8 MOMENTUM

Objectives

- Define momentum. (8.1)
- Define impulse and describe how it affects changes in momentum. (8.2)
- Explain why an impulse is greater when an object bounces than when the same object comes to a sudden stop. (8.3)
- State the law of conservation of momentum. (8.4)
- Describe how the conservation of momentum applies to collisions. (8.5)
- Describe how the vector nature of momentum affects the law of conservation of momentum. (8.6)

discover!

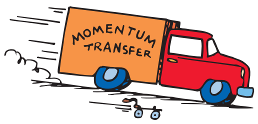
MATERIALS five marbles, ruler

EXPECTED OUTCOME When a marble or marbles collide with the marbles at rest, the momentum is the same before and after the collision. As a result, the same number of marbles emerges at the same speed on the other side.

ANALYZE AND CONCLUDE

1. When one marble collides with 5 marbles, the colliding marble stops and one marble emerges at the same speed on the other side. When 2 marbles collide with 4 marbles, 2 marbles emerge at the same speed. The pattern continues with more marbles.
2. The speed and number of marbles
3. Three marbles move to the right and two marbles move to the left.

8 MOMENTUM



THE BIG IDEA Momentum is conserved for all collisions as long as external forces don't interfere.

Have you ever wondered how a tae kwon do expert can break a stack of cement bricks with the blow of a bare hand? Or why falling on a wooden floor hurts less than falling on a cement floor? Or why follow-through is important in golf, baseball, and boxing? To understand these things, you need to recall the concept of inertia introduced and developed when we discussed Newton's laws of motion. Inertia was discussed both in terms of objects at rest and objects in motion. In this chapter we are concerned only with the concept of inertia in motion—momentum.

discover!

How Does a Collision Affect the Motion of Marbles?

1. Place five marbles, all identical in size and shape, in the center groove of a ruler. Launch a sixth marble toward the five stationary marbles. Note any changes in the marbles' motion.
2. Now launch two marbles at four stationary marbles. Then launch three marbles at three stationary marbles, and so on. Note any changes in the marbles' motion.
3. Remove all but two marbles from the groove. Roll these two marbles at each other with equal speeds. Note any changes in the marbles' motion.

Analyze and Conclude

1. **Observing** How did the approximate speed of the marbles before each collision compare to after each collision?
2. **Drawing Conclusions** What factors determine how the speed of the marbles changes in a collision?
3. **Predicting** What do you think would happen if three marbles rolling to the right and two marbles rolling to the left with the same speed were to collide?

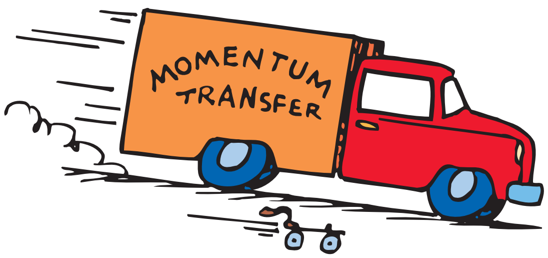


FIGURE 8.1 A truck rolling down a hill has more momentum than a roller skate with the same speed. But if the truck is at rest and the roller skate moves, then the skate has more momentum.

8.1 Momentum

We know that it's harder to stop a large truck than a small car when both are moving at the same speed. We say the truck has more momentum than the car. By momentum, we mean *inertia in motion*. More specifically, **momentum** is the mass of an object multiplied by its velocity.

$$\text{momentum} = \text{mass} \times \text{velocity}$$

or, in abbreviated notation,

$$\text{momentum} = mv$$

When direction is not an important factor, we can say

$$\text{momentum} = \text{mass} \times \text{speed}$$

which we still abbreviate *mv*.

A moving object can have a large momentum if it has a large mass, a high speed, or both. A moving truck has more momentum than a car moving at the same speed because the truck has more mass. But a fast car can have more momentum than a slow truck. And a truck at rest has no momentum at all. Figure 8.1 compares the momentum of a truck to that of a roller skate.

CONCEPT CHECK What factors affect an object's momentum?

think!

Can you think of a case where the roller skate and the truck shown in Figure 8.1 would have the same momentum?
Answer: 8.1

8.2 Impulse Changes Momentum

If the momentum of an object changes, either the mass or the velocity or both change. If the mass remains unchanged, as is most often the case, then the velocity changes and acceleration occurs. What produces acceleration? We know the answer is *force*. The greater the force acting on an object, the greater its change in velocity, and hence, the greater its change in momentum.

8.1 Momentum

Key Term
momentum

Teaching Tip State that just as a large truck and a roller skate have different masses, a moving large truck and a moving roller skate have different momenta. Define and discuss momentum as moving mass—inertia in motion.

Ask **Will a large truck always have more momentum than a roller skate?** *No, a large truck at rest has no momentum. A moving roller skate has momentum.*

CONCEPT CHECK A moving object can have a large momentum if it has a large mass, a high speed, or both.

Teaching Resources

- **Reading and Study Workbook**
- **Presentation*EXPRESS***
- **Interactive Textbook**
- **Next-Time Question** *8-1*
- **Conceptual Physics Alive! DVDs** *Momentum*

8.2 Impulse Changes Momentum

Key Term
impulse

Common Misconceptions
Impulse equals momentum.

FACT Impulse equals *change* in momentum.

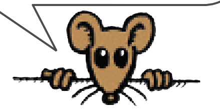
Teaching Tip Derive the impulse–momentum relationship. Equate the two definitions of acceleration: $F/m = \Delta v/t$. A simple algebraic rearrangement yields $Ft = \Delta(mv)$.

▶ **Teaching Tip** Choose your examples of changing momentum in careful sequence. First, describe those where the objective is to increase momentum (e.g., pulling a sling shot or arrow in a bow all the way back, the effect of a long cannon for maximum range, and driving a golf ball). Second, describe cases in which the objective is to minimize a force when decreasing momentum (e.g., pulling your hand backward when catching a ball, driving into a haystack vs. into a concrete wall, and falling on a spongy surface rather than on a rigid one). Last, describe examples where the objective is to maximize forces when decreasing momentum (e.g., karate chops).

Many interactions that are explainable by Newton's third law can also be explained by momentum conservation. Newton's laws flow nicely into momentum and its conservation.

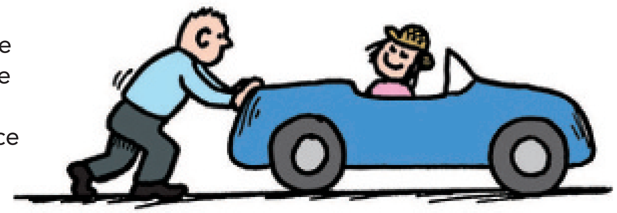
PAUL

The derivation of $Ft = \Delta(mv)$ is given in Appendix G, Note 8.2.



Impulse ✓ **The change in momentum depends on the force that acts and the length of time it acts.** As Figure 8.2 shows, apply a brief force to a stalled automobile, and you produce a change in its momentum. Apply the same force over an extended period of time and you produce a greater change in the automobile's momentum. A force sustained for a long time produces more change in momentum than does the same force applied briefly. So both force and time are important in changing an object's momentum.

FIGURE 8.2 ▶
When you push with the same force for twice the time, you impart twice the impulse and produce twice the change in momentum.



The quantity *force* × *time interval* is called **impulse.** In shorthand notation,

$$\text{impulse} = Ft$$

The greater the impulse exerted on something, the greater will be the change in momentum. The exact relationship[8.2] is

$$\text{impulse} = \text{change in momentum}$$

or

$$Ft = \Delta(mv)$$

The impulse–momentum relationship helps us to analyze a variety of situations where the momentum changes. Consider the familiar examples of impulse in the following cases of increasing and decreasing momentum.

Increasing Momentum To increase the momentum of an object, it makes sense to apply the greatest force possible for as long as possible. A golfer teeing off and a baseball player trying for a home run do both of these things when they swing as hard as possible and follow through with their swing.

The forces involved in impulses usually vary from instant to instant. Look at Figure 8.3. A golf club that strikes a golf ball exerts zero force on the ball until it comes in contact with it; then the force increases rapidly as the ball becomes distorted. The force then diminishes as the ball comes up to speed and returns to its original shape. So when we speak of such forces in this chapter, we mean the *average* force.

FIGURE 8.3 ▲
The force of impact on a golf ball varies throughout the duration of impact.

