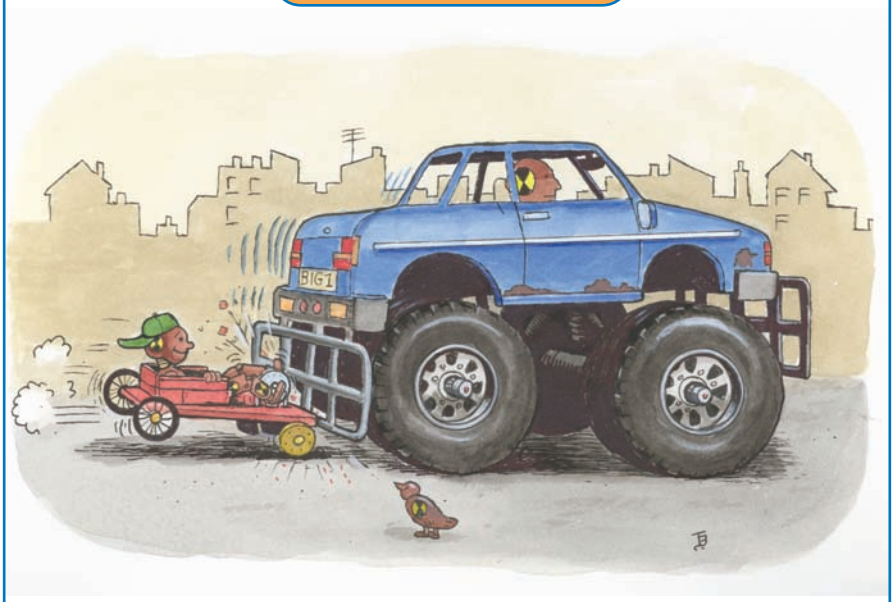
Section 5 Momentum: Concentrating on Collisions

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?

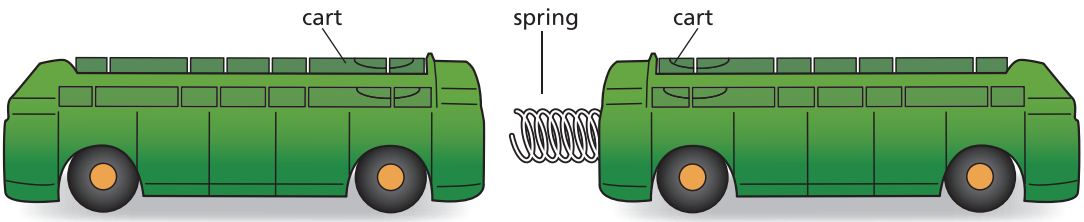
Automobile collisions are a leading cause of injury and death among teenagers.

- **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.



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.

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.

Physics Words

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

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*.

$$p = mv$$

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).

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.

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Calculating Momentum

An automobile with a mass of 1000 kg is moving at 20 m/s (approximately 40 mi/h). 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 section, 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?**

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 mi/h) has an enormous momentum and would severely injure any pedestrian upon contact.

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.