision will tend to roll further than the target cart in the first collision before coming to a stop.

5.a)

Students should observe that when the moving large-mass cart strikes the stationary small-mass cart, the small-mass cart moves off at a higher velocity than the moving cart had before the collision. The moving cart does not come to a complete stop immediately after the collision, but continues forward at a reduced speed.

5.b)

Students may describe a situation where a heavy truck hits a sports vehicle, or a pickup truck striking a compact car from the rear.

5.c)

As the speed of the large-mass cart increases, the departing speed of both the small-mass and the large-mass carts increases after the collision.

CHAPTER 3

6.a)

Students should observe that when the moving small-mass cart strikes the stationary large-mass cart, the small-mass cart bounces backward, and the large-mass cart moves off with a low speed in the same direction as the small mass had initially.

6.b)

Students might state that this is analogous to a compact vehicle or sports car striking a truck in a rear-end collision.

6.c)

Increasing the speed of the moving small-mass cart before the collision will increase the speed of rebound, and also the speed at which the large-mass cart moves off after the collision.

7.a)

Students should describe the procedures they took to determine the relative mass of a mystery cart. The students should find the cart that has the larger mass using the principles they observed in *Steps 5* and 6. If the moving cart rebounds after the collision it will have the smaller mass. If it continues moving forward after the collision, it will have the larger mass. If the carts have equal mass, then the incoming cart will come to rest after the collision and the second cart will move away.

7.b)

Using a balance should confirm the results stated above. This result is only for a relative mass measurement.

Physics Talk

MOMENTUM

Collisions, like a bat hitting a baseball or a racquet hitting a tennis ball, can be fun in sports. Collisions of automobiles are dangerous and cause injuries and deaths.

What occurs during a collision depends on both the masses of the objects and the velocities of the objects. You observed this with the collisions between carts. **Momentum** is defined as the mass multiplied by velocity and is given the symbol *p*.

$$p = mv$$

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

The collision between a small-mass cart with another small-mass cart was very similar to the collision between a large-mass cart and another large-mass cart. In contrast, the large-mass cart hitting the small-mass cart was quite different as was the small-mass cart hitting the large-mass cart. This provides the insight that it is the relative masses (not the absolute masses) of the colliding objects that are important to observe in deciding what will happen in a collision. All vehicles on the road do not have the same mass. Trucks and large SUVs have greater mass than compact vehicles. All vehicles have much greater mass than people walking or people on bicycles. This makes cars and trucks extremely dangerous to pedestrians.

When the large-mass cart hit the small-mass cart, the small-mass cart moved away from the site of the collision with a higher speed than the large-mass cart had before the collision. In a real accident, if a vehicle were to hit a pedestrian, the pedestrian would move a lot faster than the vehicle was moving. The collision would certainly result in injury to, and possibly death of, the pedestrian.

The damage an automobile can produce is related directly to its momentum. All moving automobiles have a very large momentum because of their large mass. A high-speed automobile can have the same momentum as a slow-moving massive truck. For example:

Vehicle	Mass (kg)	Speed (m/s)	Momentum (kg • m/s) $p = mv$
car	1000	20	20,000
truck	10,000	2	20,000

A tennis ball moving very fast can affect a stationary cart more than a tennis ball moving very slowly. This is similar to the damage small pieces of sand moving at very high speeds can cause (such as when a sand blaster is used to clean various surfaces).

Physics Talk

This *Physics Talk* introduces momentum and the transfer of momentum, and discusses the importance of momentum during collisions.

Have a class discussion on momentum using the information in the student text. Introduce what momentum is (mass multiplied by velocity), and how it is written mathematically. Emphasize that it is a vector quantity. Students are not introduced to the law of conservation of momentum until the next section. However, students should be able to analyze various elastic collisions by considering the relative masses and initial speeds of each of the objects. Encourage students to make connections between their observations and the examples provided in the student text.

In the same way, vehicles have different momenta depending on their mass and velocity. An 18-wheel tractor trailer has a large momentum even if it is moving only a few meters per second, since it has such a large mass. On the other hand, a small automobile (small mass) traveling at very high speeds also has a high momentum due to its speed. The damage done during a collision between objects of such different masses will produce drastically different levels of injury to the passengers in the different vehicles.

