7 Momentum

Have you ever wondered how a karate expert can sever a stack of cement bricks with the blow of her bare hand? Or why a fall on a wooden floor is not nearly as damaging as a fall on a cement floor? Or why "follow through" is important in golf, baseball, and boxing? To understand these things, you first need to recall the concept of inertia, introduced in Chapter 3 in Newton's first law of motion, and developed further in Chapters 4 and 5 in Newton's second and third laws of motion. Inertia was discussed in terms of objects both at rest and in motion. Now we concern ourselves only with the inertia of moving objects. The idea of inertia in motion is *momentum*, which refers to moving things.

7.1 Momentum

We all know that a massive truck is harder to stop than a small car moving at the same speed. We say the truck has more momentum than the car. By **momentum** we mean inertia in motion, or more specifically, the mass of an object multiplied by its velocity. That is:

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

or, in shorthand 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.

We can see from the definition that a moving object can have a large momentum if either its mass is large, or its speed is large, or if both its mass and speed are large. A truck has a larger momentum than a car moving at the same speed because its mass is larger. An enormous ship moving at a small speed can have a large momentum, whereas a small bullet moving at a high speed can also have a large momentum. And, of course, a huge object moving at a high speed, such as a massive truck rolling down a steep hill with no brakes, has a huge momentum, whereas the same truck at rest has no momentum at all.

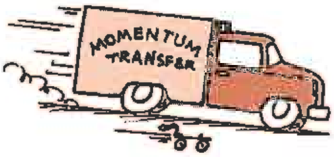

Fig. 7-1 A truck rolling down a hill has more momentum than a roller skate moving at the same speed, because the truck has more mass. But if the truck is at rest and the roller skate moves, then the skate has more momentum because only it has speed.

▶ **Question**

Can you think of a case where the roller skate and truck shown in Figure 7-1 both would have the same momentum?

7.2 Impulse Equals Change in Momentum

If the momentum of an object changes, either the mass or the velocity or both changes. If the mass remains unchanged, as is most often the case, then the velocity changes. Acceleration occurs. And what produces an acceleration? The answer is a *force*. The greater the force that acts on an object, the greater will be the change in velocity, and hence, the change in momentum.

But something else is important also: *time*—how long the force acts. Apply a force briefly to a stalled automobile, and you produce a small change in its momentum. Apply the same force over an extended period of time, and a greater change in momentum results. A long sustained force produces more change in momentum than the same force applied briefly. So for changing the momentum of an object, both force and time are important.

Interestingly enough, Newton's second law ($a = F/m$) can be re-expressed to make the *time* factor more evident when the term for acceleration is replaced by its definition, change in velocity per time.* Then the equation becomes "force × time interval" is

▶ **Answer**

The roller skate and truck can have the same momentum if the speed of the roller skate is very much greater than the speed of the truck. How much greater? As many times as the mass of the truck is greater than the mass of the roller skate! Get it?

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* We can state Newton's second law as $F = ma$. Since a = (change in velocity) ÷ (time interval), we can say $F = m \times$ [(change in v)/t]. Simple algebraic rearrangement gives Ft = change in mv, or in delta notation, $F\Delta t = \Delta mv$.

equal to the change in "mass × velocity." The quantity "mass × velocity" has already been defined as momentum. So Newton's second law can be re-expressed in the form

$$Ft = \text{change in } mv$$

which reads, "force multiplied by the time-during-which-it-acts equals change in momentum."

The quantity "force × time interval" is called **impulse**. Thus,

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

The impulse-momentum relationship helps us to analyze a variety of circumstances where momentum is changed. We will consider familiar examples of impulse for the cases of (1) increasing momentum, (2) decreasing momentum over a long time, and (3) decreasing momentum over a short time.

Fig. 7-2 The force of a golf club against a golf ball varies throughout the duration of impact.

Case 1: Increasing Momentum

It makes good sense that in order to increase the momentum of an object, we should apply the greatest force we can. Also, we should extend the time of contact as much as possible. A golfer and baseball player do both when they swing as hard as possible and "follow through" when hitting a ball.

The forces involved in impulses are usually not steady, but vary from instant to instant. For example, a golf club that strikes a ball exerts zero force on the ball until it comes in contact; then the force increases rapidly as the club and ball are distorted (Figure 7-2); the force then diminishes as the ball comes up to speed and returns to its original shape. So when we speak of such impact forces in this chapter, we mean the *average* force of impact.