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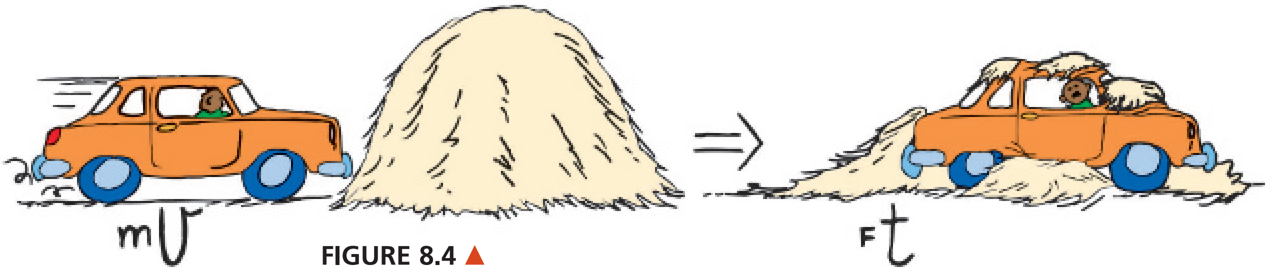


FIGURE 8.4 ▲
If the change in momentum occurs over a long time, the force of impact is small.

Decreasing Momentum If you were in a car that was out of control and had to choose between hitting a haystack, as in Figure 8.4 or a concrete wall as in Figure 8.5, you wouldn't have to call on your knowledge of physics to make up your mind. Common sense tells you to choose the haystack. But knowing the physics helps you to understand *why* hitting a soft object is entirely different from hitting a hard one.

In the case of hitting either the wall or the haystack and coming to a stop, your momentum is decreased by the same impulse. The same impulse does not mean the same amount of force or the same amount of time; rather it means the same *product* of force and time. By hitting the haystack instead of the wall, you extend the contact time—*the time during which your momentum is brought to zero.* A longer contact time reduces the force and decreases the resulting deceleration. For example, if the time is extended 100 times, the force of impact is reduced 100 times. Whenever we wish the force to be small, we extend the time.

We know that a padded dashboard in a car is safer than a rigid metal one and that airbags save lives. You also know that to catch a fast-moving ball safely with your bare hand—you extend your hand forward so there's plenty of room for it to move backward after making contact with the ball. When you extend the time of contact, you reduce the force of the catch.

think!

When a dish falls, will the impulse be less if it lands on a carpet than if it lands on a hard floor?
Answer: 8.2.1

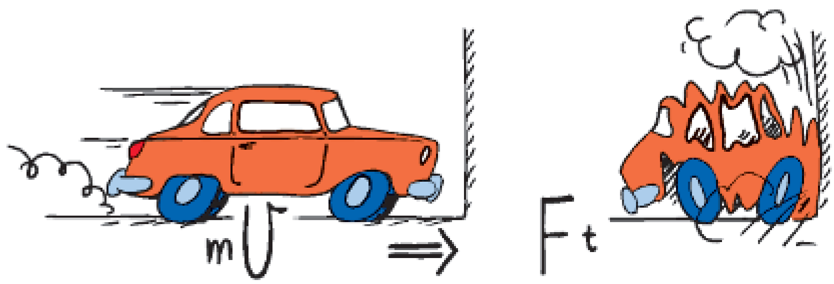
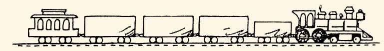


FIGURE 8.5 ▲
If the change in momentum occurs over a short time, the force of impact is large.

▶ **Teaching Tip** Use the loose coupling between railroad cars as a very good example of the impulse–momentum relationship. The slack in the coupling of railroad cars is evident when a locomotive either brings a long train from rest into motion, or when it brings a moving train to rest.



In both cases a cascade of clanks is heard as each car in turn is engaged. Without the loose coupling, a locomotive might simply sit still and spin its wheels. The friction force between the wheels and the track is simply inadequate to set the entire mass of the train in motion. There is, however, enough friction to set one car in motion so the slack allows the locomotive to get one car going. Then, when the coupling is tight, the next car is set in motion. When the coupling for two cars is tight, the third car is set in motion, and so on until the whole train is given momentum. The slack allows the required impulse to be broken into a series of smaller impulses, so that the friction between the locomotive wheels and the track can do the job.

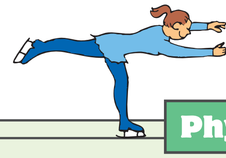
Ask **Why is falling on a floor with more give less dangerous than falling on a floor with less give?** *Because the floor with more give allows a greater time for the impulse that reduces the momentum of fall to zero. A greater time for a change in momentum results in less force.*

▶ **Teaching Tip** Have your students design and construct a case to hold an egg that is to be dropped from a three- or four-story building without breaking. Be sure students see that the key consideration is maximizing the time of impact in order to minimize the force of impact. The design cannot include means to increase air resistance, so all cases should strike the ground with about the same speed. By requiring the masses of all cases to be the same, the impulses of all will be the same upon impact. The force of impact, of course, should be minimized by maximizing the time of impact.

CONCEPT CHECK The change in momentum depends on the force that acts and the length of time it acts.

Teaching Resources

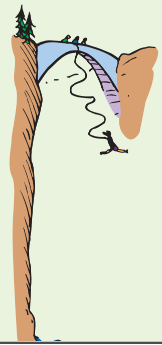
- **Reading and Study Workbook**
- **Problem-Solving Exercises in Physics** *5-1*
- **Laboratory Manual** *23*
- **Transparency** *11*
- **Presentation*EXPRESS***
- **Interactive Textbook**



Physics of Sports

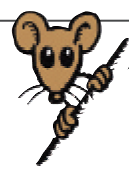
Bungee Jumping

The impulse–momentum relationship is put to a thrilling test during bungee jumping. Be glad the rubber cord stretches when the jumper's fall is brought to a halt, because the cord has to apply an impulse equal to the jumper's momentum in order to stop the jumper—hopefully above ground level.



Note how $Ft = \Delta(mv)$ applies here. The momentum, mv, we wish to change is the amount gained before the cord begins stretching. Ft is the impulse the cord supplies to reduce the momentum to zero. Because the rubber cord stretches for a long time, a large time interval t ensures that a small average force F acts on the jumper. Elastic cords typically stretch to twice their original length during the fall.

Whether body A acts on body B, or body B acts on body A, in accordance with Newton's third law, both have the same amount of impulse Ft.



When jumping from an elevated position down to the ground, you should bend your knees when your feet make contact with the ground. By doing so you extend the time during which your momentum decreases by 10 to 20 times that of a stiff-legged, abrupt landing. The resulting force on your bones is reduced by 10 to 20 times. A wrestler thrown to the floor tries to extend his time of hitting the mat by relaxing his muscles and spreading the impulse into a series of smaller ones as his foot, knee, hip, ribs, and shoulder successively hit the mat. Of course, falling on a mat is preferable to falling on a solid floor because the mat also increases the stopping time.

When a boxer gets punched, the impulse provided by the boxer's jaw must counteract the momentum of the punch. As Figure 8.6a shows, when the boxer moves away from the punch, he increases the time of contact and reduces the force. When the boxer moves toward the punch, as in Figure 8.6b, the time of contact is reduced and the force is increased.

think!

If the boxer in Figure 8.6 is able to make the contact time five times longer by "riding" with the punch, how much will the force of the punch impact be reduced?
Answer: 8.2.2

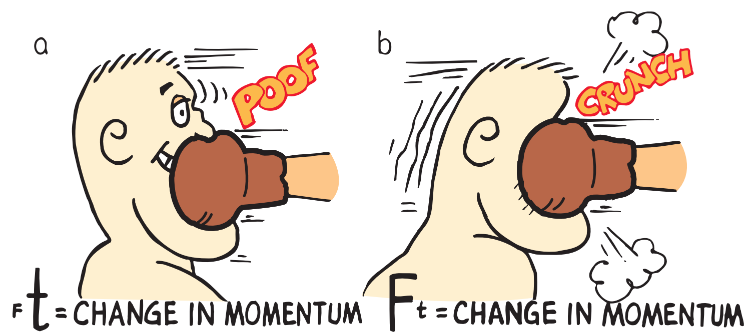


FIGURE 8.6 ▲
The impulse provided by a boxer's jaw counteracts the momentum of the punch. **a.** The boxer moves away from the punch. **b.** The boxer moves toward the punch. Ouch!

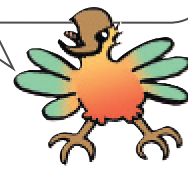
We know a glass dish is more likely to survive if it is dropped on a carpet rather than a sidewalk because the carpet has more "give" than the sidewalk. Ask why a surface with more give makes for a safer fall and you will get a puzzled response from most people. They may simply say, "Because it gives more." However, your question is, "*Why* is a surface with more give safer for the dish?" In this case, a common explanation isn't enough. A deeper explanation is needed.

To bring the dish or its fragments to rest, the carpet or the sidewalk must provide an impulse, which you know involves two variables—force and time. Since time is longer hitting the carpet than hitting the sidewalk, a smaller force results. The shorter time hitting the sidewalk results in a greater stopping force. The safety net used by circus acrobats is a good example of how to achieve the impulse needed for a safe landing. The safety net reduces the stopping force on a fallen acrobat by substantially increasing the time interval of the contact.

