These ice boats sail across the ice at great speeds. What gets the boats moving in the first place? What keeps them moving once they're going?

What Causes Motion?

Galileo was the first to realize that objects in *uniform motion* require no "cause" for their motion. Only *changes* in motion—accelerations—require a cause: a *force*.

What is a Force?

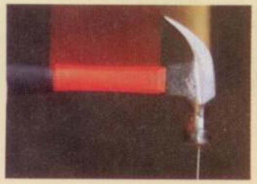
We'll understand force by first examining the properties common to all forces, then by studying a number of forces we'll encounter often.

Forces are a *push* or a *pull*, act on an *object*, and have an identifiable *agent*. Forces are *vectors*.

Looking Back ◀◀
1.5 Vectors and motion

Newton's Third Law

When two objects interact, each exerts a force on the other. Newton's third law tells us that these two forces point in *opposite* directions but have the *same* magnitudes.

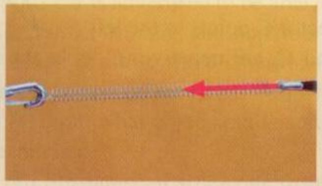


The force of the hammer on the nail has the same magnitude as the force of the nail on the hammer.

Some Important Forces

It's important to understand the characteristics of a number of important forces. Some of the forces you'll learn about in this chapter are . . .

Weight
The force of gravity acting on an object.

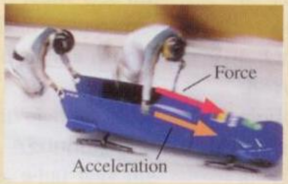


Spring force
The force exerted by a stretched or compressed spring.

Normal force
A force that a surface exerts on an object.

Newton's Second Law

Newton's second law tells us what forces *do* when applied to an object. We'll find that forces act to *accelerate* objects. We will use Newton's second law throughout this textbook to solve a wide variety of physics problems.



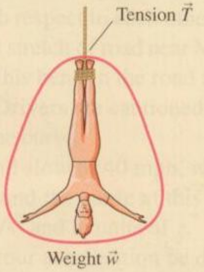
An object's acceleration vector is in the same direction as the net force acting on the object.

Looking Back ◀◀
2.4 Acceleration

Looking Back ◀◀
3.2–3.3 Vectors and coordinate systems

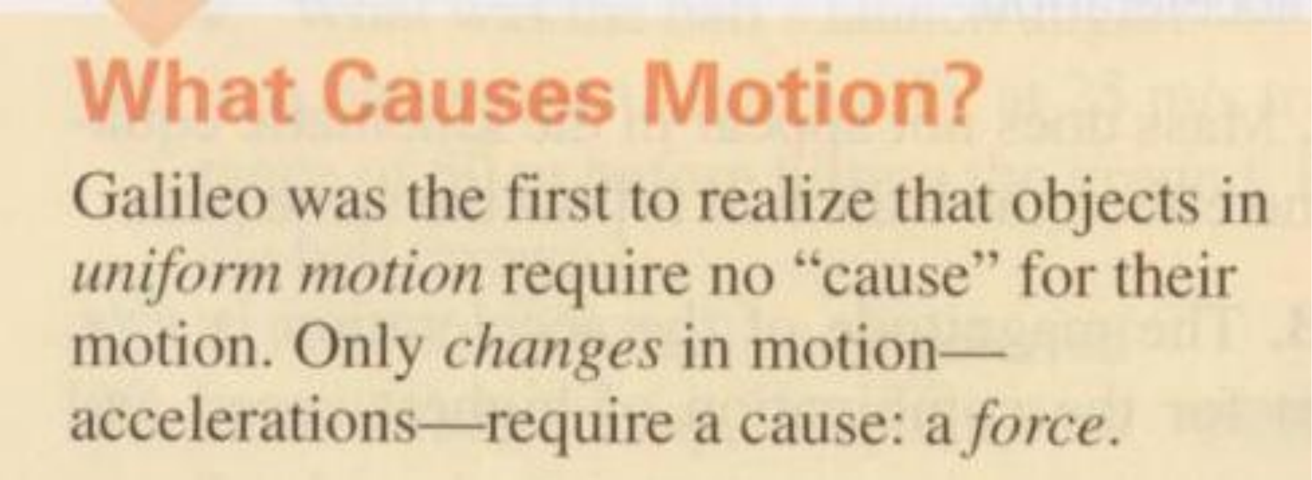
Identifying and Representing Forces

One of the most important skills you'll learn in this chapter is to properly identify the forces that act on an object. Then you'll learn to organize these forces in a *free-body diagram.*



Other than the weight force, all forces acting on an object come from other objects that *touch* it.

We can represent all the forces acting on an object in a free-body diagram.



What Causes Motion?

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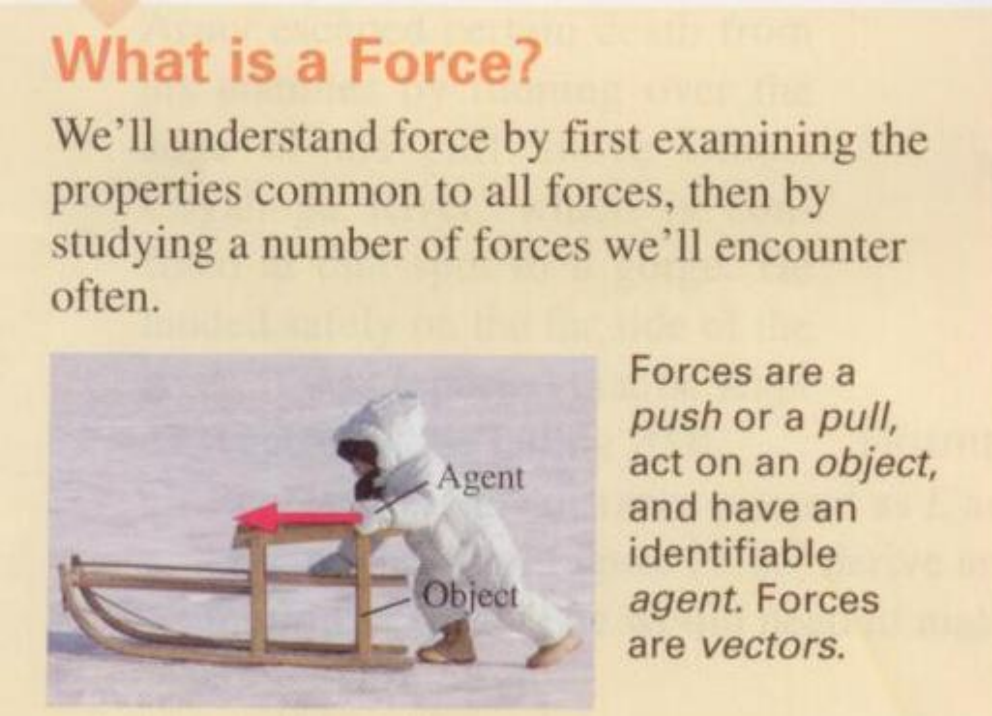


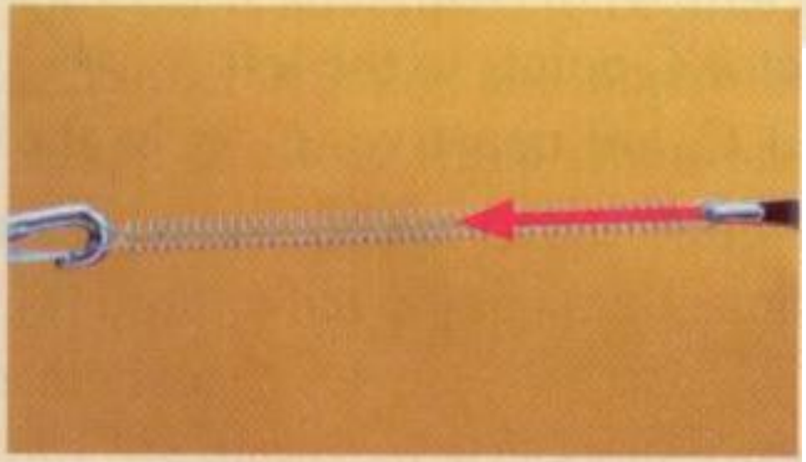
What is a Force?