Case 2: Decreasing Momentum over a Long Time

If you were in a car that was out of control, and you had your choice of hitting a concrete wall or a haystack, you wouldn't have to call on your knowledge of physics to make up your mind. But knowing some physics helps you to understand *why* hitting something soft is entirely different from hitting something hard. In the case of hitting either the wall or the haystack, your momentum will be decreased by the same impulse. The same impulse means the same *product* of force and time, not the same force or the same time. You have a choice. By hitting the haystack instead of the wall, you extend the time of impact—*you extend the time during which your momentum is brought to zero*. The longer time is compensated by a lesser force. If you extend the time of impact 100 times, you reduce the force of impact by 100. So whenever you wish the force of impact to be small, extend the time of impact.

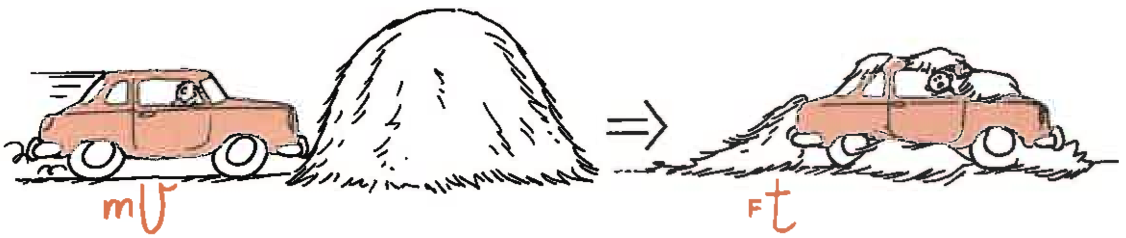

Fig. 7-3 If the change in momentum occurs over a long time, the force of impact is small.

Everyone knows that a padded dashboard in a car is safer than a bare metal one, and that airbags save lives. Most people also know that if you're going to catch a fast baseball with your bare hand, you extend your hand forward so you'll have plenty of room to let your hand move backward after you make contact with the ball. You wouldn't intentionally hold your hand stationary, as in catching a ball with your bare hand against a hard wall! In these cases you extend the time of impact and thereby reduce the force of impact.

When you jump off something to the ground below, you don't keep your legs straight and stiff (ouch!). Instead, you bend your knees upon making contact. By doing this, you extend the time during which your momentum is decreasing by 10 to 20 times that of a stiff-legged abrupt landing. The forces your bones experience are thus reduced 10 to 20 times by such knee bending.

A wrestler thrown to the floor tries to extend his time of arrival on the mat by relaxing his muscles and spreading the impact into a series of smaller impacts, as his foot, knee, hip, ribs, and shoulder fold onto the mat in turn. Of course, falling on a mat is preferable to falling on a solid floor, for this also increases the time of impact.

Everyone knows that it is less harmful to fall on a wooden floor than on a concrete floor. And most people know that this is because the wooden floor has more "give" than the concrete floor. Ask most people why a floor with more give makes for an easier fall, and you'll get a puzzled response. They may say, "Because it has more give." But your question is, "Why does a floor with more give produce a safer fall?" The answer is, we know, because an impulse is required to bring your momentum to a halt, and the impulse is composed of two variables, impact force and impact time. By extending the impact time as the floor gives, the impact force is correspondingly reduced. The safety net used by acrobats provides an obvious example of small impact force over a long time to provide the required impulse to reduce the momentum of fall.

A boxer confronted with a high-momentum punch wishes to minimize the force of impact. If he cannot avoid being hit, at least he can control the length of time it takes for his body to absorb the incoming momentum of his opponent's fist. So he wisely extends the impact time by "riding or rolling with the punch." This lessens the force of impact.

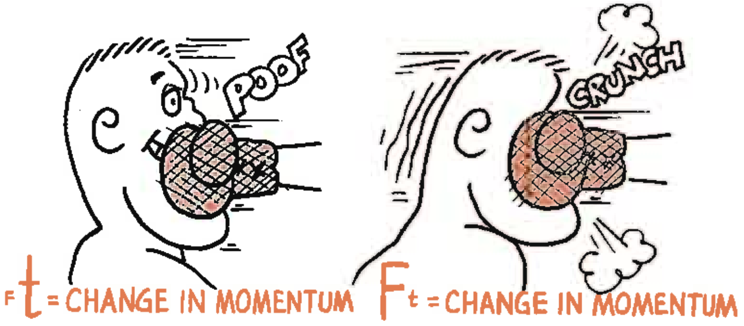

Fig. 7-4 In both cases the impulse provided by the boxer's jaw reduces the momentum of the punch. (Left) When the boxer moves away (rides with the punch), the chief ingredient of impulse is time. (Right) When the boxer moves into the glove, the time is reduced and the chief ingredient of impulse is force.