Collisions between two objects often involve changes in momentum for each object. When a moving automobile strikes a stationary automobile, the first automobile slows down and the second automobile moves away at some speed. That is, the first automobile loses some of its momentum, and the second automobile picks up some momentum. You will study this relationship in the next section.

Checking Up

1. Which object has greater momentum, a butterfly traveling at 16 km/h (10 mi/h) or an eagle traveling at 16 km/h (10 mi/h)?
2. Describe how the transfer of momentum works.
3. Using what you know of momentum, describe what would happen if a car hit a skateboarder.

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
•			

Calculating Momentum

An automobile with a mass of 1000 kg is moving at 20 m/s (approximately 40 mph). Its momentum is

$p = mv$

$p = (1000\ \text{kg})(20\ \text{m/s})$

$p = 20{,}000\ \text{kg} \cdot \text{m/s}$

Approximate the masses of the following objects and calculate how fast each would have to be traveling to have the same momentum as the automobile.

a) truck

b) SUV

c) bicycle

d) baseball

e) bowling ball

What Do You Think Now?

At the beginning of this activity you were asked:

- **A small sports automobile hits a heavy truck in a collision. What factors determine the outcome for the passengers of the two vehicles?**
- **Which driver will sustain worse injuries? Why?**

Checking Up

1.

If two objects have the same speed, then the object with the greater mass has the greater momentum. In this case, the eagle has greater momentum than the butterfly.

2.

Students' descriptions should include that a change in motion indicates a transfer of momentum. Encourage students to provide examples such as those from their *Investigate* observations. They may say, "When two objects of equal mass collide elastically, where initially one object is at rest, after the collision the object that was at rest moves away and the object that was initially moving stops moving. This shows a transfer of momentum from one object to the other."

3.

Students' responses should indicate an understanding of how mass plays an important role in collisions and the transfer of momentum. Encourage students to support their responses using their observations from the *Investigate*. When a vehicle strikes a skateboarder, it transfers momentum to the skateboarder. The skateboarder's speed will increase in the direction that the vehicle was moving in, and the skateboarder is likely to sustain severe injuries.

Active Physics Plus

This *Active Physics Plus* is geared toward increasing students' ability to apply the concept of momentum to solve problems algebraically. Review the example of calculating the momentum of an automobile. Have a discussion of students' responses for *Steps a)* through *e)*. Students may have different estimates of the mass of each object however they should not be very far off.

a)

The approximate mass of a truck is 10,000 kg (about 22,000 lbs). For a truck to have a momentum of $p = 20{,}000\ \text{kg} \cdot \text{m/s}$, it must have a speed of

$$v = \frac{p}{m} = \frac{20{,}000\ \text{kg} \cdot \text{m/s}}{10{,}000\ \text{kg}} =$$

2 m/s (≈ 4 mi/h), about fifteen times the speed of a garden snail.

CHAPTER 3

b)

The approximate mass of an SUV is 4000 kg (about 8800 lbs). For an SUV to have a momentum of $p = 20{,}000\ \text{kg}\cdot\text{m/s}$, it must have a speed of

$$v = \frac{p}{m} = \frac{20{,}000\ \text{kg}\cdot\text{m/s}}{4000\ \text{kg}} =$$

$5\ \text{m/s}$ $(\approx 11\ \text{mi/h})$, about half the average walking speed.

c)

The approximate mass of a bicycle is 14 kg (about 30 lbs). For a bicycle to have a momentum of $p = 20{,}000\ \text{kg}\cdot\text{m/s}$, it must have a speed of

$$v = \frac{p}{m} = \frac{20{,}000\ \text{kg}\cdot\text{m/s}}{14\ \text{kg}} =$$

$1400\ \text{m/s}$ $(\approx 3100\ \text{mi/h})$, about the wind speed of a tornado.

d)

The approximate mass of a baseball is 0.15 kg (about 0.33 lbs). For a baseball to have a momentum of $p = 20{,}000\ \text{kg}\cdot\text{m/s}$, it must have a speed of

$$v = \frac{p}{m} = \frac{20{,}000\ \text{kg}\cdot\text{m/s}}{0.15\ \text{kg}} =$$