Sometimes a difference in time is important even if you can't notice the give in a surface. For example, a wooden floor and a concrete floor may both seem rigid, but the wooden floor can have enough give to make quite a difference in the forces that these two surfaces exert.

CONCEPT CHECK What factors affect how much an object's momentum changes?

A flower pot dropped onto your head bounces quickly. Ouch! If bouncing took a longer time, as with a safety net, then the force of the bounce would be much smaller.



8.3 Bouncing

If a flower pot falls from a shelf onto your head, you may be in trouble. If it bounces from your head, you may be in more serious trouble. Why? Because impulses are greater when an object bounces. ✓ **The impulse required to bring an object to a stop and then to "throw it back again" is greater than the impulse required merely to bring the object to a stop.** Suppose, for example, that you catch the falling pot with your hands. You provide an impulse to reduce its momentum to zero. If you throw the pot upward again, you have to provide additional impulse. It takes a greater impulse to catch the pot *and* throw it back up than merely to catch it. This increased amount of impulse is supplied by your head if the pot bounces from it. The karate expert in Figure 8.7 strikes the bricks in such a way that her hand is made to bounce back, yielding as much as twice the impulse to the bricks.

FIGURE 8.7 ▲
Cassy imparts a large impulse to the bricks in a short time and produces considerable force.

8.3 Bouncing

▶ **Teaching Tip** Explain that the magnitude of an impact force when bouncing occurs depends on impact time. For an elastic collision where momentum is reversed, and $\Delta(mv)$ is twice that of merely halting, impulse is doubled. Although impulse is greater for bouncing, impact may or may not depend on time.

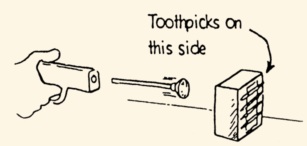
▶ **Teaching Tip** Explain that if the impulse is over a short time, impact force is large.

A karate expert does not pull back upon striking his target. He strikes in such a way that his hand is made to bounce back, yielding up to twice the impulse to his target.

PAUL

Demonstration

Tape some toothpicks to one side of a floppy disk box. Fire a dart from a dart gun against the smooth side of the box. The dart sticks and the box slides an observed distance across the table. Then repeat, but with the box turned around so the dart hits the toothpick side. When the dart hits, it bounces. Note the appreciably greater distance the box slides!



CONCEPT CHECK The impulse required to bring an object to a stop and then to "throw it back again" is greater than the impulse required merely to bring the object to a stop.

8.4 Conservation of Momentum

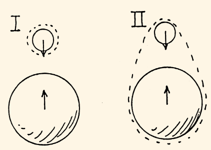
Key Term
law of conservation of momentum

Either Newton's third law or momentum conservation can be considered fundamental. That is, momentum conservation can be a consequence of Newton's third law, or just as well, Newton's third law can be a consequence of momentum conservation.

PAUL

▶ **Teaching Tip** Distinguish between external forces and internal forces (e.g., the difference between sitting inside a car and pushing on the dashboard and standing outside and pushing against the outside of the car). Point out that only an external force will produce a change in the momentum of the car. When $F = 0$, $\Delta(mv) = 0$.

▶ **Teaching Tip** Discuss the idea of isolating a system when applying the conservation of momentum. We isolate a system in space by imagining a dotted boundary line around the perimeter of the system, and we isolate a system in time by considering only the duration of the interaction.



Show that where momentum may be conserved for a particular system, it may not be conserved for part of the system.

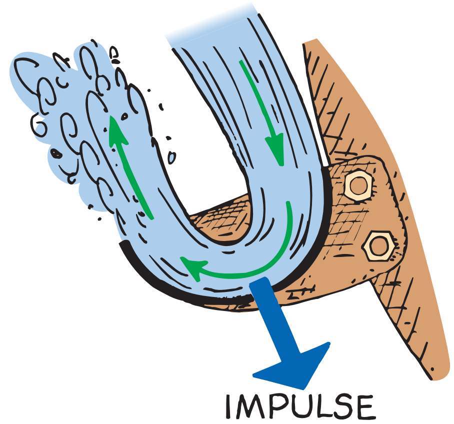


FIGURE 8.8 ▶
The curved blades of the Pelton Wheel cause water to bounce and make a U-turn, producing a large impulse that turns the wheel.

The fact that impulses are greater when bouncing takes place was used with great success during the California Gold Rush. The waterwheels used in gold mining operations were not very effective. A man named Lester A. Pelton saw that the problem had to do with the flat paddles on the waterwheel. He designed the curve-shaped paddle that is shown in Figure 8.8. This paddle caused the incoming water to make a U-turn upon impact with the paddle. Because the water "bounced," the impulse exerted on the waterwheel was increased. Pelton patented his idea and probably made more money from his invention, the Pelton Wheel, than any of the gold miners earned. Physics can indeed make you rich!

CONCEPT CHECK **How does the impulse of a bounce compare to stopping only?**

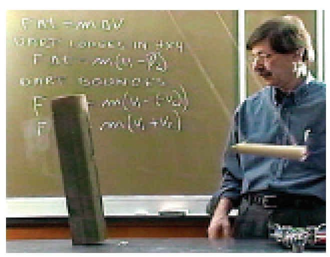


FIGURE 8.9 ▲
Teacher Howie Brand shows that the block topples when the swinging dart bounces from it. When he removes the rubber head of the dart so it doesn't bounce when it hits the block, no toppling occurs.

8.4 Conservation of Momentum

From Newton's second law you know that to accelerate an object, a net force must be applied to it. This chapter says much the same thing, but in different language. If you wish to change the momentum of an object, exert an impulse on it.

In either case, the force or impulse must be exerted on the object by something outside the object. Internal forces won't work. For example, the molecular forces within a basketball have no effect on the momentum of the basketball, just as a push against the dashboard of a car you're sitting in does not affect the momentum of the car. Molecular forces within the basketball and a push on the dashboard are internal forces. They come in balanced pairs that cancel within the object. To change the momentum of the basketball or the car, an outside push or pull is required. If no outside force is present, no change in momentum is possible.

Consider the cannon being fired in Figure 8.10. The force on the cannonball inside the cannon barrel is equal and opposite to the force causing the cannon to recoil. Recall Newton's third law about action and reaction forces. These forces are internal to the system comprising the cannon and the cannonball, so they don't change the momentum of the cannon–cannonball system. Before the firing, the system is at rest and the momentum is zero. After the firing the net momentum, or total momentum, is *still* zero. Net momentum is neither gained nor lost. Let's consider the effects of internal and external forces carefully.

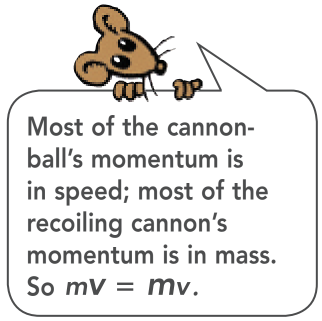
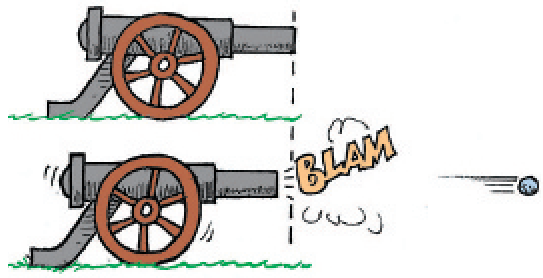


FIGURE 8.10 ▶
The momentum before firing is zero. After firing, the net momentum is still zero because the momentum of the cannon is equal and opposite to the momentum of the cannonball.



Momentum, like the quantities velocity and force, has both direction and magnitude. It is a *vector quantity.* Like velocity and force, momentum can be canceled. So, although the cannonball in the preceding example gains momentum when fired and the recoiling cannon gains momentum in the opposite direction, the cannon–cannonball *system* gains none. The momenta (plural form of momentum) of the cannonball and the cannon are equal in magnitude and opposite in direction. Therefore, these momenta cancel each other out for the system as a whole. No external force acted on the system before or during firing. Since no net force acts on the system, there is no net impulse on the system and there is no net change in the momentum.

In every case, the momentum of a system cannot change unless it is acted on by external forces. A system will have the same momentum before some internal interaction as it has after the interaction occurs. When momentum, or any quantity in physics, does not change, we say it is *conserved.* The **law of conservation of momentum** describes the momentum of a system. ✅ **The law of conservation of momentum states that, in the absence of an external force, the momentum of a system remains unchanged.** If a system undergoes changes wherein all forces are internal as for example in atomic nuclei undergoing radioactive decay, cars colliding, or stars exploding, the net momentum of the system before and after the event is the same.

CONCEPT CHECK What does the law of conservation of momentum state?