▸ **Question**

If the boxer in Figure 7-4 is able to make the duration of impact five times as long by riding with the punch, by how much will the force of impact be reduced?

Case 3: Decreasing Momentum over a Short Time

Ride a bicycle into a concrete wall, and you're in trouble. When you catch a high-speed baseball, move your hand toward the ball instead of away upon contact, and your hand is messed up. When boxing, move into a punch instead of away, and your opponent has a better chance of scoring a knockout. In these cases the principal ingredients of impulses required to reduce momentum are impact forces because the times of impact are brief.

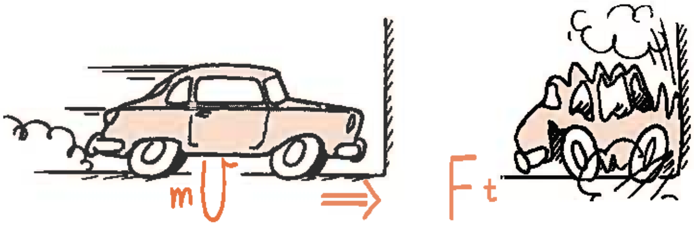

Fig. 7-5 If the change in momentum occurs over a short time, the impact force is large.

▸ **Answer**

The force of impact will be 5 times less than if he didn't pull back.

The idea of short time of contact explains how a karate expert can sever a stack of bricks with the blow of her bare hand (Figure 7-6). She brings her arm and hand swiftly against the bricks with considerable momentum. This momentum is quickly reduced when she delivers an impulse to the bricks. The impulse is the force of her hand against the bricks multiplied by the time her hand makes contact with the bricks. By swift execution she makes the time of contact very brief, and correspondingly makes the force of impact huge. If her hand is made to *bounce* upon impact, the force is even greater.

Fig. 7-6 A large impulse to the bricks in a short time produces a considerable force.

▸ **Question**

A boxer being hit with a punch contrives to extend time for best results, whereas a karate expert delivers a force in a short time for best results. Isn't there a contradiction here?

7.3 Bouncing

If a flower pot falls from a shelf onto your head, you may be in trouble. If it bounces from your head, you're certainly in trouble. Impulses are greater when bouncing takes place. This is because

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▸ **Answer**

There is no contradiction because the best results for each are quite different. The best result for the boxer is reduced force, accomplished by maximizing time, and the best result for the karate expert is increased force delivered in minimum time.

the impulse required to bring something to a stop and then, in effect, "throw it back again" is greater than the impulse required merely to bring something to a stop. Suppose, for example, that you catch the falling pot with your hands. Then you provide an impulse to catch it and reduce its momentum to zero. If you were to then throw the pot upward, you would have to provide additional impulse. So it would take more impulse to catch it *and* throw it back up than merely to catch it. The same greater impulse is supplied by your head if the pot bounces from it.

The fact that impulses are greater when bouncing takes place was employed with great success in California during the gold rush days. The water wheels used in gold-mining operations were inefficient. A man named Lester A. Pelton saw that the problem had to do with their flat paddles. He designed curved-shape paddles that would cause the incident water to make a U-turn upon impact—to "bounce." In this way the impulse exerted on the water wheels was greatly increased. Pelton patented his idea and made more money from his invention, the Pelton wheel, than any of the gold miners.

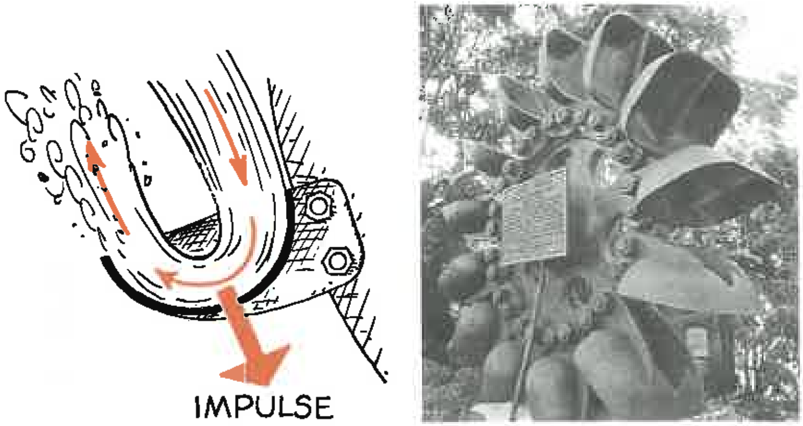

Fig. 7-7 The Pelton wheel. The curved blades cause water to bounce and make a U-turn, which produces a greater impulse to turn the wheel.