We’ll understand force by first examining the properties common to all forces, then by studying a number of forces we’ll encounter often.

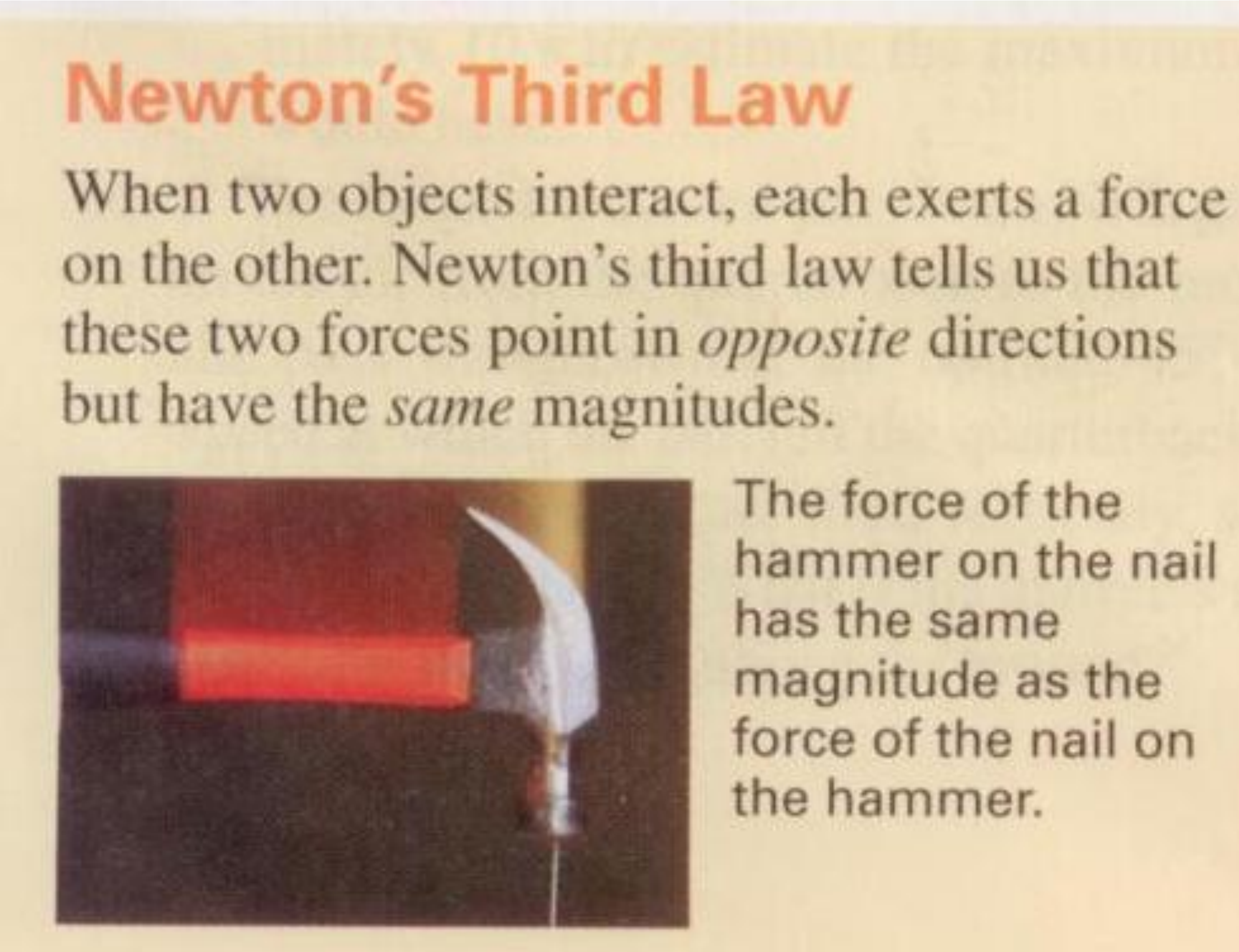
Forces are a *push* or a *pull*, act on an *object*, and have an identifiable *agent*. Forces are *vectors*.

Weight
The force of gravity acting on an object.

Normal force
A force that a surface exerts on an object.



Spring force
The force exerted by a stretched or compressed spring.



Newton's Third Law

When two objects interact, each exerts a force on the other. Newton's third law tells us that these two forces point in *opposite* directions but have the *same* magnitudes.

The force of the hammer on the nail has the same magnitude as the force of the nail on the hammer.

Galileo reopened the question of the "natural state" of objects. He suggested focusing on the *idealized case* in which resistance to the motion (e.g., friction or air resistance) is zero. He performed many experiments to study motion. Let's imagine a modern experiment of this kind, as shown in **FIGURE 4.1**.

FIGURE 4.1 Sleds sliding on increasingly smooth surfaces.

(**a**) Smooth snow

On smooth snow, the sled soon comes to rest.

(**b**) Slick ice

On slick ice, the sled slides farther.

(**c**) Frictionless surface

If friction could be reduced to zero, the sled would *never* stop.

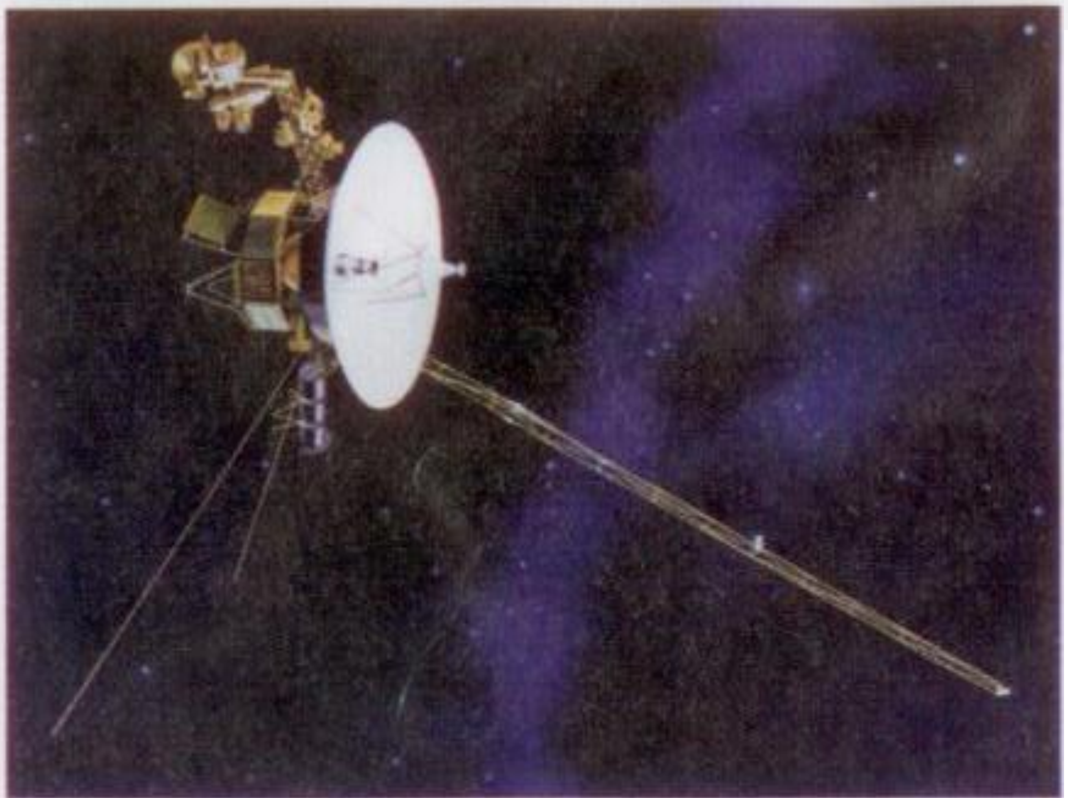
Tyler slides down a hill on his sled, then out onto a horizontal patch of smooth snow, which is shown in Figure 4.1a. Even if the snow is quite smooth, the friction between the sled and the snow will soon cause the sled to come to rest. What if Tyler slides down the hill onto some very slick ice, as in Figure 4.1b? This gives very low friction, and the sled could slide for quite a distance before stopping. Galileo's genius was to imagine the case where *all* sources of friction, air resistance, and other retarding influences were removed, as for the sled in Figure 4.1c sliding on idealized *frictionless* ice. We can imagine in that case that the sled, once started in its motion, would continue in its motion *forever,* moving in a straight line with no loss of speed. In other words, **the natural state of an object—its behavior if free of external influences—is *uniform motion* with constant velocity!** Further, "at rest" has no special significance in Galileo's view of motion; it is simply uniform motion that happens to have a velocity of zero. This implies that an object at rest, in the absence of external influences, will remain at rest forever.