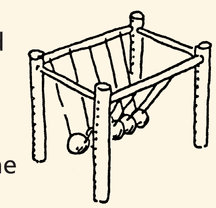
Go Online SCI LINKS NSTA
For: Links on momentum
Visit: www.SciLinks.org
Web Code: csn – 0804

think!
Newton's second law states that if no net force is exerted on a system, no acceleration occurs. Does it follow that no change in momentum occurs?
Answer: 8.4

▶ **Teaching Tip** Consider a dropped rock in free fall. If the system is taken to be the rock, then momentum is not conserved as it falls because an external force acts on the system (its vector is seen to penetrate the dotted border of the system). This external force, gravity, produces an impulse on the rock that changes its momentum. If the system is instead considered to be the rock and Earth, then the interaction between the rock and Earth is internal to the system (there is no penetrating vector). For this larger system, momentum is conserved. That is, the momentum of Earth as it "races up" to meet the falling rock is equal and opposite to the momentum of the rock as it drops to meet Earth (at its center of mass). The momentum of any interaction is always conserved if you make your system big enough.

Demonstration

Use the popular swinging balls apparatus to demonstrate momentum conservation. Show students that when the balls on one side are lifted and released so they make contact with the others, the momentum of balls is the same before and after the collision—the same number of balls emerge at the same speed on the other side.



CONCEPT CHECK The law of conservation of momentum states that, in the absence of an external force, the momentum of a system remains unchanged.

discover!

MATERIALS skateboard, heavy object

EXPECTED OUTCOME You only move when you release the object.

THINK In both Steps 1 and 2, the total momentum is zero. In order for momentum to be conserved in Step 1, you must move in the opposite direction that the object moves. In order for the total momentum to be conserved in Step 2, you must stay at rest because the object does not move away.

Teaching Resources

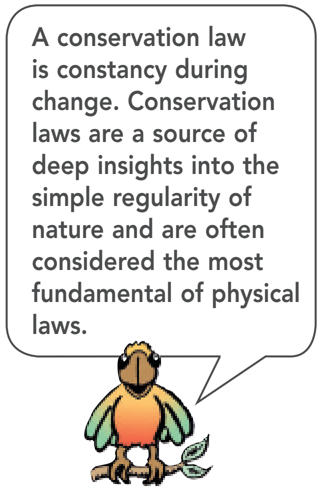
- Reading and Study Workbook
- Probeware Lab Manual *6*
- Presentation*EXPRESS*
- Interactive Textbook

8.5 Collisions

Key Terms
elastic collision, inelastic collision

Common Misconceptions
Momentum is conserved only when collisions are perfectly elastic.

FACT Even in an inelastic collision, the net momentum before the collision is equal to the net momentum after the collision.



discover!

How Are Motion and Conservation of Momentum Related?

1. Stand at rest on a skateboard and throw a massive object forward or backward. What do you notice?
2. Repeat the throwing motion in Step 1, but this time don't let go of the object. What do you notice?
3. **Think** How is the difference in your motion in Steps 1 and 2 related to conservation of momentum?

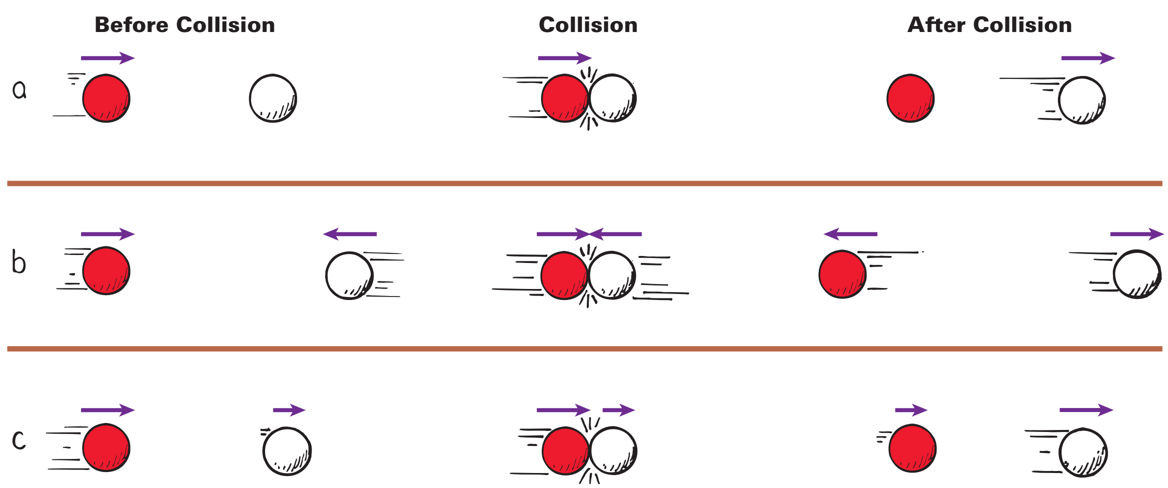
8.5 Collisions

The collision of objects clearly shows the conservation of momentum. **Whenever objects collide in the absence of external forces, the net momentum of both objects before the collision equals the net momentum of both objects after the collision.**

$$\text{net momentum}_{\text{before collision}} = \text{net momentum}_{\text{after collision}}$$

Elastic Collisions When a moving billiard ball collides head-on with a ball at rest, the first ball comes to rest and the second ball moves away with a velocity equal to the initial velocity of the first ball. We see that momentum is transferred from the first ball to the second ball. When objects collide without being permanently deformed and without generating heat, the collision is said to be an **elastic collision.** Colliding objects bounce perfectly in perfect elastic collisions, as shown in Figure 8.11. Note that the sum of the momentum vectors is the same before and after each collision.

FIGURE 8.11 ▼
Colliding objects bounce perfectly in elastic collisions. **a.** A moving ball strikes a ball at rest. **b.** Two moving balls collide head-on. **c.** Two balls moving in the same direction collide.



132

Inelastic Collisions A collision in which the colliding objects become distorted and generate heat during the collision is an **inelastic collision.** Momentum conservation holds true even in inelastic collisions. Whenever colliding objects become tangled or couple together, a totally inelastic collision occurs. The freight train cars in Figure 8.12 provide an example. Suppose the freight cars are of equal mass *m*, and that one car moves at 4 m/s toward the other car that is at rest. Can you predict the velocity of the coupled cars after impact? From the conservation of momentum,

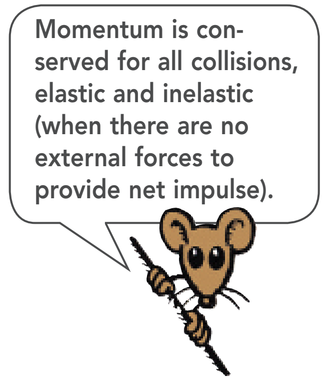
$$\text{net momentum}_{\text{before collision}} = \text{net momentum}_{\text{after collision}}$$

or, in equation form,

$$(\text{net } mv)_{\text{before}} = (\text{net } mv)_{\text{after}}$$

$$(m)(4 \text{ m/s}) + (m)(0 \text{ m/s}) = (2m)(v_{\text{after}})$$

Since twice as much mass is moving after the collision, can you see that the velocity, v_{after}, must be one half of 4 m/s? Solving for the velocity after the collision, we find $v_{\text{after}} = 2$ m/s in the same direction as the velocity before the collision, v_{before}. The initial momentum is shared by both cars without loss or gain. Momentum is conserved.



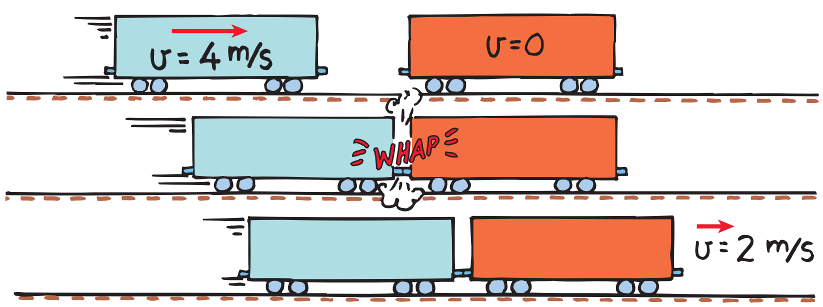


FIGURE 8.12
In an inelastic collision between two freight cars, the momentum of the freight car on the left is shared with the freight car on the right.

Most collisions usually involve some external force. Billiard balls do not continue indefinitely with the momentum imparted to them. The moving balls encounter friction with the table and the air. These external forces are usually negligible during the collision, so the net momentum does not change during collision. The net momentum of two colliding trucks is the same before and just after the collision. As the combined wreck slides along the pavement, friction provides an impulse to decrease its momentum. Similarly, a pair of space vehicles docking in orbit have the same net momentum just before and just after contact. Since there is no air resistance in space, the combined momentum of the space vehicles after docking is then changed only by gravity.