7.4 Conservation of Momentum

Newton's second law tells you that if you wish to accelerate an object, you must apply a force to it. This chapter is saying 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 do not count.

For example, the molecular forces within a basketball have no effect upon the momentum of the basketball, just as your push against the dashboard of a car you're sitting in will have no effect in changing the momentum of the car. This is because these forces are internal forces. They act and react within the object. To change the momentum of the basketball or car, an outside push or pull is required. If no outside force is present, then no change in momentum is possible.

Consider a rifle being fired. The force that pushes on the bullet when it is inside the rifle barrel is equal to the force that makes the rifle recoil (Newton's third law, action and reaction). These forces, interestingly enough, are internal to the "system" that comprises the rifle and bullet. So they don't change the momentum of the rifle-and-bullet system. Before the firing, the system is at rest and the momentum is zero. After the firing, the *net*, or total, momentum is *still* zero. No net momentum is gained and no net momentum is lost. Let's look at this carefully.

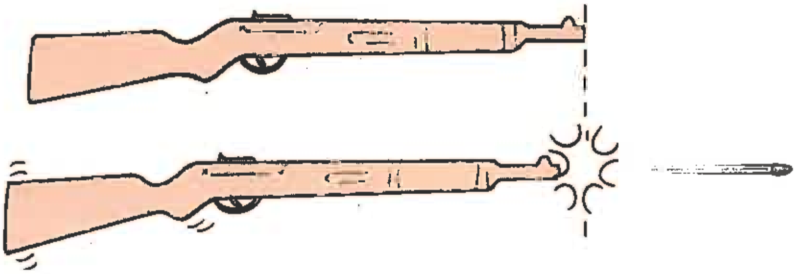

Fig. 7-8 The momentum before firing is zero. After firing, the net momentum is still zero because the momentum of the rifle cancels the momentum of the bullet.

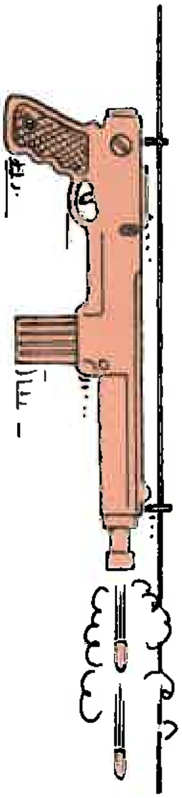

Fig. 7-9 The machine gun recoils from the bullets it fires and climbs upward.

Momentum, like the quantities velocity and force, has a direction as well as a size—it is a *vector quantity*. Hence, like velocity and force, it can be cancelled. So although the bullet in the preceding example has considerable momentum as it accelerates within the rifle barrel and then continues at high speed outside the barrel, and the recoiling rifle has momentum in and of itself, the *system* of both bullet and rifle has none. The momenta (plural form of momentum) of the bullet and the rifle are equal in size but opposite in direction. They cancel each other for the system as a whole. No external force acted on the system before or during firing. When there is no net force, there can be no net acceleration. Or, when there is no net force, there is no net impulse and therefore no net change in momentum. You can see that *if no net force acts on a system, then the momentum of that system cannot change.*

If you extend the idea of a rifle recoiling or "kicking" from the bullet it fires, you can understand rocket propulsion. Consider a machine gun recoiling each time a bullet is fired. The momen-

▶ **Questions**

1. Newton's second law says that if there is no net force exerted on a system, no acceleration is possible. Does it follow from this that no change in momentum can occur?
2. Newton's third law says that the force a rifle exerts on its bullet is equal and opposite to the force the bullet exerts on the rifle. Does it follow that the *impulse* the rifle exerts on the bullet is equal and opposite to the *impulse* the bullet exerts on the rifle?

tum of recoil increases by an amount equal to the momentum of each bullet fired. If the machine gun is fastened so it is free to slide on a vertical wire (Figure 7-9), it will accelerate upward as bullets are fired downward. A rocket accomplishes acceleration by the same means. It is continually "recoiling" from the ejected exhaust gases. Each molecule of exhaust gas can be thought of as a tiny bullet shot from the rocket (Figure 7-10). It is interesting to note that the momentum of the rocket is equal and opposite to the momentum of the exhaust gases. So if we consider the total system of rocket and exhaust gases, like the rifle and bullet, there is no net change in momentum. As a practical matter, we are usually not concerned with the net momentum of rocket-exhaust, but of the rocket itself.