Galileo's ideas were completely counter to those of the ancient Greeks. We no longer need to explain why a sled continues to slide across the ice; that motion is its "natural" state. What needs explanation, in this new viewpoint, is why objects *don't* continue in uniform motion. Why does a sliding puck eventually slow to a stop? Why does a stone, thrown upward, slow and eventually fall back down? Galileo's new viewpoint was that the stone and the puck are *not* free of "influences": The stone is somehow pulled toward the earth, and some sort of retarding influence acted to slow the sled down. Today, we call such influences that lead to deviations from uniform motion **forces.**

Galileo's experiments were limited to motion along horizontal surfaces. It was left to Newton to generalize Galileo's conclusions, and today we call this generalization Newton's first law of motion.

Newton's first law Consider an object with no force acting on it. If it is at rest, it will remain at rest; if it is moving, it will continue to move in a straight line at a constant speed.

▶ **Interstellar coasting** A nearly perfect example of Newton's first law is the pair of Voyager space probes launched in 1977. Both spacecraft long ago ran out of fuel and are now coasting through the frictionless vacuum of space. Although not entirely free of influence from the sun's gravity, they are now so far from the sun and other stars that gravitational influences are very nearly zero. Thus, according to the first law, they will continue at their current speed of about 40,000 miles per hour essentially forever. Billions of years from now, long after our solar system is dead, the Voyagers will still be drifting through the stars.



At the instant of impact, the car and driver are moving at the same speed.

The car slows as it hits, but the driver continues at the same speed . . .

. . . until he hits the now-stationary dashboard. Ouch!

As an important application of Newton's first law, consider the crash test of **FIGURE 4.2**. As the car contacts the wall, the wall exerts a force on the car and it begins to slow. But the wall is a force on the *car,* not on the dummy. In accordance with Newton's first law, the unbelted dummy continues to move straight ahead at his original speed. Only when he collides violently with the dashboard of the stopped car is there a force acting to halt the dummy's uniform motion. If he had been wearing a seatbelt, the influence (i.e., the force) of the seatbelt would have slowed the dummy at the much lower rate at which the car slows down. We'll study the forces of collisions in detail in Chapter 10.

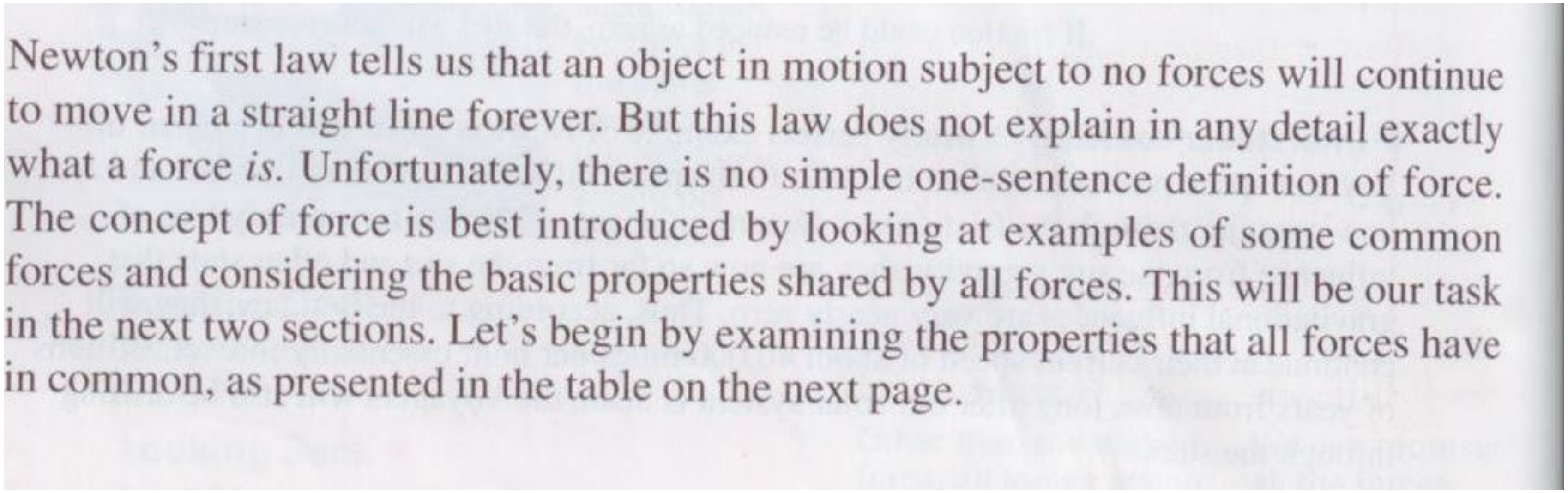
TRY IT YOURSELF

Getting the ketchup out The ketchup stuck at the bottom of the bottle is initially at rest. If you hit the bottom of the bottle, the bottle suddenly moves down, taking the ketchup on the bottom of the bottle with it, so that the ketchup just stays stuck to the bottom. But if instead you hit *up* on the bottle, as shown, you force the bottle rapidly upward. By the first law, the ketchup that was stuck to the bottom stays at rest, so it separates from the upward-moving bottle: The ketchup has moved forward with respect to the bottle!