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▶ **Teaching Tip** Distinguish between elastic (bouncy) and inelastic (sticky) collisions. Point out that when no external forces act on a system, no change in the total momentum of that system occurs.

▶ **Teaching Tip** For the case of equal-mass carts in an inelastic collision (Figure 8.12), go over the equation in the middle of the page in detail. Write similar equations for the collisions you demonstrate on the air track so students will relate the equations to visual examples. Have your students write the equations for other examples you show. In writing the equations for head-on collisions, be careful to show velocities in one direction as positive and oppositely-directed velocities as negative. For example, the equation for Figure 8.11b is $[mv + m(-v)]_{\text{before}} = [m(-v) + mv]_{\text{after}}$. In both the before and after cases, the net momentum is zero.

Demonstration

Show examples of momentum conservation in both elastic and inelastic collisions using carts on an air track. If you represent the collisions on the board, use the exaggerated symbol technique (big *m*, little *v*, and vice versa).

CONCEPT CHECK Whenever objects collide in the absence of external forces, the net momentum of both objects before the collision equals the net momentum of both objects after the collision.

Teaching Resources

- **Reading and Study Workbook**
- **Laboratory Manual** *24, 25*
- **Concept-Development Practice Book** *8-1*
- **Problem-Solving Exercises in Physics** *5-2*
- **Transparency** *12*
- **Presentation*EXPRESS***
- **Interactive Textbook**

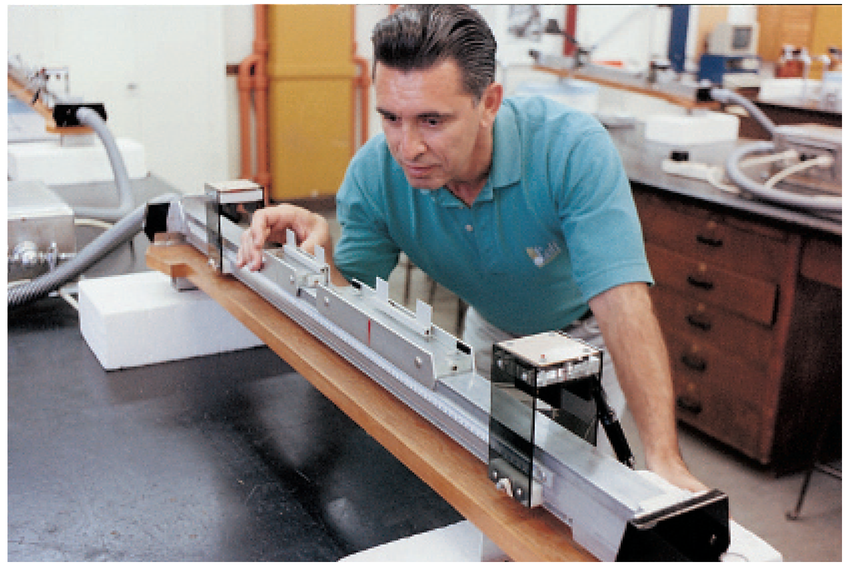
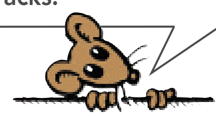


FIGURE 8.13 ▲
An air track nicely demonstrates conservation of momentum. Many small air jets provide a nearly frictionless cushion of air for the gliders to slide on.

Pucks and carts ride nearly free of friction on cushions of air on air tracks like the one shown in Figure 8.13. Galileo worked hard to produce smooth surfaces to minimize friction. How he would have loved to experiment with today's air tracks!



Perfectly elastic collisions are not common in the everyday world. We find in practice that some heat is generated during collisions. Drop a ball and after it bounces from the floor, both the ball and the floor are a bit warmer. Even a dropped superball will not bounce to its initial height. At the microscopic level, however, perfectly elastic collisions are commonplace. For example, electrically charged particles bounce off one another without generating heat; they don't even touch in the classic sense of the word. Later chapters will show that the concept of touching needs to be considered differently at the atomic level.

CONCEPT CHECK **How does conservation of momentum apply to collisions?**

think!

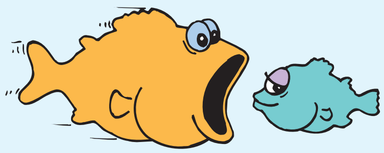
Suppose one of the gliders in Figure 8.13 is loaded so it has three times the mass of the other glider. The loaded glider is initially at rest. The unloaded glider collides with the loaded glider and the two gliders stick together. Describe the motion of the gliders after the collision. *Answer: 8.5*

Resist making a big deal out of this section unless you have ample time on your hands and your class is anxious for you to set your academic plow deeper. I think it is enough for students to be exposed to the general idea here and then move on.

PAUL

do the math!

Consider a 6-kg fish that swims toward and swallows a 2-kg fish that is at rest. If the larger fish swims at 1 m/s, what is its velocity immediately after lunch?



Momentum is conserved from the instant before lunch until the instant after (in so brief an interval, water resistance does not have time to change the momentum), so we can write

$$\text{net momentum}_{\text{before lunch}} = \text{net momentum}_{\text{after lunch}}$$
$$(\text{net } mv)_{\text{before}} = (\text{net } mv)_{\text{after}}$$
$$(6\text{ kg})(1\text{ m/s}) + (2\text{ kg})(0\text{ m/s}) = (6\text{ kg} + 2\text{ kg})(v_{\text{after}})$$
$$6\text{ kg·m/s} = (8\text{ kg})(v_{\text{after}})$$
$$v_{\text{after}} = \frac{6\text{ kg·m/s}}{8\text{ kg}}$$
$$v_{\text{after}} = \frac{3}{4}\text{ m/s}$$

We see that the small fish has no momentum before lunch because its velocity is zero. Using simple algebra we see that after lunch the combined mass of the two-fish system is 8 kg and its speed is $\frac{3}{4}$ m/s in the same direction as the large fish's direction before lunch.

Suppose the small fish is not at rest but is swimming toward the large fish at 2 m/s. What is the velocity of the larger fish immediately after lunch?

If we consider the direction of the large fish as positive, then the velocity of the small fish is –2 m/s.

$$(\text{net } mv)_{\text{before}} = (\text{net } mv)_{\text{after}}$$
$$(6\text{ kg})(1\text{ m/s}) + (2\text{ kg})(-2\text{ m/s}) = (6\text{ kg} + 2\text{ kg})(v_{\text{after}})$$
$$(6\text{ kg·m/s}) + (-4\text{ kg·m/s}) = (8\text{ kg})(v_{\text{after}})$$
$$\frac{2\text{ kg·m/s}}{8\text{ kg}} = v_{\text{after}} = \frac{1}{4}\text{ m/s}$$

The negative momentum of the small fish is very effective in slowing the large fish. If the small fish were swimming at –3 m/s, then both fish would have equal and opposite momenta. Zero momentum before lunch would equal zero momentum after lunch, and both fish would come to a halt.

More interestingly, suppose the small fish swims at –4 m/s.

$$(\text{net } mv)_{\text{before}} = (\text{net } mv)_{\text{after}}$$
$$(6\text{ kg})(1\text{ m/s}) + (2\text{ kg})(-4\text{ m/s}) = (6\text{ kg} + 2\text{ kg})(v_{\text{after}})$$
$$(6\text{ kg·m/s}) + (-8\text{ kg·m/s}) = (8\text{ kg})(v_{\text{after}})$$
$$\frac{-2\text{ kg·m/s}}{8\text{ kg}} = v_{\text{after}} = -\frac{1}{4}\text{ m/s}$$

The minus sign tells us that after lunch the two-fish system moves in a direction opposite to the large fish's direction before lunch.

8.6 Momentum Vectors

Momentum is conserved even when interacting objects don't move along the same straight line. To analyze momentum in any direction, we use the vector techniques we've previously learned. ✓ **The vector sum of the momenta is the same before and after a collision.** We'll look at momentum conservation involving angles by briefly considering the three following examples.

▶ **Teaching Tip** You may find it helpful to review the rules of vectors here.

▶ **Teaching Tip** Illustrate the vector nature of momentum by discussing Figures 8.14, 8.15, and 8.16.

▶ **Teaching Tip** When discussing Figure 8.15, explain that for collisions involving *x* and *y* directions, $\Sigma(mv_x)_{before} = \Sigma(mv_x)_{after}$ and $\Sigma(mv_y)_{before} = \Sigma(mv_y)_{after}$. For the falling firecracker, $\Sigma(mv_x)_{before} = \Sigma(mv_x)_{after} = 0$, so mv_x of the piece that flies off to the right equals $-mv_x$ of the piece that flies off to the left.

CONCEPT CHECK The vector sum of the momenta is the same before and after a collision.