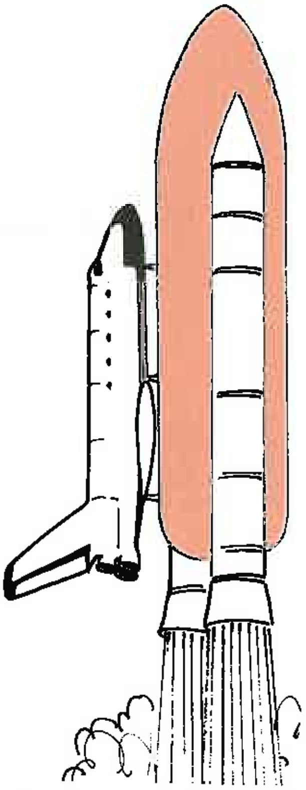

Fig. 7-10 The rocket recoils from the "molecular bullets" it fires and climbs upward.

The momentum of a system cannot change unless prodded by external forces. The momentum possessed by a system before some internal interaction will be the same as the momentum possessed by the system after the interaction. When the momentum (or any quantity in physics) does not change, we say it is **conserved.** The idea that momentum is conserved when no external force acts is elevated to a central law of mechanics, called the **law of conservation of momentum**:

> In the absence of an external force, the momentum of a system remains unchanged.

If a system undergoes changes wherein all forces are internal,

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▶ **Answers**

1. Yes, it follows because the absence of acceleration means there is no change in velocity, which in turn means no change in momentum (mass × velocity). Another line of reasoning is simply that no net force means no net impulse, which means no change in momentum.
2. Yes, because the *time* during which the rifle acts on the bullet and the bullet acts on the rifle is the same. Since time is equal for both, and force is equal and opposite for both, then force × time (impulse) is equal and opposite for both. Impulse, like force, is a vector quantity and can be cancelled.

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.

▸ **Question**

About 50 years ago it was argued that a rocket wouldn't operate in outer space because there is no air for it to push against. But a rocket works even better in outer space precisely because there is no air. How can you explain this?

7.5 Collisions

The law of conservation of momentum is neatly seen in collisions. Whenever objects collide in the absence of external forces, the total or net momentum never changes:

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

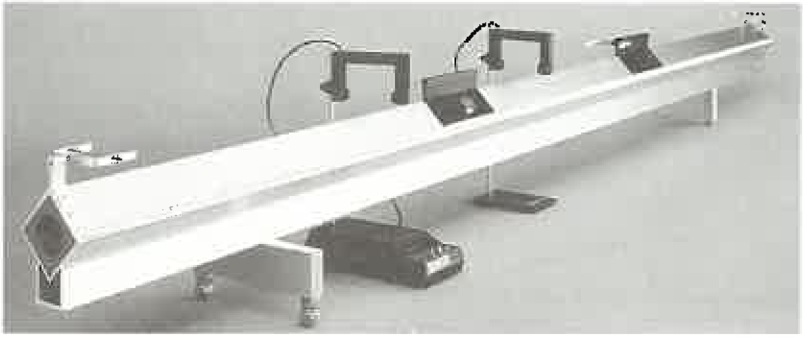

Fig. 7-11 Conservation of momentum is neatly demonstrated with the use of this air track. Jets of air from the many tiny holes in the track provide an air cushion upon which the glider slides nearly friction-free.

Elastic Collisions

When a moving billiard ball makes a head-on collision with another billiard ball at rest, the moving ball comes to rest and the struck ball moves with the initial velocity of the colliding ball. We see that momentum is simply transferred from one ball to

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▸ **Answer**

Just as a gun doesn't need air to push against in order to recoil, a rocket doesn't need air to push against in order to accelerate. The presence of air impedes acceleration by offering air resistance, so a rocket actually works better where there is no air. A rocket is not propelled by pushing against air, but by pushing against its own exhaust.

the other. When the colliding objects bound or rebound without lasting deformation or the generation of heat, the collision is said to be an **elastic collision**. Colliding objects bounce perfectly in elastic collisions (Figure 7-12).