$130{,}000\ \text{m/s}$ $(\approx 290{,}000\ \text{mi/h})$,

almost 400 times the speed of sound in air at sea level and 0°C, and more than the escape velocity needed to leave Earth's atmosphere.

e)

The approximate mass of a bowling ball is 5 kg (about 12 lbs). For a bowling ball to have a momentum of $p = 20{,}000\ \text{kg}\cdot\text{m/s}$, it must have a speed of

$$v = \frac{p}{m} = \frac{20{,}000\ \text{kg}\cdot\text{m/s}}{5\ \text{kg}} =$$

Based on the relative amounts of momentum, what is the outcome of a head-on collision between a heavy truck and a small sports automobile if both have the same speed? How do your ideas now compare to your initial ideas?

Physics Essential Questions

What does it mean?

Define momentum and explain under what circumstances a compact automobile could have the same momentum as a more massive sport utility vehicle.

How do you know?

Explain, using two sets of observations, how you can determine the relative masses of two carts by observing collisions.

Why do you believe?

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

* Physicists define new quantities because they are useful in describing real events. Mass and velocity are two easily observable quantities. Why did physicists introduce the term momentum?

Why should you care?

How will the design of your safety system for the *Chapter Challenge* take into account the speed, thus momentum, of the cart carrying the egg?

Reflecting on the Section and the Challenge

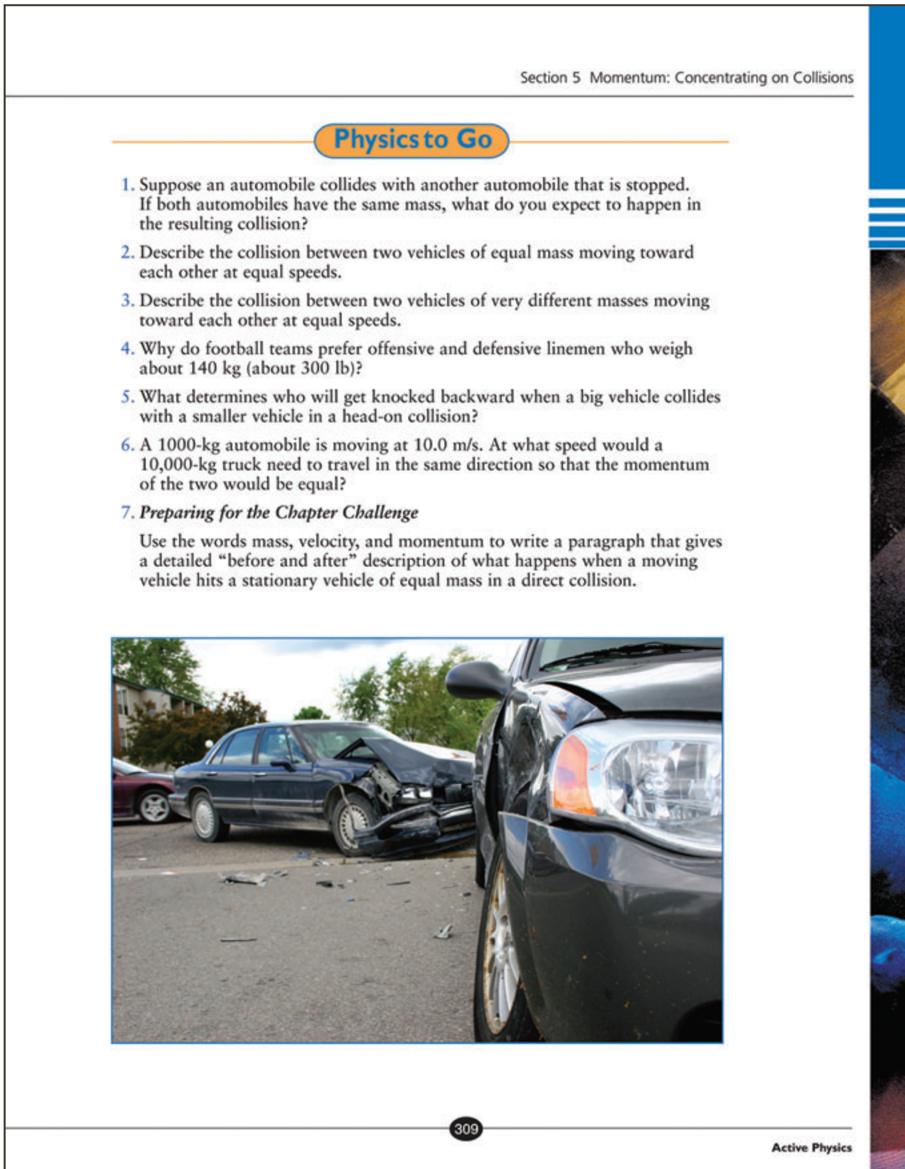
In collisions between objects of equal mass, the resulting effect on each object is pretty much the same. But when one vehicle is much more massive than the second one, as in the case of the cart and a tennis ball or a heavy truck colliding head-on with a sports automobile, the results for the smaller vehicle is often disastrous. The object with the low mass suffers the most drastic damage.