Teaching Resources

- **Concept-Development Practice Book** *8-2*
- **Reading and Study Workbook**
- **Presentation*EXPRESS***
- **Interactive Textbook**

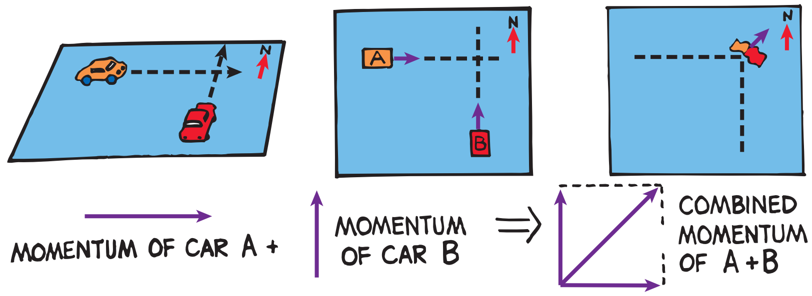


FIGURE 8.14 ▶
Momentum is a vector quantity. The momentum of the wreck is equal to the vector sum of the momenta of car A and car B before the collision.

Notice in Figure 8.14 that the momentum of car A is directed due east and that of car B is directed due north. If their momenta are equal in magnitude, after colliding their combined momentum will be in a northeast direction with a magnitude $\sqrt{2}$ times the momentum either vehicle had before the collision (just as the diagonal of a square is $\sqrt{2}$ times the length of a side).

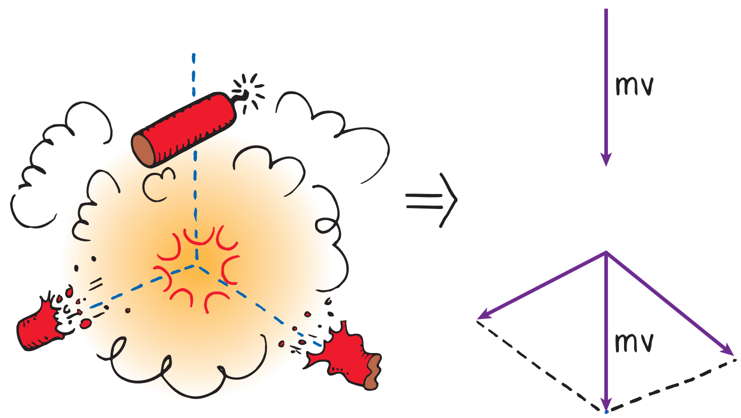


FIGURE 8.15 ▶
When the firecracker bursts, the vector sum of the momenta of its fragments add up to the firecracker's momentum just before bursting.

Figure 8.15 shows a falling firecracker that explodes into two pieces. The momenta of the fragments combine by vector rules to equal the original momentum of the falling firecracker.

Figure 8.16 shows tracks made by subatomic particles in a bubble chamber. The mass of these particles can be computed by applying both the conservation of momentum and conservation of energy laws—the conservation of energy law will be discussed in the next chapter. The conservation laws are extremely useful to experimenters in the atomic and subatomic realms. A very important feature of their usefulness is that forces do not show up in the equations. Forces in collisions, however complicated, are not a concern.

Conservation of momentum and, as the next chapter will discuss, conservation of energy are the two most powerful tools of mechanics. Their application yields detailed information that ranges from understanding the interactions of subatomic particles to entire galaxies.

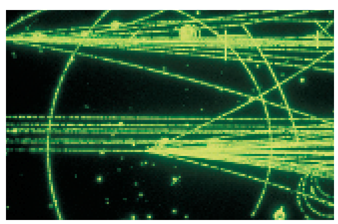


FIGURE 8.16 ▲
Momentum is conserved for the high-speed elementary particles, as shown by the tracks they leave in a bubble chamber.

CONCEPT CHECK **What is true about the vector sum of momenta in a collision?**

8 REVIEW

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Concept Summary

- A moving object can have a large momentum if it has a large mass, a high speed, or both.
- The change in momentum depends on the force that acts and the length of time it acts.
- The impulse required to bring an object to a stop and then to "throw it back again" is greater than the impulse required merely to bring the object to a stop.
- The law of conservation of momentum states that in the absence of an external force, the momentum of a system remains unchanged.
- Whenever objects collide in the absence of external forces, the net momentum of both objects before collision equals the net momentum of both objects after collision.
- The vector sum of the momenta is the same before and after a collision.

Key Terms

momentum *(p. 125)*
impulse *(p. 126)*
law of conservation of momentum *(p. 131)*
elastic collision *(p. 132)*
inelastic collision *(p. 133)*

think! Answers

8.1 The roller skate and truck can have the same momentum if the speed of the roller skate is much greater than the speed of the truck. How much greater? As many times greater as the truck's mass is greater than the roller skate's mass. Get it? For example, a 1000-kg truck backing out of a driveway at 0.01 m/s has the same momentum as a 1-kg skate going 10 m/s. Both have momentum = 10 kg m/s.

8.2.1 No. The impulse would be the same for either surface because the same momentum change occurs for each. It is the *force* that is less for the impulse on the carpet because of the greater time of momentum change.

8.2.2 Since the time of impact increases five times, the force of impact will be reduced five times.

8.4 Yes, because no acceleration means that no change occurs in velocity or in momentum (mass × velocity). Another line of reasoning is simply that no net force means there is no net impulse and thus no change in momentum.

8.5 The mass of the stuck-together gliders is four times that of the unloaded glider. Thus, the postcollision velocity of the stuck-together gliders is one-fourth of the unloaded glider's velocity before collision. This velocity is in the same direction as before, since the direction as well as the amount of momentum is conserved.

8 REVIEW

Teaching Resources

- Teacher*EXPRESS*
- Virtual Physics Lab *11*
- Conceptual Physics Alive! DVDs *Momentum*

8 ASSESS

Check Concepts

1. Mass is inertia; momentum is inertia in motion.
2. a. the truck b. the rolling skateboard
3. Force is a push or pull; impulse = force × time.
4. Impact designates a force; impulse = force × time.
5. Increases
6. Impulse = force × time; momentum is inertia in motion.
7. Change in momentum
8. a. doubles
   b. doubles
9. Greater time means less force.
10. It is reduced to one fourth.
11. Greater time means less force; less time means greater force.
12. a. yes
    b. yes
    c. yes
    d. catching and throwing it out again
13. The change in momentum is greater so the impulse is greater.
14. It causes a greater change in the fluid's momentum and so it provides more impulse.
15. The cannon's momentum must be equal and opposite to that of the cannonball.
16. The momentum before the collision is the same as the momentum after the collision.

8 ASSESS

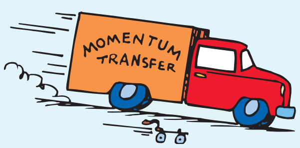
Check Concepts

Section 8.1

1. Distinguish between *mass* and *momentum*. Which is inertia and which is inertia in motion?
2. a. Which has the greater mass, a heavy truck at rest or a rolling skateboard?
   b. Which has greater momentum?
3. Distinguish between *force* and *impulse*.

Section 8.2

4. Distinguish between *impact* and *impulse*. Which designates a force and which is force multiplied by time?
5. When the force of impact on an object is extended in time, does the impulse increase or decrease?
6. Distinguish between *impulse* and *momentum*. Which is force × time and which is inertia in motion?
7. Does impulse equal momentum, or a *change* in momentum?



8. For a constant force, suppose the duration of impact on an object is doubled.
   a. How much is the impulse increased?
   b. How much is the resulting change in momentum increased?
9. In a car crash, why is it advantageous for an occupant to extend the time during which the collision takes place?
10. If the time of impact in a collision is extended by four times, how much does the force of impact change?
11. Why is it advantageous for a boxer to ride with the punch? Why should he avoid moving into an oncoming punch?

Section 8.3

12. Visualize yourself on a skateboard.
    a. When you throw a ball, do you experience an impulse?
    b. Do you experience an impulse when you catch a ball of the same speed?
    c. Do you experience an impulse when you catch it and then throw it out again?
    d. Which impulse is greatest?

13. Why is more impulse delivered during a collision when bouncing occurs than during one when it doesn't?
14. Why is the Pelton Wheel an improvement over paddle wheels with flat blades?

Section 8.4

15. In terms of momentum conservation, why does a cannon recoil when fired?
16. What does it mean to say that momentum is conserved?

Section 8.5

17. Distinguish between an elastic and an inelastic collision.

18. Imagine that you are hovering next to the space shuttle in an Earth orbit. Your buddy of equal mass, who is moving at 4 km/h with respect to the shuttle, bumps into you. If he holds onto you, how fast do you both move with respect to the ship?