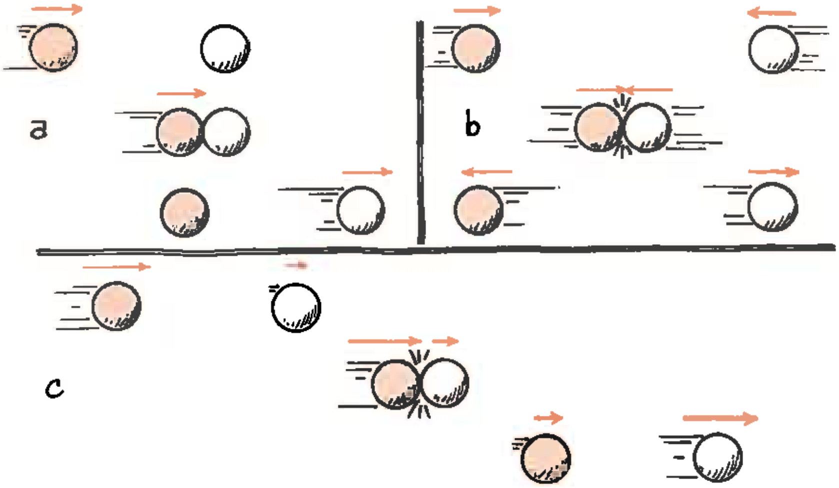

Fig. 7-12 Elastic collisions. (a) The dark ball strikes a ball at rest. (b) A head-on collision between two moving balls. (c) A collision of two balls moving in the same direction. In all cases, momentum is simply transferred or redistributed without loss or gain.

Inelastic Collisions

Momentum conservation holds true even when the colliding objects become distorted and generate heat during the collision. Such collisions are called **inelastic collisions**. Whenever colliding objects become tangled or couple together, we have an inelastic collision. The freight train cars shown in Figure 7-13 provide an illustrative example. Suppose the freight cars are of equal mass m, and one moves at 4 m/s while the other is at rest. Can we predict the velocity of the coupled cars after impact? From the conservation of momentum,

$$\text{net momentum before} = \text{net momentum after}$$
$$(m \times 4\ \text{m/s}) + (m \times 0\ \text{m/s}) = (2m \times ?\ \text{m/s})$$

Since twice as much mass is moving after the collision, can you see that the velocity must be half as much as the 4 m/s value before the collision? This is 2 m/s, in the same direction as before.

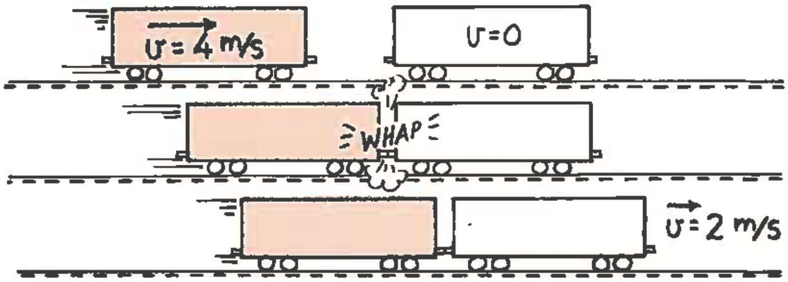

Fig. 7-13 Inelastic collision. The momentum of the freight car on the left is shared with the freight car on the right.

Then both sides of the equation are equal. The initial momentum is shared between both cars without loss or gain. Momentum is conserved.

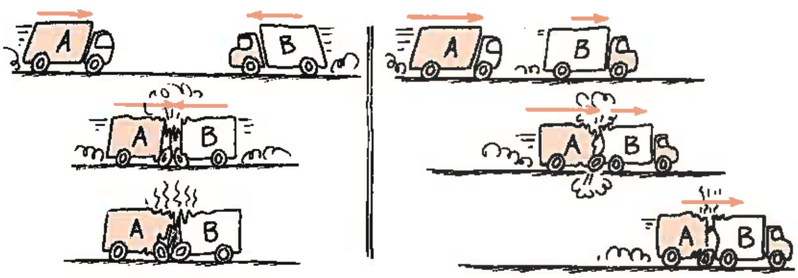

Fig. 7-14 More inelastic collisions. The net momenta of the vehicles before and after collision are the same.

▶ **Questions**

The following questions refer to the gliders on the air track in Figure 7-11.

1. Suppose both gliders have the same mass. They move toward each other at the same speed and experience an elastic collison. Describe their motion after the collision.
2. Suppose both gliders have the same mass and have Velcro on them so that they stick together when they collide. They move toward each other at equal speed. Describe their motion after the collision.
3. Suppose one of the gliders is at rest and is loaded so that it has 3 times the mass of the moving glider. Again, the gliders have Velcro on them. Describe their motion after the collision.

▶ **Answers**

1. Since the collision is elastic, the gliders will simply reverse directions upon colliding and move away from each other at the same speed as before.
2. Before the collision, the gliders had equal and opposite momenta, since they had equal mass and were moving in opposite directions at the same speed. The net momentum was zero. Since momentum is always conserved, their net momentum after the collision must also be zero. As they are now stuck together, this means they must slam to a dead halt.
3. Before the collision, the net momentum equals the momentum of the unloaded, moving glider. After the collision, the net momentum is the same as before, but now the gliders are stuck together and moving as a single unit. The mass of the stuck-together gliders is four times that of the unloaded glider. Thus, the velocity can be only ¼ that of the unloaded glider before the collision. It is in the same direction as before, since the direction of the momentum is conserved as well as the amount.