The key to understanding collisions is to calculate the momentum of each colliding object. Momentum is mass multiplied by velocity. This is also written as $p = mv$. Objects with a small mass and high speed can have the same momentum as massive objects moving at slow speeds. An automobile with a mass of 1000 kg moving at 5 m/s (10 mph) has an enormous momentum and would severely injure any pedestrian upon contact.

$4000\ \text{m/s}$ $(\approx 9000\ \text{mi/h})$, ten times greater than the speed of sound in air.

What Do You Think Now?

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



Physics to Go

1. Suppose an automobile collides with another automobile that is stopped. If both automobiles have the same mass, what do you expect to happen in the resulting collision?
2. Describe the collision between two vehicles of equal mass moving toward each other at equal speeds.
3. Describe the collision between two vehicles of very different masses moving toward each other at equal speeds.
4. Why do football teams prefer offensive and defensive linemen who weigh about 140 kg (about 300 lb)?
5. What determines who will get knocked backward when a big vehicle collides with a smaller vehicle in a head-on collision?
6. A 1000-kg automobile is moving at 10.0 m/s. At what speed would a 10,000-kg truck need to travel in the same direction so that the momentum of the two would be equal?
7. ***Preparing for the Chapter Challenge***

   Use the words mass, velocity, and momentum to write a paragraph that gives a detailed "before and after" description of what happens when a moving vehicle hits a stationary vehicle of equal mass in a direct collision.

Reflecting on the Section and the Challenge

Have a discussion on how collisions involving objects of similar and different masses affect the amount of damage and possible injury. Then emphasize that momentum is a key concept in understanding collisions. Remind students that momentum is the mass multiplied by the velocity, and that the greater the momentum of an object, the greater the damage it can do when it collides with another object.

Physics Essential Questions

What does it mean?

Momentum is the product of mass and velocity $p = mv$. A massive sport utility vehicle with a small velocity can have the same momentum as a compact vehicle with a large velocity.

How do you know?

If a moving vehicle collides elastically with a stationary vehicle and both vehicles move forward after the collision, then the moving vehicle is more massive. If the moving vehicle moves backward after the collision, it is less massive.

Why do you believe?

Momentum is defined because in a collision it is the momentum, not the mass nor the velocity alone that informs you about the collision.

Why should you care?

The more momentum the egg has, the more protection it will need.

Physics to Go

1.

Students should refer to the observations from the *Investigate* to support their responses. If the collision is elastic, then the momentum of the moving automobile is transferred to the automobile initially at rest. The automobile initially moving will come to rest, while the automobile initially at rest will move off with a speed equal to that of the other automobile's initial speed.

2.

Since students have not yet been introduced to the law of conservation of momentum, they should reason this problem out using evidence from the *Investigate*. Students should assume the collision is elastic, and consider what would happen if the first vehicle was moving and the second vehicle was not moving, but at rest. This would result in the same answer as in *Question 1*, resulting in all the momentum of the first vehicle being transferred to the second vehicle. Similarly, if the second vehicle was moving and the first vehicle was at rest, all of the second vehicle's momentum would be transferred to the first vehicle. Since the vehicles are the same mass, after the collision both vehicles will move away from each other with the same speed.