TRY IT YOURSELF

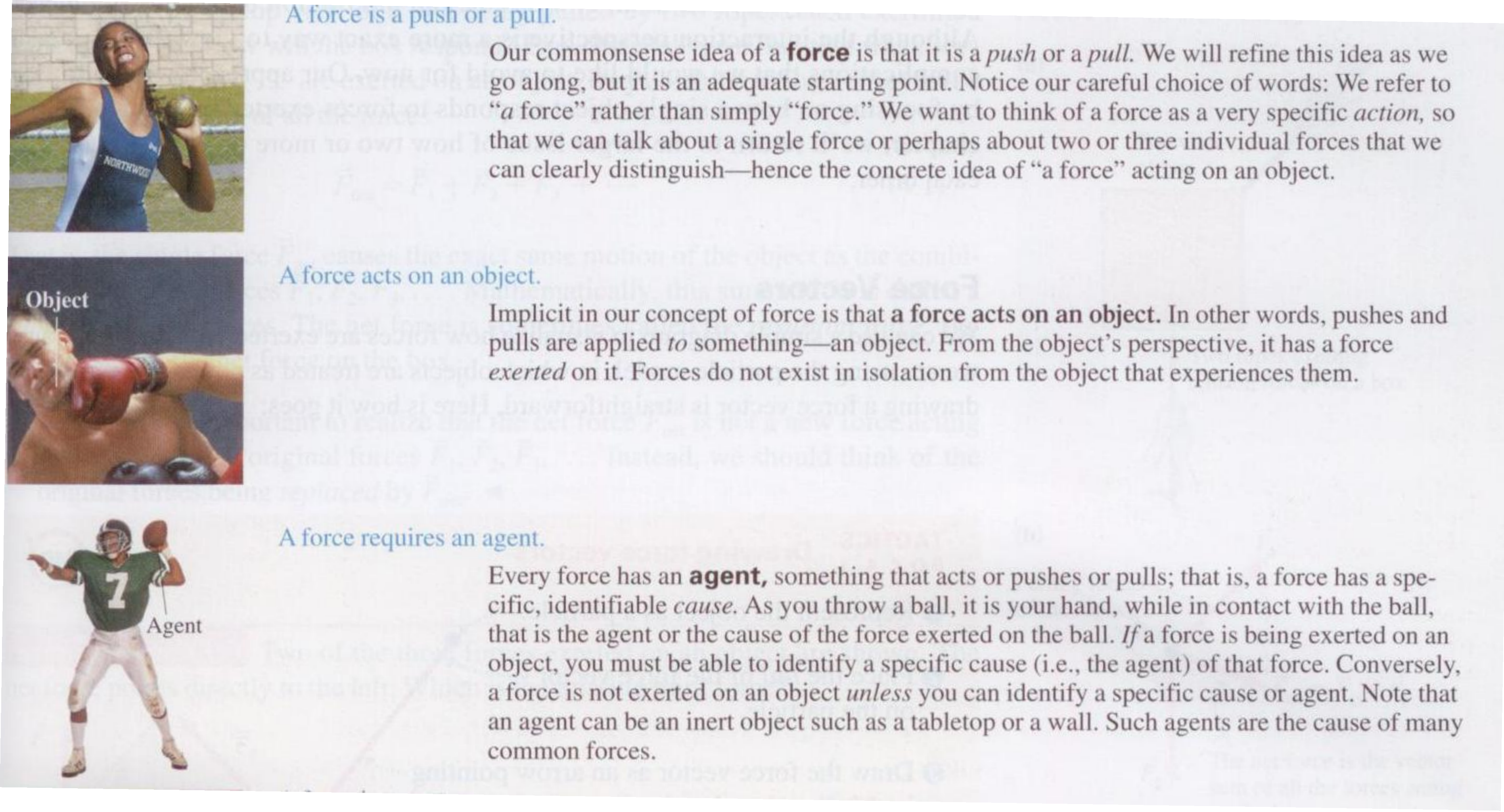
Feel the difference Because of its high sugar content, a can of regular soda has a mass about 4% greater than that of a can of diet soda. If you try to judge which can is more massive by simply holding one in each hand, this small difference is almost impossible to detect. If you *move* the cans up and down, however, the difference becomes subtly but noticeably apparent: People evidently are more sensitive to how the mass of each can resists acceleration than they are to the cans' weights alone.

Force



Newton's first law tells us that an object in motion subject to no forces will continue to move in a straight line forever. But this law does not explain in any detail exactly what a force *is*. Unfortunately, there is no simple one-sentence definition of force. The concept of force is best introduced by looking at examples of some common forces and considering the basic properties shared by all forces. This will be our task in the next two sections. Let's begin by examining the properties that all forces have in common, as presented in the table on the next page.

Force



A force is a push or a pull.

Our commonsense idea of a **force** is that it is a *push* or a *pull.* We will refine this idea as we go along, but it is an adequate starting point. Notice our careful choice of words: We refer to "*a* force" rather than simply "force." We want to think of a force as a very specific *action,* so that we can talk about a single force or perhaps about two or three individual forces that we can clearly distinguish—hence the concrete idea of "a force" acting on an object.

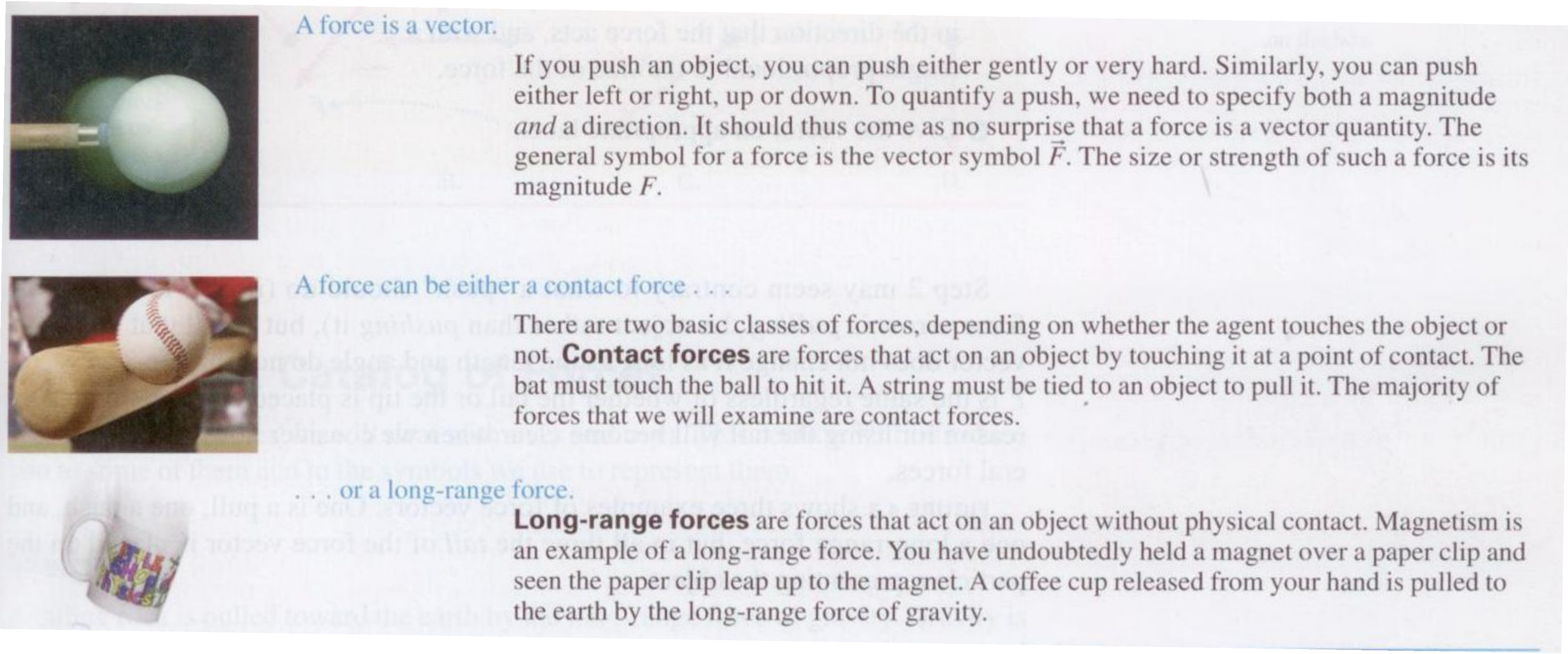
A force acts on an object.

Implicit in our concept of force is that **a force acts on an object.** In other words, pushes and pulls are applied *to* something—an object. From the object's perspective, it has a force *exerted* on it. Forces do not exist in isolation from the object that experiences them.

A force requires an agent.

Every force has an **agent,** something that acts or pushes or pulls; that is, a force has a specific, identifiable *cause.* As you throw a ball, it is your hand, while in contact with the ball, that is the agent or the cause of the force exerted on the ball. *If* a force is being exerted on an object, you must be able to identify a specific cause (i.e., the agent) of that force. Conversely, a force is not exerted on an object *unless* you can identify a specific cause or agent. Note that an agent can be an inert object such as a tabletop or a wall. Such agents are the cause of many common forces.

Force



A force is a vector.

If you push an object, you can push either gently or very hard. Similarly, you can push either left or right, up or down. To quantify a push, we need to specify both a magnitude *and* a direction. It should thus come as no surprise that a force is a vector quantity. The general symbol for a force is the vector symbol $\vec{F}$. The size or strength of such a force is its magnitude F.

