At this point in your study of physics, you can already solve a wide range of problems using just the conservation laws. Up to now we have applied these laws in only isolated or closed systems, however, and it is not always possible to identify such a system when working on problems. For this reason, you also need to know an approach to problem solving that is valid in systems that are interacting with their surroundings. If you look back at the material in earlier chapters, you will notice that many of the interactions we discussed involve pushing, pulling, or rubbing—all actions related to the everyday notion of *force*. So, in order to be able to deal with systems that are not isolated, you must know about the concept of force.

The term *force* is a familiar one—usually associated with the capacity to either move objects (for example, pushing a chair along the floor) or cause physical change (say, crushing an empty can). To which of the physical quantities I have defined so far does this notion of force best correspond, however, and how can we quantify it?

8.1 Momentum and force

To relate the intuitive concept of force to the quantities we have encountered so far, consider the following scenario. You are on a bicycle coming down a steep hill and approaching a sharp turn at 30 km>h. Suddenly you discover that your brakes are not working, leaving you no option but to slam into a concrete wall. The force of impact will be considerable, and if you were going faster—say, 40 km/h—it would be even greater. Conversely, if you were going at a mere 3 km>h, the impact might not be that bad. And it is not just your speed that matters. When you are carrying a backpack full of bricks and traveling at 30 km/h, the force of impact is greater than when you are traveling at the same speed but carrying nothing on your back.

Realizing that both your speed and your inertia govern the force of the impact you make with the wall, you may be tempted to believe that force is related solely to change in momentum, but things are not that simple. To see why, imagine that part of the concrete wall is padded with mattresses. Which part do you head for? You don't need any physics to realize that the mattresses offer you protection. When you hit a mattress, the force of impact is smaller than when you hit the concrete. In terms of momentum change and energy change, however, it doesn't make any difference which one you choose. In either case, your speed decreases by the same amount, 30 km>h, and so the decreases in your momentum and kinetic energy are the same no matter how you come to a stop.

The difference between hitting a mattress and hitting the concrete is that the mattress changes your momentum over a longer time interval. The momentum change therefore occurs at a slower rate. Evidently, the longer the interaction time, the smaller the force of impact. In other words, what determines the magnitude of the force of impact is not the absolute value of your momentum change but rather the rate at which this change happens. The faster your momentum changes, the larger the force of the impact on you.

This scenario illustrates two important points about forces. First, forces are manifestations of interactions—the force exerted by the mattress on you, for example, is one part of the interaction between you and the mattress (another part is the force exerted by you on the mattress). Second, for an object that is participating in one interaction only, we can quantitatively define **force:**

The force exerted on the object is the time rate of change in the object's momentum.

Because it is related to a change in momentum, force is a vector and so has direction as well as magnitude. The direction of any given force is the same as the direction of the momentum change the force causes. When you hit the wall in our bicycling example, for instance, the direction of the force exerted by the wall on you is opposite your direction of travel because the direction of your momentum change is opposite your direction of travel.

Even though the arguments leading up to the relationship between force and time rate of change in momentum all sound very plausible, I should warn you that the consequences of this relationship differ from your intuitive notions about forces in a number of ways.

> **8.1** Imagine pushing a crate in a straight line along a surface at a steady speed of 1 m/s. What is the time rate of change in the momentum of the crate?

The answer to this checkpoint should surprise you. After all, you *are* pushing the crate. So how can the time rate of change in the momentum of the crate be zero? The problem here is that the crate is interacting not just with you but also with the surface because there is friction between it and the surface. The directions and magnitudes of these two interactions (between the crate and your hands and between the crate and the surface) are such that their combined action causes no change in the momentum of the crate, and so it continues to move at constant speed in the direction of your push. In each interaction, there is a force exerted on the crate—exerted by you in one case and by the surface in the other case. The force exerted by your hands on the crate tends to move the crate forward, while the force exerted in the horizontal direction by the surface on the crate (the *force of friction* or *frictional force*) tends to resist the forward motion of the crate. If the two opposing forces exerted on the crate are equal in magnitude, their vector sum (sometimes called the *net force*) is zero. In other words, if the surface pushes on the crate just as hard as you push on it in the opposite direction, the acceleration effects of the two opposing forces cancel and the crate moves at constant velocity (Figure 8.1). If the force exerted by the surface on the crate is smaller than the force you exert on it, the crate

CONCEPTS

ANNOTATION	EVALUATION	
A: I'm surprised that force is being introduced this late. Normally it is one of the first concepts introduced.	Does not demonstrate any thoughtful reading.	0
A: If there is no interaction, is there no force?	Question exhibits superficial reading, but does not exhibit any interpretation of the textbook.	1
B: I think there has to be some sort of interaction	Response not backed up by any reasoning or theoretical assumptions. No evidence of thoughtful reading of text.	0
C: I would agree, that seems to make the most sense. Newton's first law says that objects in motion tend to stay in motion, objects at rest tend to stay at rest, unless they are acted on. Since this holds true, force is needed to create change, an action is needed from an outside object and therefore an interaction between 2 things is required.	Explanation that makes a claim substantiated by reasoning or theoretical assumptions. The explanation demonstrates an understanding of unified concepts by connecting Newton's first law to the definition of force interactions.	2
E: I don't understand the concept of force.	Does not demonstrate thoughtful reading of the text.	0
E: I don't understand the concept of force. Why is it considered to be a vector? I thought vectors had to have both a direction and magnitude. Isn't a force only a magnitude?	Demonstrates only superficial reading of the textbook.	1
C: Does this mean that momentum and force are linearly proportional?	Interprets the text and applies understanding of concepts.	2