CHAPTER 9
Statics and Torque

FIGURE 9.1 On a short time scale, rocks like these in Australia's Kalbarri National Park are static, or motionless relative to the Earth. (credit: Richard Liblanc/Flickr)

CHAPTER OUTLINE

INTRODUCTION TO STATICS AND TORQUE What might desks, bridges, buildings, trees, and mountains have in common—at least in the eyes of a physicist? The answer is that they are ordinarily motionless relative to the Earth. Furthermore, their acceleration is zero because they remain motionless. That means they also have something in common with a car moving at a constant velocity, because anything with a constant velocity also has an acceleration of zero. Now, the important part—Newton's second law states that net $\mathbf{F} = m\mathbf{a}$, and so the net external force is zero for all stationary objects and for all objects moving at constant velocity. There are forces acting, but they are balanced. That is, they are in *equilibrium*.

Statics

Statics is the study of forces in equilibrium, a large group of situations that makes up a special case of Newton's second law. We have already considered a few such situations; in this chapter, we cover the topic more thoroughly, including consideration of such possible effects as the rotation and deformation of an object by the forces acting on it.

How can we guarantee that a body is in equilibrium and what can we learn from systems that are in equilibrium? There are actually two conditions that must be satisfied to achieve equilibrium. These conditions are the topics of the first two sections of this chapter.

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9.1 The First Condition for Equilibrium

LEARNING OBJECTIVES

By the end of this section, you will be able to:

- State the first condition of equilibrium.
- Explain static equilibrium.
- Explain dynamic equilibrium.

The first condition necessary to achieve equilibrium is the one already mentioned: the net external force on the system must be zero. Expressed as an equation, this is simply

$$\text{net } \mathbf{F} = 0 \tag{9.1}$$

Note that if net $\mathbf{F}$ is zero, then the net external force in *any* direction is zero. For example, the net external forces along the typical *x*- and *y*-axes are zero. This is written as

$$\text{net } F_x = 0 \text{ and net } F_y = 0 \tag{9.2}$$

Figure 9.2 and Figure 9.3 illustrate situations where $\text{net } \mathbf{F} = 0$ for both **static equilibrium** (motionless), and **dynamic equilibrium** (constant velocity).

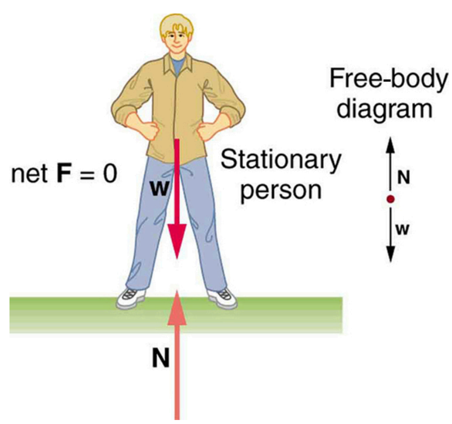

FIGURE 9.2 This motionless person is in static equilibrium. The forces acting on him add up to zero. Both forces are vertical in this case.

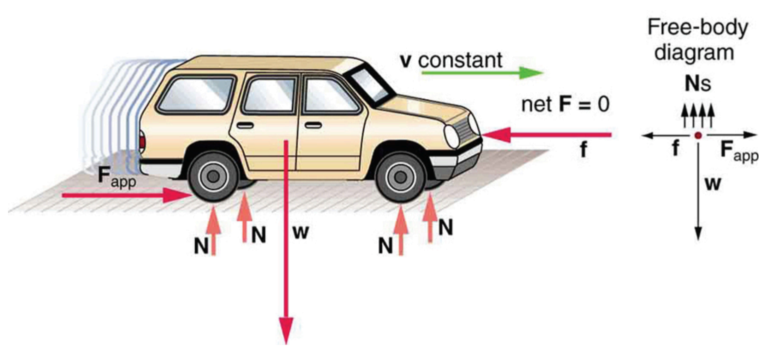

FIGURE 9.3 This car is in dynamic equilibrium because it is moving at constant velocity. There are horizontal and vertical forces, but the net external force in any direction is zero. The applied force $\mathbf{F}_{\text{app}}$ between the tires and the road is balanced by air friction, and the weight of the car is supported by the normal forces, here shown to be equal for all four tires.

However, it is not sufficient for the net external force of a system to be zero for a system to be in equilibrium. Consider the two situations illustrated in Figure 9.4 and Figure 9.5 where forces are applied to an ice hockey stick lying flat on ice. The net external force is zero in both situations shown in the figure; but in one case, equilibrium is achieved, whereas in the other, it is not. In Figure 9.4, the ice hockey stick remains motionless. But in Figure 9.5, with the same forces applied in different places, the stick experiences accelerated rotation. Therefore, we know that the point at which a force is applied is another factor in determining whether or not equilibrium is achieved. This will be explored further in the next section.

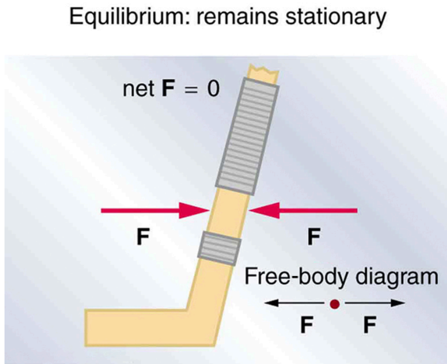

FIGURE 9.4 An ice hockey stick lying flat on ice with two equal and opposite horizontal forces applied to it. Friction is negligible, and the gravitational force is balanced by the support of the ice (a normal force). Thus, net $\mathbf{F} = 0$. Equilibrium is achieved, which is static equilibrium in this case.

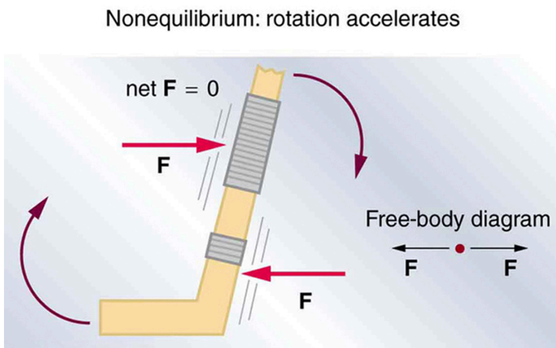

FIGURE 9.5 The same forces are applied at other points and the stick rotates—in fact, it experiences an accelerated rotation. Here net $\mathbf{F} = 0$ but the system is *not* at equilibrium. Hence, the net $\mathbf{F} = 0$ is a necessary—but not sufficient—condition for achieving equilibrium.

PHET EXPLORATIONS

Torque

Investigate how torque causes an object to rotate. Discover the relationships between angular acceleration, moment of inertia, angular momentum and torque.

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9.2 The Second Condition for Equilibrium

LEARNING OBJECTIVES

By the end of this section, you will be able to:

- State the second condition that is necessary to achieve equilibrium.
- Explain torque and the factors on which it depends.
- Describe the role of torque in rotational mechanics.

Torque

The second condition necessary to achieve equilibrium involves avoiding accelerated rotation (maintaining a