3.

If two vehicles, one much more massive than the other, traveling at equal speeds collide head-on, the more massive vehicle will continue moving in its original direction at a reduced speed. The less massive vehicle will reverse its direction. This is one of the reasons why heavier vehicles are considered safer. Encourage students to use their observations from the *Investigate* to support their responses.

4.

It is more difficult to change an object's momentum as its mass increases hence, it is more difficult to change the momentum of a massive person. The more mass means the more inertia, which means the more massive the linemen, the more difficult it is to get them moving if they are stopped, or stop them if they are moving.

5.

For an elastic collision, it is the relative masses of the vehicles that determine which vehicle gets knocked backward if one of the vehicles is initially at rest.

Note: Because one can always move into an inertial reference frame where one of the objects is initially at rest, the description is as general as both objects initially moving toward each other.

6.

The momentum of the automobile is $p_{car} = (1000\text{ kg})(10\text{ m/s}) =$

$10{,}000\text{ kg}\cdot\text{m/s}$.

The momentum of the truck is the same as that of the automobile, so its speed can be calculated using

$$v = \frac{p}{m} = \frac{(10{,}000\text{ kg}\cdot\text{m/s})}{10{,}000\text{ kg}} = 1\text{ m/s}.$$

7.

Preparing for the Chapter Challenge

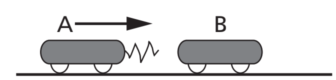
Consider having students support their claims with the evidence from the *Investigate*. Students should have the following information in their paragraph:

When vehicles of equal mass collide elastically, and one vehicle is initially stationary, the vehicles trade conditions following the collision. The vehicle that was originally moving is stationary after the collision, and the vehicle that was originally stationary is moving at about the same speed as the initial speed of the other vehicle.

SECTION 5 QUIZ

3-5a **Blackline Master**

1. The diagram at right shows a collision between two carts of equal mass. Cart A has a spring on the front and is moving forward, while cart B is at rest. After cart A hits cart B, which of the following will occur?



   a) Cart A stops and cart B moves forward.

   b) Cart A continues forward with the same speed as cart B.

   c) Cart A bounces backward and cart B stays at rest.

   d) Cart A bounces backward and cart B moves forward.

2. In *Question 1*, cart B now has a mass double that of cart A when the collision occurs. After cart A hits cart B, which of the following will occur?

   a) Cart A stops and cart B moves forward.

   b) Cart A continues forward with the same speed as cart B.

   c) Cart A bounces backward and cart B stays at rest.

   d) Cart A bounces backward and cart B moves forward.

3. Football players A and B both have the same momentum when running downfield. Football player A has a mass of 100 kg, while player B has a mass of 120 kg. Which statement below must be true?

   a) Player A is running faster than player B.

   b) Player B is running faster than player A.

   c) Both players must be running with the same speed.

   d) Both players must have the same kinetic energy.

4. A student does an experiment to check the mass of a cart. The student sends a 1.0-kg cart with a spring attached at the front end into a collision with a cart of unknown mass. After the collision, the student notes that the 1.0-kg cart moves forward with reduced speed, and the unknown cart moves forward at a faster speed than the 1.0-kg cart. What does this experiment show about the mass of the unknown cart?

   a) The unknown cart is more than 1.0 kg.

   b) The unknown cart is 1.0 kg.

   c) The unknown cart is less than 1.0 kg.

   d) No information about the mass of the unknown cart can be obtained from this experiment.

CHAPTER 3

5. The product of an object's mass and velocity is

a) force.

b) kinetic energy.

c) weight.

d) momentum.

SECTION 5 QUIZ ANSWERS

1. a) Cart A stops and cart B moves forward.
2. d) Cart A bounces backward and cart B moves forward.
3. a) Player A is running faster than Player B.
4. c) The unknown cart is less than 1.0 kg.
5. d) momentum.

NOTES