Laura Milner

In most collisions there are usually some external forces that act on a system. Billiard balls do not continue indefinitely with the momentum imparted to them. The balls encounter some friction with the table and the air they move through. These external forces are usually negligible during the collision itself, so the net momentum does not change during the collision. The net momentum of a couple of trucks that collide is the same before and just after collision. As the combined wreck slides along the pavement, friction provides an impulse to decrease momentum. For a pair of space vehicles docking in outer space, however, the net momentum before and after contact is exactly the same, and persists until the vehicles encounter external forces.

Another thing: perfectly elastic collisions are not common in the everyday world. We find in practice that some heat is generated in collisions. Drop a ball, and after it bounces from the floor, both the ball and the floor are a bit warmer. So 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. (As later chapters will show, the notion of touching at the atomic level is different from at the everyday level.)

7.6 Momentum Vectors

Momentum is conserved even when colliding objects move at an angle to each other. To analyze momentum for angular directions, we use the vector techniques discussed in Chapter 6. It will be enough in this chapter if you merely become acquainted with momentum conservation for cases that involve angles, so three examples that convey the idea will be considered briefly without going into depth.

In Figure 7-15 you can see that car A has momentum directed due east, and that car B has momentum directed due north. If their individual momenta are equal in magnitude, then after collision their combined momentum will be in a northeast direction. Just as the diagonal of a square is not simply the arithmetic sum of two of its sides, the momentum of the wreck will not be twice the arithmetic sum of the individual momenta before collision.*

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* It will be $\sqrt{2}$ times the momentum of either vehicle before collision, just as the diagonal of a square is $\sqrt{2}$ the length of a side.

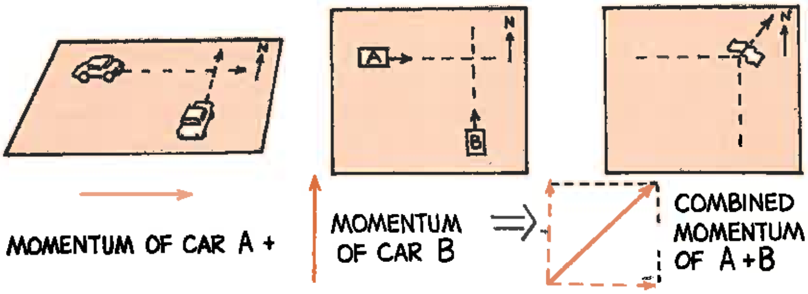

Fig. 7-15 Momentum is a vector quantity. The momentum of the wreck is equal to the vector sum of the momenta of cars A and B before collision.

Figure 7-16 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.

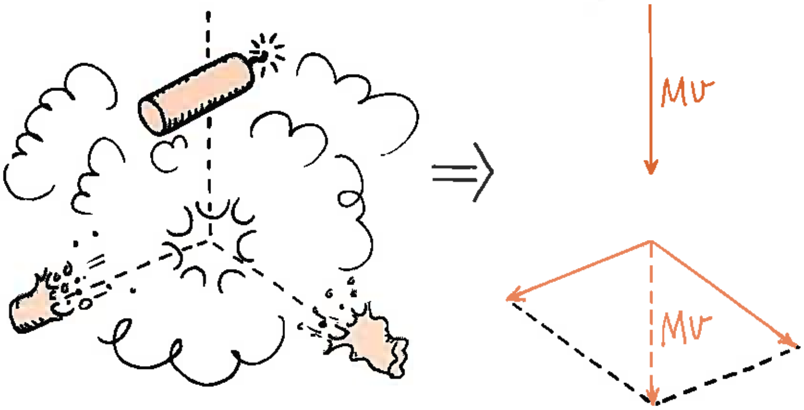

Fig. 7-16 When the firecracker bursts, the momenta of its fragments add up (by the vector parallelogram rule) to the momentum just before bursting.

Fig. 7-17 Momentum is conserved for the high-speed elementary particles, as shown by the tracks they leave in a streamer spark chamber. The relative masses of the particles is determined, among other things, by the paths they take after collision.

Figure 7-17 is a photo of tracks made by subatomic particles in a streamer spark chamber. The masses of these particles can be computed by applying both the conservation of momentum and the conservation of energy (which is covered 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 the fact that forces don't show up in the equations. The forces of the collision processes, however complicated, need not be of concern.

The law of conservation of momentum and, as the next chapter will discuss, the law of 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 measuring the spin rates of entire galaxies.