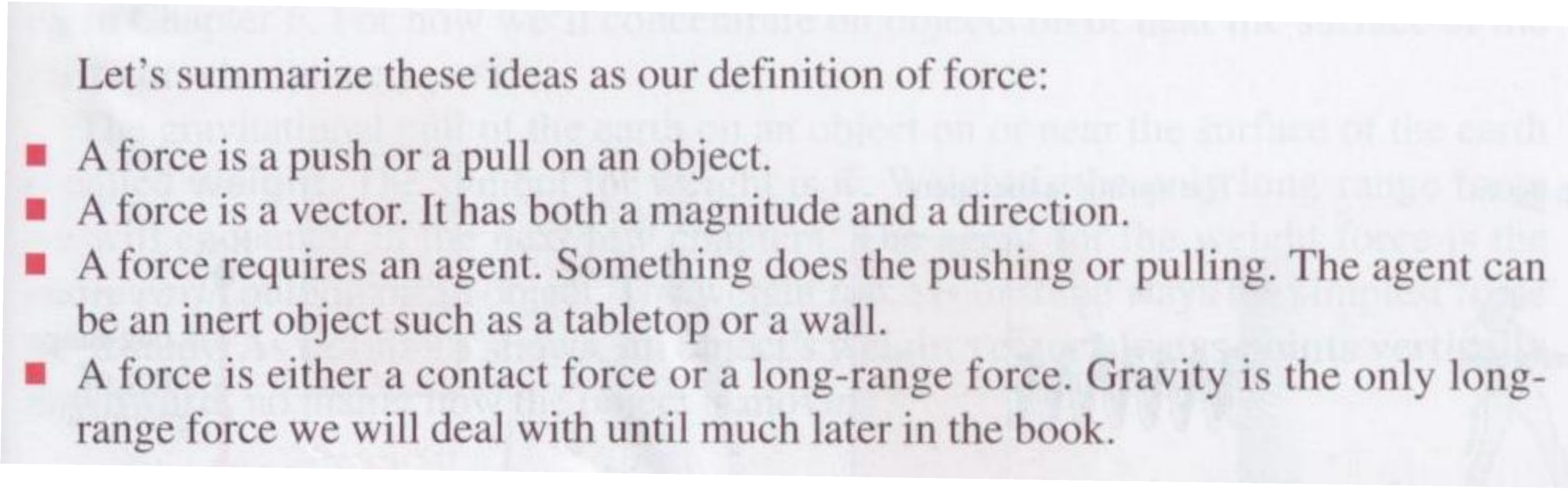
A force can be either a contact force . . .

There are two basic classes of forces, depending on whether the agent touches the object or not. **Contact forces** are forces that act on an object by touching it at a point of contact. The bat must touch the ball to hit it. A string must be tied to an object to pull it. The majority of forces that we will examine are contact forces.

. . . or a long-range force.

Long-range forces are forces that act on an object without physical contact. Magnetism is an example of a long-range force. You have undoubtedly held a magnet over a paper clip and seen the paper clip leap up to the magnet. A coffee cup released from your hand is pulled to the earth by the long-range force of gravity.

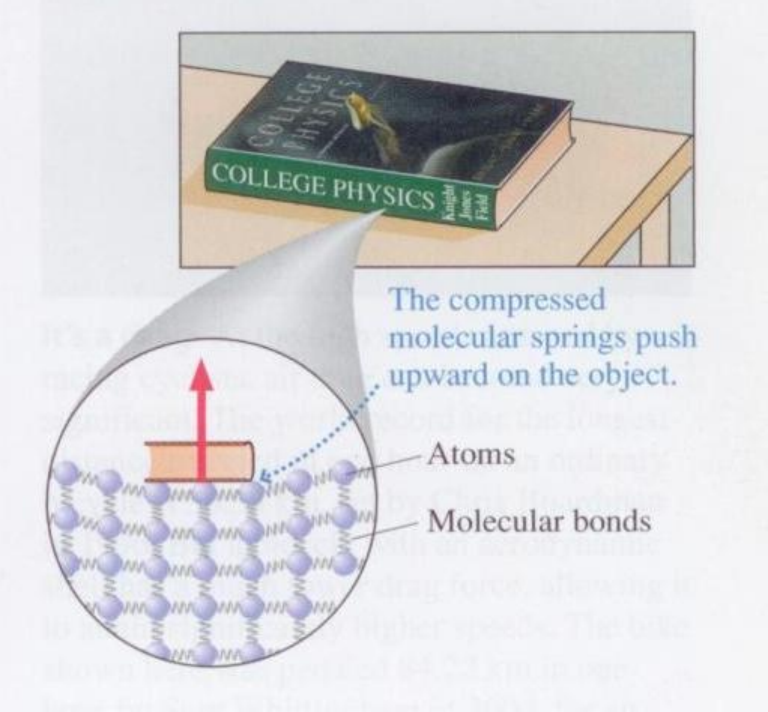
Force



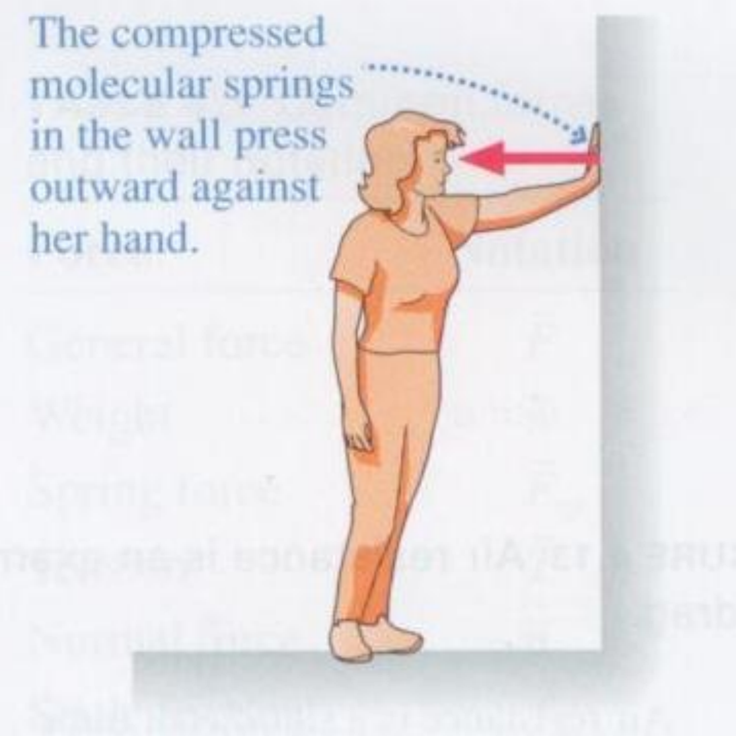
Let's summarize these ideas as our definition of force:

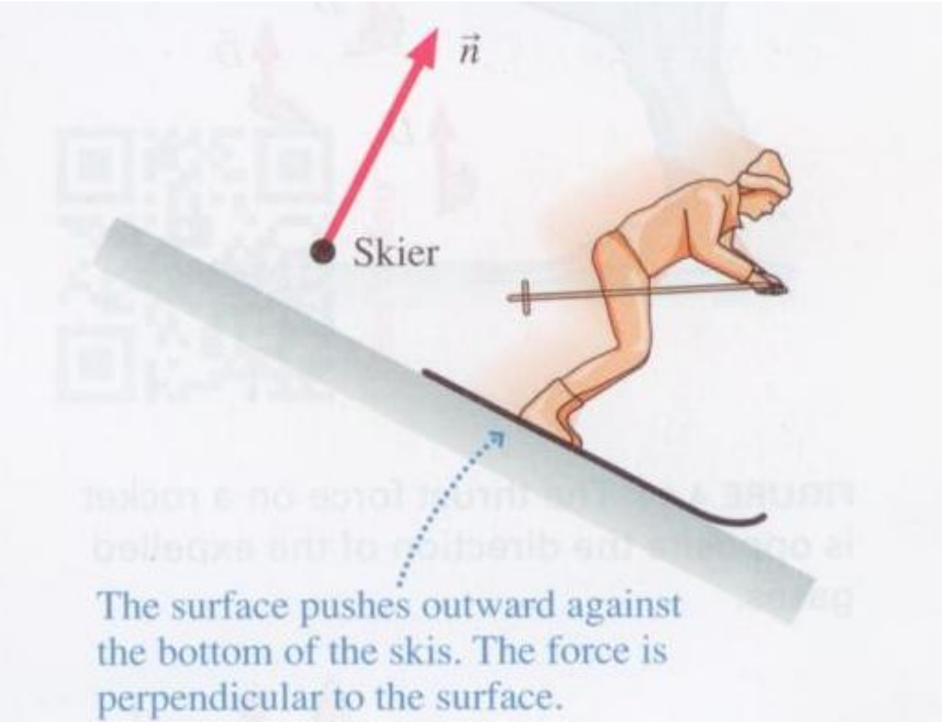
- A force is a push or a pull on an object.
- A force is a vector. It has both a magnitude and a direction.
- A force requires an agent. Something does the pushing or pulling. The agent can be an inert object such as a tabletop or a wall.
- A force is either a contact force or a long-range force. Gravity is the only long-range force we will deal with until much later in the book.