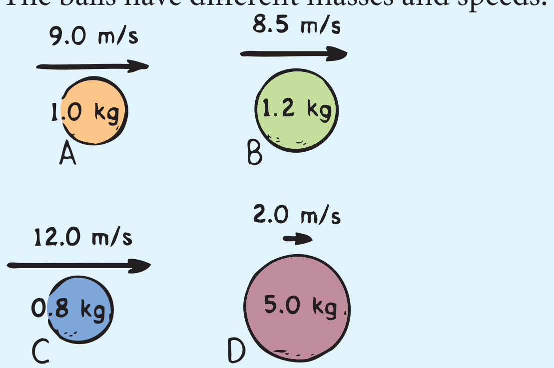
Section 8.6

19. Is momentum conserved for colliding objects that are moving at angles to one another? Explain.

Think and Rank

Rank each of the following sets of scenarios in order of the quantity or property involved. List them from left to right. If scenarios have equal rankings, then separate them with an equal sign. (e.g., A = B)

20. The balls have different masses and speeds.

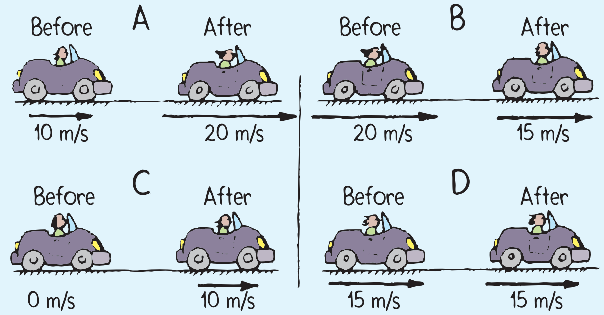


Rank the following from greatest to least.

a. momentum

b. the impulse needed to stop them

21. Below are before-and-after pictures of a car's speed. The mass of the car doesn't change.

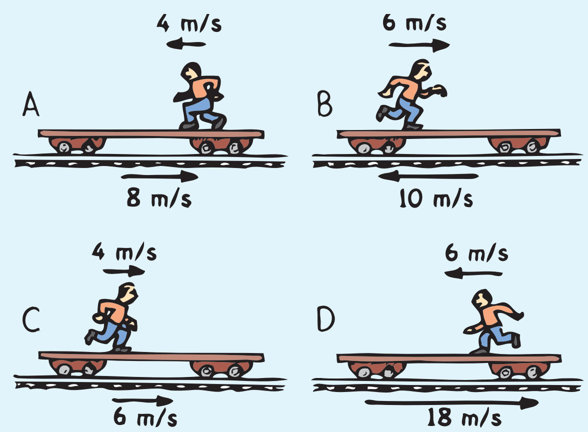


Rank the following from greatest to least.

a. the magnitude of momentum change

b. the magnitude of the impulse producing the momentum change

22. Jogging Jake runs along a train flatcar that moves at the velocities shown. In each case, Jake's velocity is given relative to the car.



Rank the following from greatest to least.

a. the magnitude of Jake's momentum relative to the car

b. Jake's momentum to the right relative to an observer at rest on the ground

17. An elastic collision involves bounces. Objects become distorted and generate heat during an inelastic collision.

18. The mass doubles so the speed is halved; 2 km/h.

19. Yes. Resulting motions follow the vector rules.

Think and Rank

20. a. B, D, C, A
b. B, D, C, A

21. a. A = C, B, D
b. A = C, B, D

22. a. B = D, A = C
b. D, C, A, B

23. **a.** A, B, C
b. C, B, A
c. A, B, C

Plug and Chug

24. $mv = (10 \text{ kg})(2 \text{ m/s}) = 20 \text{ kg·m/s}$

25. $mv = (50 \text{ kg})(4 \text{ m/s}) = 200 \text{ kg·m/s}$

26. $Ft = (10 \text{ N})(2.5 \text{ s}) = 25 \text{ N·s}$

27. $Ft = (10 \text{ N})(5.0 \text{ s}) = 50 \text{ N·s}$

Think and Explain

28. The momentum is the same. (Its weight changes, but not its mass.)

29. So that the reaction force of the handlebars on you will produce a backward-acting impulse

30. No, the forces within are internal and provide no impulses.

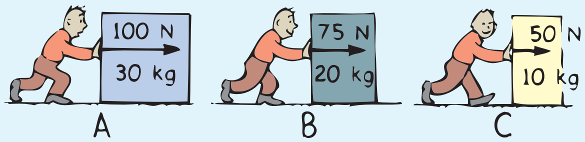
31. Same momentum change for both Brian and canoe; since canoe moves back as Brian jumps forward, he falls short of the dock.

32. He will move to and fro with no net change. If there is no momentum change to ball, there is no oppositely directed momentum change to Jason.

33. Jason can't exert force on ball unless ball exerts an equal and opposite force on him. For the system of Jason, the ball, and the roller skates, these are internal forces that add to zero and produce no net momentum.

8 ASSESS *(continued)*

23. Rick pushes crates starting at rest across a floor for 3 seconds with a net force as shown.



For each crate, rank the following from greatest to least.
a. change in momentum
b. final speed
c. momentum in 3 seconds

Plug and Chug

The key equations of the chapter are shown below in bold type.

$$\textbf{Momentum} = m \times v$$

24. Calculate the momentum of a 10-kg bowling ball rolling at 2 m/s.

25. Calculate the momentum of a 50-kg carton that slides at 4 m/s across an icy surface.

$$\textbf{Impulse} = Ft$$

26. Calculate the impulse when an average force of 10 N is exerted on a cart for 2.5 s.

27. Calculate the impulse when an average force of 10 N acts on a cart for 5.0 s.

Think and Explain

For answers to Think and Explains and Think and Solves, you may express momentum with the symbol p. Then $p = mv$.

28. A lunar vehicle is tested on Earth at a speed of 10 km/h. When it travels as fast on the moon, is its momentum more, less, or the same?

29. When you ride a bicycle at full speed and the bike stops suddenly, why do you have to push hard on the handlebars to keep from flying forward?

30. Can Andrew produce a net impulse on an automobile by sitting inside and pushing on the dashboard? Can the internal forces within a soccer ball produce an impulse on the soccer ball that will change its momentum?

31. Brian tries to jump from his canoe to the dock. He lands in the water, delighting his companions. What's your explanation for his mishap?

32. Jason throws a ball horizontally while standing on roller skates. He rolls backward with a momentum that matches that of the ball. Will he end up rolling backward if he goes through the motions of throwing the ball, but does not let go of it? Explain.

33. The example in the previous question can be explained in terms of momentum conservation and in terms of Newton's third law. Assuming you've answered it in terms of momentum conservation, answer it also in terms of Newton's third law (or vice versa if you answered already via Newton's third law).

140

34. In the previous chapter, rocket propulsion was explained in terms of Newton's third law. That is, the force that propels a rocket is from the exhaust gases pushing against the rocket, the reaction to the force the rocket exerts on the exhaust gases. Explain rocket propulsion in terms of momentum conservation.

35. In terms of impulse and momentum, why are air bags in automobiles a good idea?

36. Why do gymnasts use floor mats that are very thick?

37. When jumping from a significant height, why is it advantageous to land with your knees slightly bent?

38. In terms of impulse and momentum, why are nylon ropes, which stretch considerably under tension, favored by mountain climbers?

39. Would it be a dangerous mistake for a bungee jumper to use a steel cable rather than an elastic cord?

40. When catching a foul ball at a baseball game, why is it important to extend your bare hands upward so they can move downward as the ball is being caught?

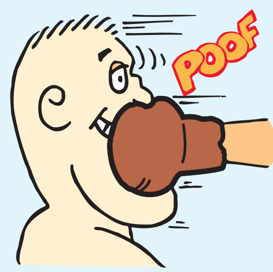
41. Why would it be a poor idea to have the back of your hand up against the outfield wall when you catch a long fly ball?

42. Many years ago, automobiles were manufactured to be as rigid as possible. Today's autos are designed to crumple upon impact. Why?

43. Why is it difficult for a firefighter to hold a hose that ejects large amounts of water at high speed?

44. You can't throw a raw egg against a wall without breaking the shell, but you can throw it at the same speed into a sagging sheet without breaking it. Explain.

45. Why can Muhammad exert a greater punching force with his bare fist than he can while wearing a boxing glove?



46. Why do 6-ounce boxing gloves hit harder than 16-ounce gloves?

47. Suppose you roll a bowling ball into a pillow and the ball stops. Now suppose you roll it against a spring and it bounces back with an equal and opposite momentum.
   a. Which object exerts a greater impulse, the pillow or the spring?
   b. If the time it takes the pillow to stop the ball is the same as the time of contact of the ball with the spring, how do the average forces exerted on the ball compare?

34. By momentum conservation, conservation of p_{rocket} + p_{gases} is constant, so $\Delta p_{rocket} = p_{gases}$. Rocket gains momentum in one direction; gases gain equal momentum in opposite direction.