7 Chapter Review

Concept Summary

Momentum of an object is the product of mass times velocity.

- The change in momentum depends on the force that acts and on the length of time it acts.
- Impulse is force multiplied by the time during which it acts.
- The change in momentum equals the impulse.

According to the law of conservation of momentum, momentum is conserved when there is no net external force.

- When objects collide in the absence of external forces, momentum is conserved no matter whether the collision is elastic or inelastic.

Momentum is a vector quantity.

- Momenta combine by vector rules.

Important Terms

conserved (7.4)
elastic collision (7.5)
impulse (7.2)
inelastic collision (7.5)
law of conservation of momentum (7.4)
momentum (7.1)

Review Questions

1. a. Which has the greater mass—a heavy truck at rest or a rolling skateboard?
   b. Which has greater momentum? (7.1)
2. When the average force of impact on an object is extended in time, does this increase or decrease the impulse? (7.2)
3. What is the relationship between impulse and momentum? (7.2)
4. a. For a constant force, if the duration of impact upon an object is doubled, by how much is the impulse increased?
   b. By how much is the resulting change in momentum increased? (7.2)
5. a. If both the force that acts on an object *and* the time of impact are doubled, by how much is the impulse increased?
   b. By how much is the resulting change in momentum increased? (7.2)
6. In a car crash, why is it advantageous for an occupant to extend the time during which the collision is taking place? (7.2)
7. If the time of impact in a collision is extended by four times, by how much is the force of impact altered? (7.2)
8. a. Why is it advantageous for a boxer to ride with the punch?
   b. Why is it disadvantageous to move into an oncoming punch? (7.2)
9. When you throw a ball, do you experience an impulse? Do you experience an impulse if you instead catch a ball of the same speed? If you catch it, then throw it out again? Which impulse is greatest? (Visualize yourself on a skateboard.) (7.3)
10. Why is the force of impact greater in a collision that involves bouncing? (7.3)
11. Why is the Pelton wheel design a better one than paddle wheels with flat blades? (7.3)
12. What does it mean to say that momentum is a vector quantity? (7.4)
13. In terms of momentum conservation, why does a gun kick when fired? (7.4)

Ashley Sprague

14. The text states that if no net force acts on a system, then the momentum of that system cannot change. It also states there is no change in momentum when a rifle is fired. Doesn't the fact that a bullet undergoes a considerable change in momentum as it accelerates along the barrel contradict this? Explain. (7.4)

15. What does it mean to say that momentum is conserved? (7.4)

16. How can a rocket be propelled above the atmosphere where there is no air to "push against"? (7.4)

17. Distinguish between an *elastic* and *inelastic* collision. (7.5)

18. What effect does friction have on the momentum of an object? (7.5)

19. Imagine that you are hovering next to a space shuttle in earth orbit and your buddy of equal mass who is moving at 4 km/h with respect to the ship bumps into you. If he holds onto you, how fast do you both move with respect to the ship? (7.5)

20. Is momentum conserved for colliding objects that are moving at angles to one another? Explain. (7.6)

Think and Explain

1. When you ride a bicycle at full speed, which has the greater momentum—you or the bike? (Does this help explain why you go over the handlebars if the bike is brought to an abrupt halt?)

2. For the least harm to your hand, should you catch a fast-moving baseball while your hand is at rest, while it moves toward the ball, or while it is pulling back away from the ball? Explain.

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

4. Everybody knows that you will be harmed less if you fall on a floor with "give" than a rigid floor. In terms of impulse and momentum, why is this so?

5. If you throw a heavy rock from your hands while standing on a skateboard, you roll backwards. Would you roll backwards if you didn't actually throw a rock but went through the motions of throwing the rock? Defend your answer.

6. A bug and the windshield of a fast-moving car collide. Tell whether the following statements are 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.

7. When a space shuttle dips back into the atmosphere from orbit, it turns to the left and right in giant S-curves. How does this maneuver increase the impulse delivered to the shuttle so that it will slow before landing?

8. Who is in greater trouble—a person who comes to an abrupt halt when he falls to the pavement below or a person who bounces upon impact? Explain.

9. A railroad diesel engine weighs 4 times as much as a flatcar. If a diesel coasts at 5 km/h into a flatcar that is initially at rest, how fast do the two coast after they couple together?

10. An alpha particle is a nuclear particle of known mass. Suppose one is accelerated to a high speed in an atomic accelerator and directed into an observation chamber. There it collides and sticks to a target particle that is initially at rest. As a result of the impact, the combined target particle and alpha particle is observed to move at half the initial speed of the alpha particle. Why do observers conclude that the target particle is itself an alpha particle?