Supporting force



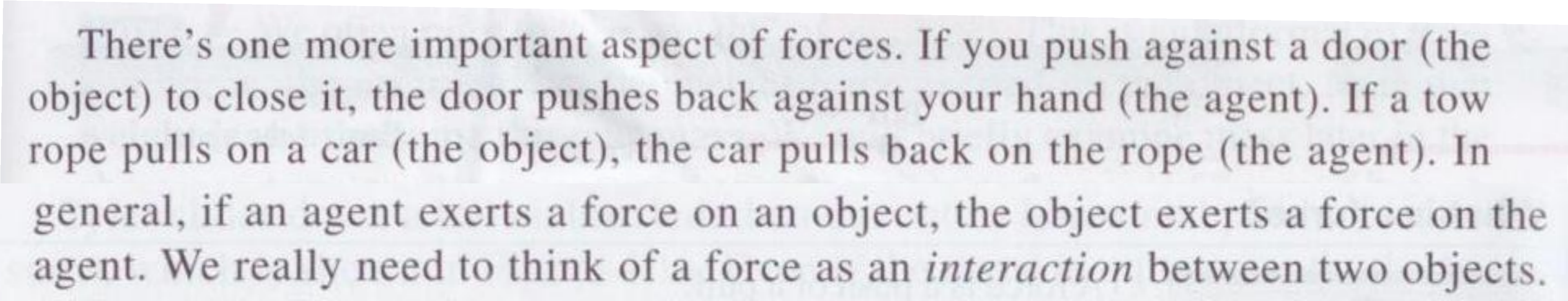
The compressed molecular springs push upward on the object.


The compressed molecular springs in the wall press outward against her hand.

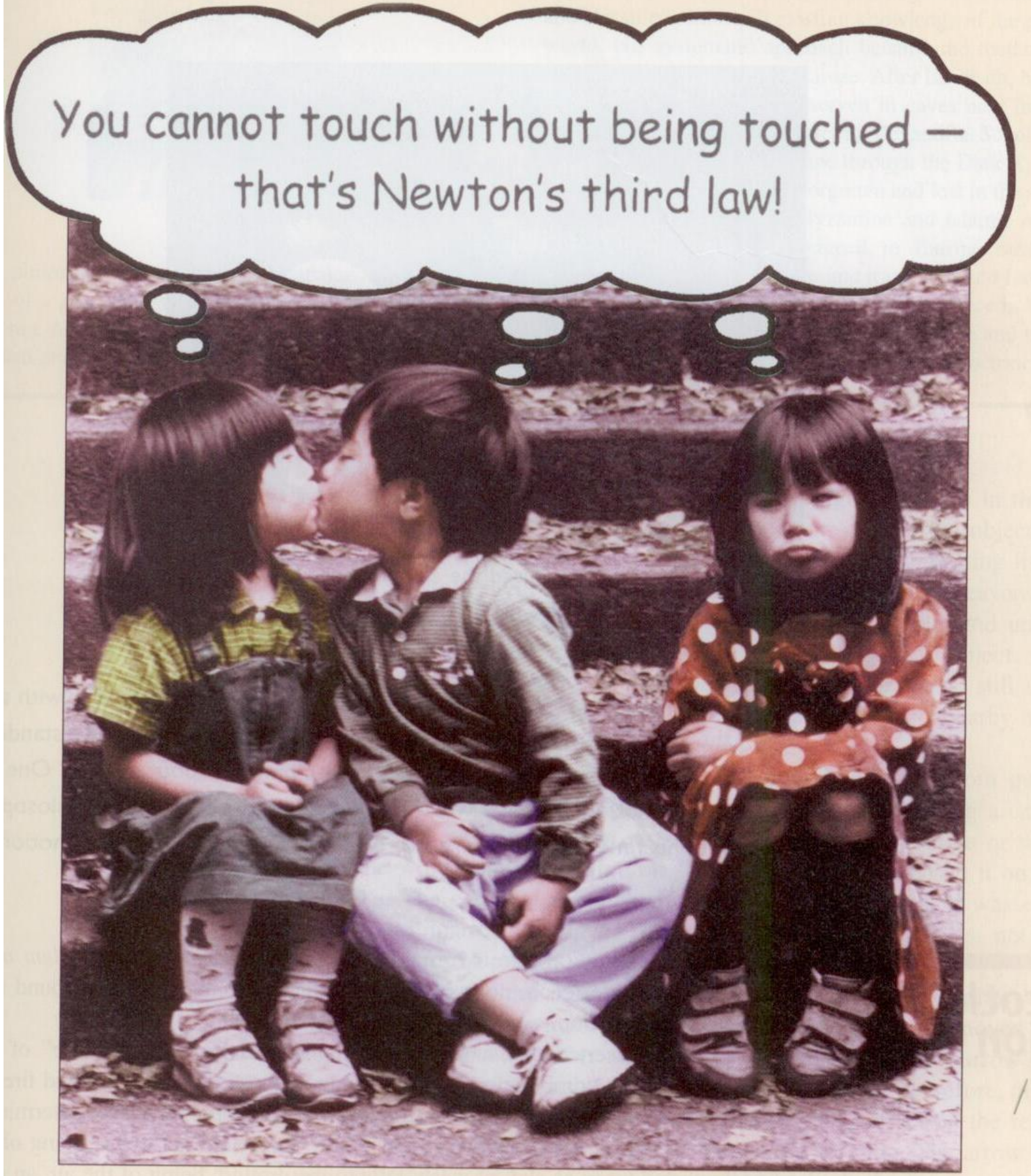


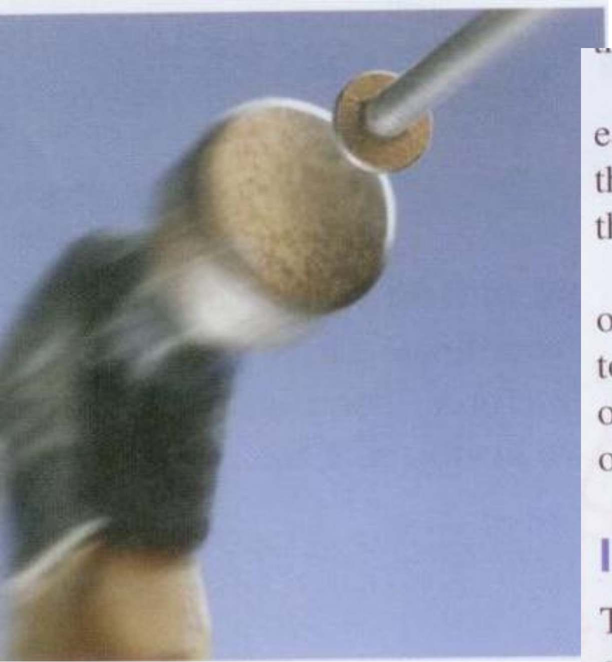
The surface pushes outward against the bottom of the skis. The force is perpendicular to the surface.