35. Air bags increase your stopping time in a head-on collision. Greater time of impact means less force of impact.

36. The extra thickness extends time of momentum change and reduces force for the same impulse.

37. Less impact force because bent knees provide longer time to change your momentum.

38. If you fall, longer time to decrease momentum means less force if rope stops a fall.

39. Small stretch means small stopping time means greater force. Ouch!

40. Extended hands allows more time to reduce the momentum of ball to zero; less force of impact on hands.

41. Much less time in changing ball's momentum, leading to damaged hand!

42. Longer time of momentum change means less impact force, so less damage to occupants.

43. The hose tends to recoil from the ejected water.

44. The time it takes to stop is extended. More time means less force, and a less-likely broken egg.

45. Less impact time with bare fist; more impact force

46. Less padding in lighter gloves and less ability to extend impact time

47. **a.** the spring
b. Twice the impulse in the same time means twice the average force.

48. If the system is you and Earth, then your momentum toward Earth is equal and opposite to Earth's momentum toward you. There's no net change in momentum because while you're falling down, Earth is falling (much less noticeably) up.

49. The magnitude of force, impulse, and change in momentum is the same for each. The empty cart undergoes the greater acceleration due to less mass.

50. **a.** true
b. true
c. False, the changes in speed are very different due to the different masses and resulting accelerations.
d. True, the impulses are of the same size.

51. There is more kick from the solid ball because of a greater change in momentum for the solid ball.

52. The astronauts would recoil and the circle would widen.

53. The electron has much less mass than the proton.

Think and Solve

54. Multiply units of N, kg·m/s^2, by s and get N·s = kg·m/s.

55. **a.** $\Delta(mv)$ = (1000 kg)(20 m/s) = 20,000 N/s
b. $F = \Delta(mv)/t$; but we don't know t! Without knowledge of the impact time, we can't solve for the force of impact.

56. $F = \Delta(mv)/t$ = (1000 kg × 20 m/s)/(10 s) = 2000 kg·m/s^2 = 2000 N

57. **a.** 1.5 m/s
b. v = (6 kg·m/s) ÷ (2 kg + 4 kg) = 1 m/s

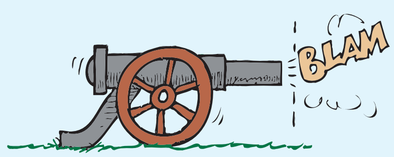
8 ASSESS *(continued)*

48. If you topple from your treehouse, you'll continuously gain momentum as you fall to the ground below. Doesn't this violate the law of conservation of momentum? Defend your answer.

49. If a fully loaded shopping cart and an empty one traveling at the same speed have a head-on collision, which cart will experience the greater force of impact? The greater impulse? The greater change in momentum? The greater acceleration?

50. A bug and the windshield of a fast-moving car collide. Indicate whether each of the following statements is true or false.
a. The forces of impact on the bug and on the car are the same size.
b. The impulses on the bug and on the car are the same size.
c. The changes in speed of the bug and of the car are the same.
d. The changes in momentum of the bug and of the car are the same size.

51. What difference in recoil would you expect in firing a solid ball versus firing a hollow ball from the same cannon? Explain.



52. A group of playful astronauts, each with a bag full of balls, form a circle as they free-fall in space. Describe what happens when they begin tossing balls simultaneously to one another.

53. A proton from an accelerator strikes an atom. An electron is observed flying forward in the same direction the proton was moving and at a speed much greater than the speed of the proton. What conclusion can you draw about the relative mass of a proton and an electron?

Think and Solve

54. Using units, show that kg·m/s is equivalent to N·s.

55. A 1000-kg car moving at 20 m/s slams into a building and comes to a halt. Which of the following questions can be answered using the given information, and which one *cannot* be answered? Explain.
a. What impulse acts on the car?
b. What is the force of impact on the car?

56. A car with a mass of 1000 kg moves at 20 m/s. What braking force is needed to bring the car to a halt in 10 s?

57. A 2-kg blob of putty moving at 3 m/s slams into a 2-kg blob of putty at rest.
a. Calculate the speed of the two stuck-together blobs of putty immediately after colliding.
b. Calculate the speed of the two blobs if the one at rest was 4 kg.

58. A 1-kg dart moving horizontally at 10 m/s strikes and sticks to a wood block of mass 9 kg, which slides across a friction-free level surface. What is the speed of the block and the dart after the collision?

142

59. Assume an 8-kg bowling ball moving at 2 m/s bounces off a spring at the same speed that it had before bouncing.
a. What is its momentum of recoil?
b. What is its change in momentum? (*Hint:* What is the change in temperature when something goes from 1° to –1°?)
c. If the interaction with the spring occurs in 0.5 s, calculate the average force the spring exerts on it.

60. Brakes are applied in bringing a 1200-kg car moving at 25 m/s to rest in 20.0 s. Show that the amount of braking force is 1500 N.

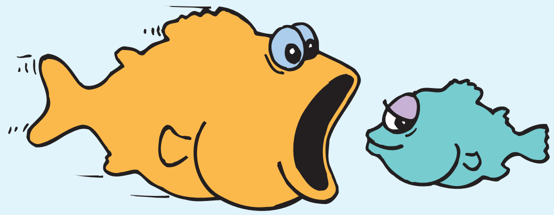
61. A 20.0-kg mass moving at a speed of 3.0 m/s is stopped by a constant force of 15.0 N. Show that the stopping time required is 4.0 s.

62. A 1-kg ostrich egg is thrown at 2 m/s at a bed sheet and is brought to rest in 0.2 s. Show that the average amount of force on the egg is 10 N.

63. A railroad diesel engine weighs four times as much as a freight car. If the diesel engine coasts at 5 km/h into a freight car that is at rest, how fast do the two coast after they couple?

64. A comic-strip superhero meets an asteroid in outer space and hurls it at 100 m/s. The asteroid is a thousand times more massive than the superhero is. In the strip, the superhero is seen at rest after the throw. Taking physics into account, what would be his recoil speed? What is this in miles per hour?

65. A 5-kg fish swimming 1 m/s swallows an absent-minded 1-kg fish at rest. What is the speed of the large fish immediately after lunch? What would its speed be if the small fish were swimming toward it at 4 m/s?



Activity

66. Visit your local pool or billiards parlor and bone up on momentum conservation. Note that no matter how complicated the collision of balls, the momentum along the line of action of the cue ball before impact is the same as the combined momentum of all the balls along this direction after impact. Also, the components of momenta perpendicular to this line of action add to zero after impact, the same value as before impact in this direction. When rotational skidding, English, is imparted by striking the cue ball off center, rotational momentum, which is also conserved, somewhat complicates the analysis. But regardless of how the cue ball is struck, in the absence of external forces, both linear and rotational momentum are always conserved. Pool or billiards offers a first-rate exhibition of momentum conservation in action.

More Problem-Solving Practice
Appendix F

58. $m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$. Since the wood block is initially at rest, $v_2 = 0$. Since both objects move together after the collision, $v_1' = v_2' = v'$. So $m_1v_1 = (m_1 + m_2)v'$ and $v' = (m_1v_1)/(m_1 + m_2) =$ (1 kg × 10 m/s)/(1 kg + 9 kg) = 1 m/s.

59. **a.** (8 kg)(−2 m/s) = −16 kg·m/s
b. 32 kg·m/s
c. $F = \Delta(mv)/t$ = (32 kg·m/s) ÷ (0.5 s) = 64 N

60. $Ft = \Delta p = mv$, so $F = mv/t$ = (1200 kg × 25 m/s)/20.0 s = 1500 N

61. $Ft = \Delta p = mv$, so $t = mv/F$ = (20 kg × 3.0 m/s)/15.0 N = 4.0 s

62. $Ft = \Delta p = mv$, so $F = mv/t$ = (1 kg × 2m/s)/0.2 s = 10 N

63. Four times the weight means four times the mass. $(4m)$(5 km/h) + 0 = $(4m + m)v$, so v = $(20m$ km/h)/$(5m)$ = 4 km/h

64. Asteroid mass × 100 m/s = superhero's mass × v. Since the asteroid's mass is 1000 times superhero's, $(1000m)$(100 m/s) = mv_{after} so v = 1000(100 m/s) = 100,000 m/s. This is a whopping 224,000 mi/h!

65. Case 1: (5 kg)(1 m/s) + 0 = (5 kg + 1 kg) × v, so v = 5/6 m/s
Case 2: (5 kg)(1 m/s) + (1 kg)(−4 m/s) = (5 kg + 1 kg)v, so v = (1 kg·m/s)/(6 kg) = 1/6 m/s

Activity

66. Students should see how the vector nature of momentum applies to the motion of balls on the pool table.

Teaching Resources
- Computer Test Bank
- Chapter and Unit Tests