Force Pairs



There's one more important aspect of forces. If you push against a door (the object) to close it, the door pushes back against your hand (the agent). If a tow rope pulls on a car (the object), the car pulls back on the rope (the agent). In general, if an agent exerts a force on an object, the object exerts a force on the agent. We really need to think of a force as an *interaction* between two objects.


You cannot touch without being touched — that's Newton's third law!

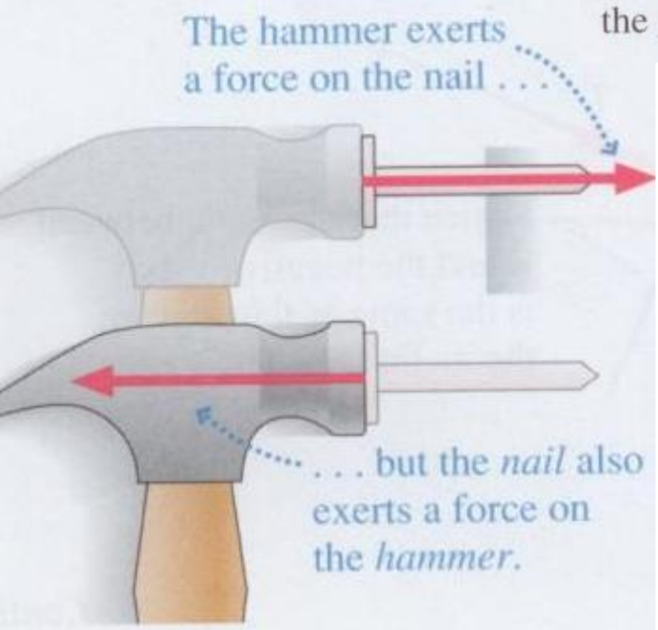


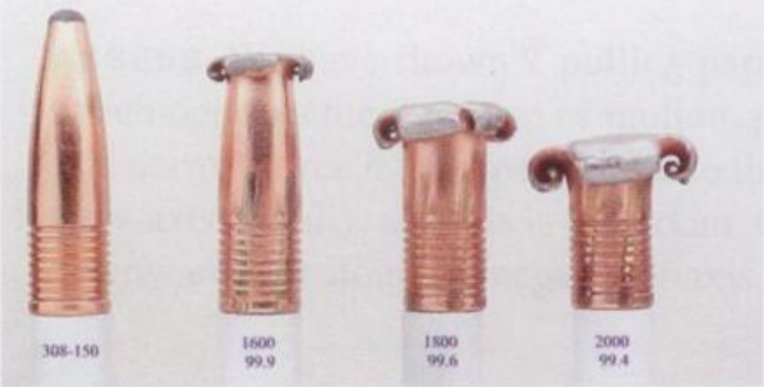
But motion in the real world often involves two or more objects *interacting* with each other. Consider the hammer and nail in **FIGURE 4.27**. As the hammer hits the nail, the nail pushes back on the hammer. A bat and a ball, your foot and a soccer ball, and the earth–moon system are other examples of interacting objects.

Newton's second law is not sufficient to explain what happens when two or more objects interact. It does not explain how the force of the hammer on the nail is related to the force of the nail on the hammer. In this section we will introduce another law of physics, Newton's *third* law, that describes how two objects interact with each other.

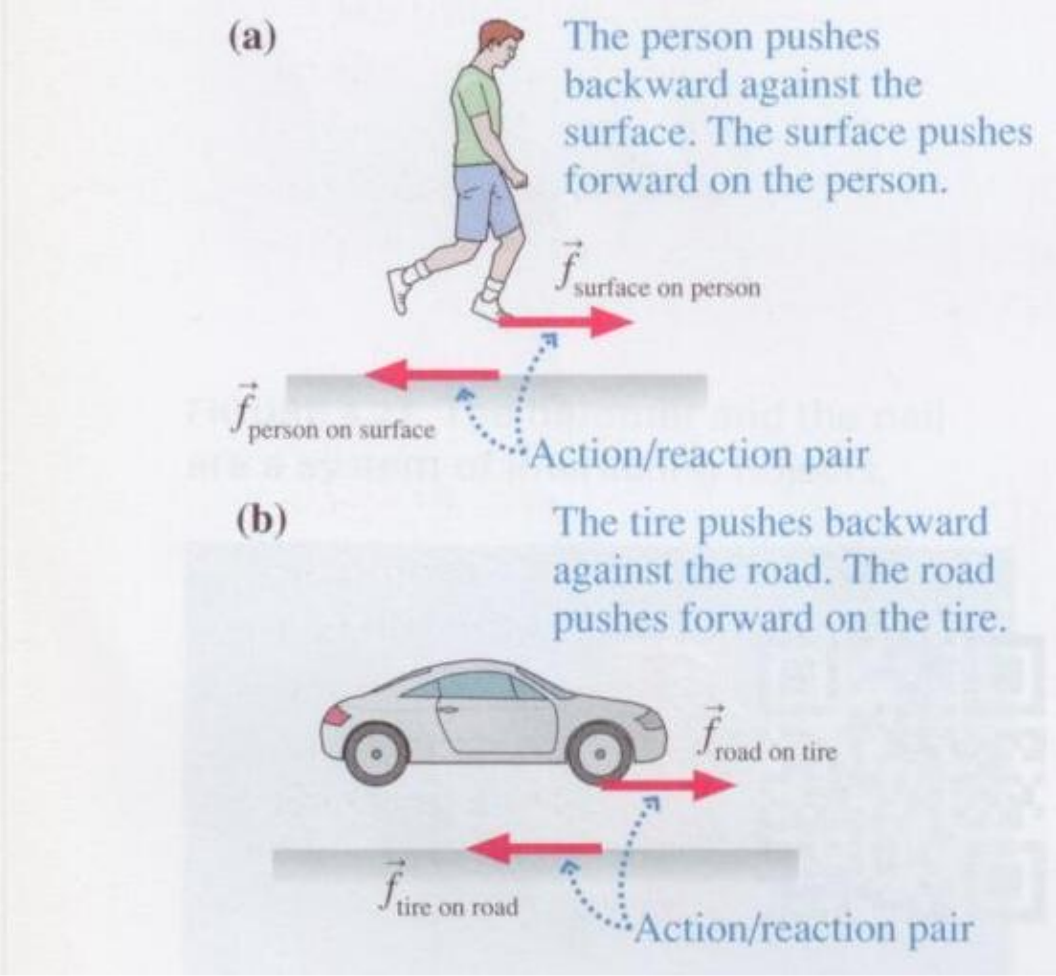
Interacting Objects

Think about the hammer and nail in Figure 4.27. As **FIGURE 4.28** shows, the hammer certainly exerts a force on the nail as it drives the nail forward. At the same time, the nail exerts a force on the hammer. If you are not sure that it does, imagine hitting the nail with a glass hammer. It's the force of the nail on the hammer that would cause the glass to shatter.





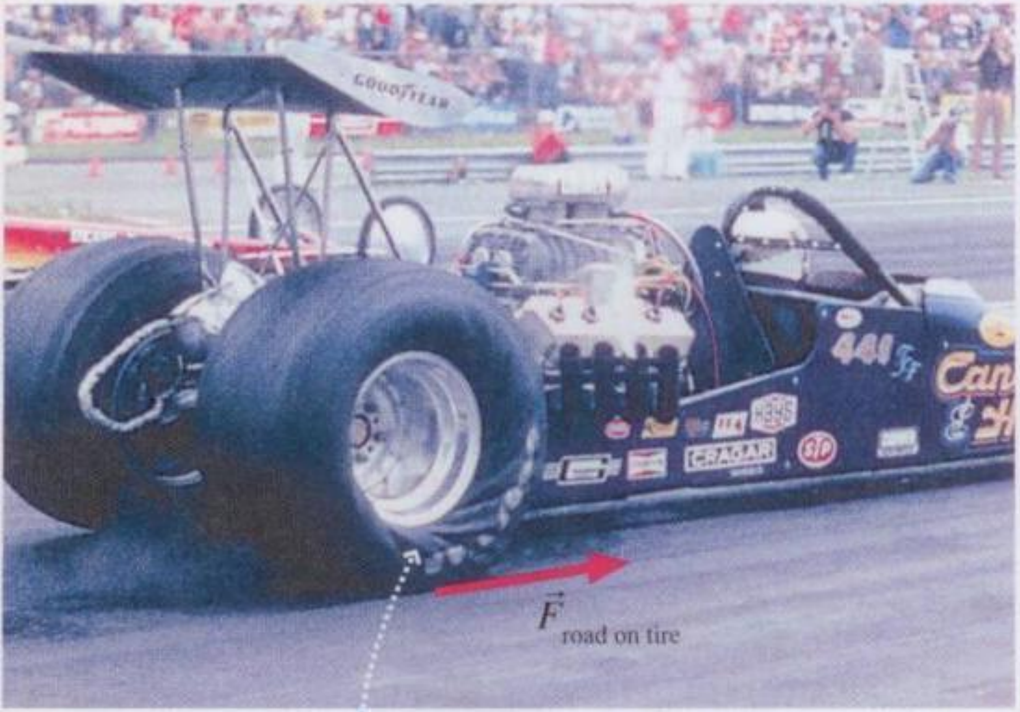
Revenge of the target We normally think of the damage that the force of a bullet inflicts on its target. But according to Newton's third law, the target exerts an equal force on the bullet. The photo shows the damage sustained by bullets fired at 1600, 1800, and 2000 ft/s, after impacting a test target. The appearance of the bullet before firing is shown at the left.



The person pushes backward against the surface. The surface pushes forward on the person.

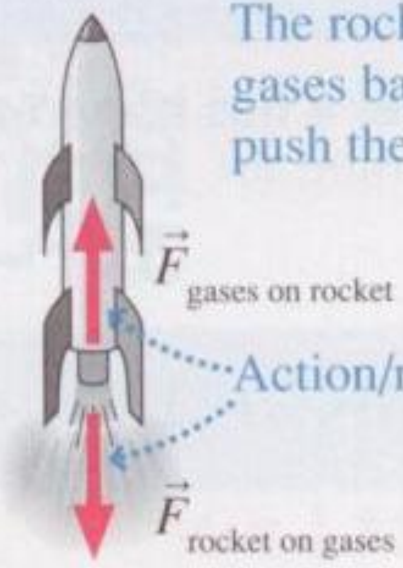
The tire pushes backward against the road. The road pushes forward on the tire.

FIGURE 4.32 When the driver hits the gas, the force of the track on the tire is so great that the tire deforms.



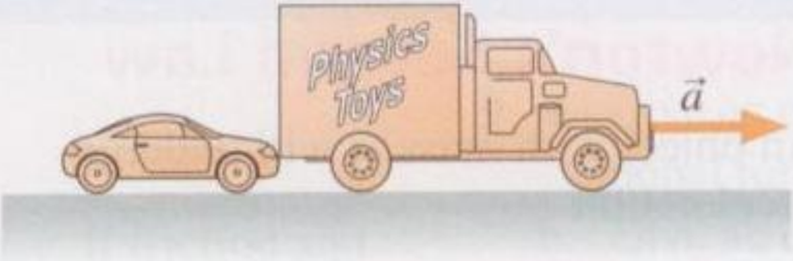
You can *see* that the force of the road on the tire points forward by the way it twists the rubber of the tire.

The rocket pushes the hot gases backward. The gases push the rocket forward.



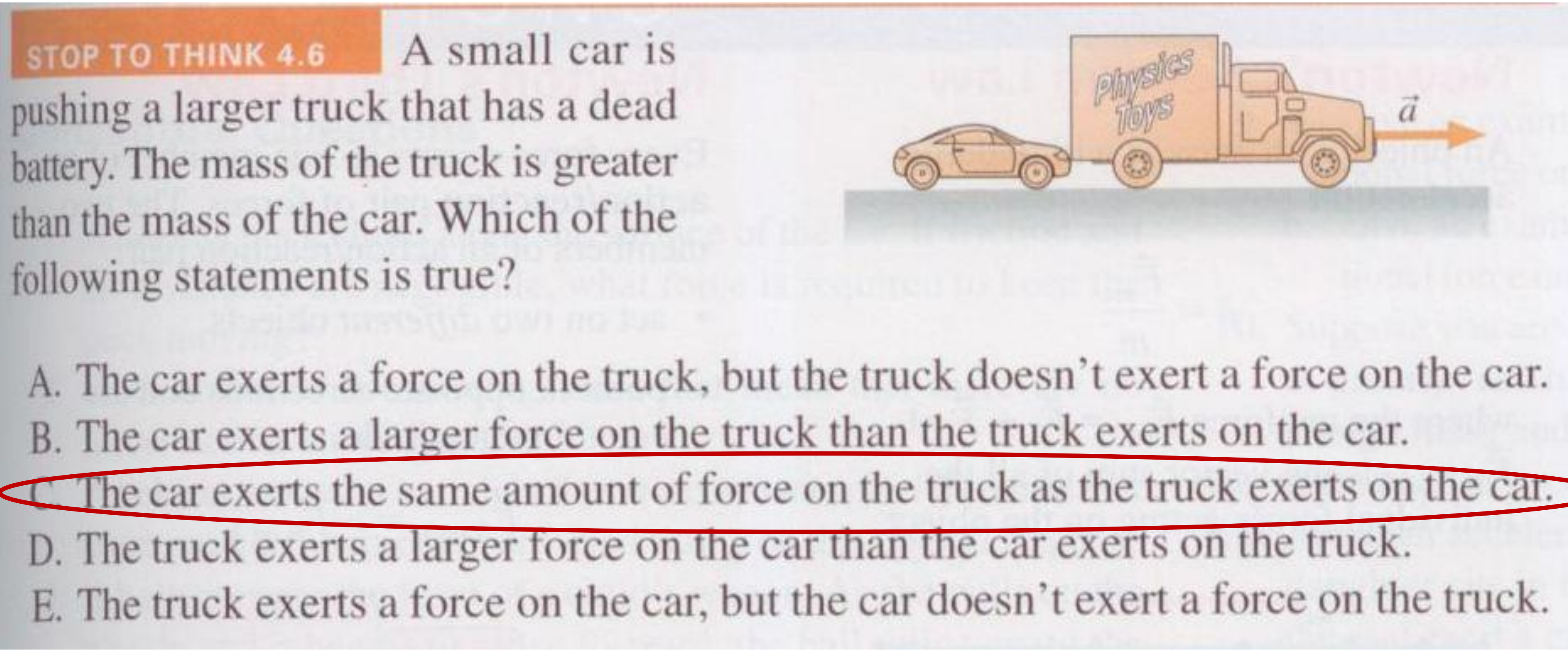
Action/reaction pair

STOP TO THINK 4.6 A small car is pushing a larger truck that has a dead battery. The mass of the truck is greater than the mass of the car. Which of the following statements is true?



A. The car exerts a force on the truck, but the truck doesn't exert a force on the car.
B. The car exerts a larger force on the truck than the truck exerts on the car.
C. The car exerts the same amount of force on the truck as the truck exerts on the car.
D. The truck exerts a larger force on the car than the car exerts on the truck.
E. The truck exerts a force on the car, but the car doesn't exert a force on the truck.

Force pairs are EQUAL



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A. The car exerts a force on the truck, but the truck doesn't exert a force on the car.
B. The car exerts a larger force on the truck than the truck exerts on the car.
[✓ C. The car exerts the same amount of force on the truck as the truck exerts on the car.]
D. The truck exerts a larger force on the car than the car exerts on the truck.
E. The truck exerts a force on the car, but the car doesn't exert a force on the truck.