

## 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

$$\text{net } F = 0 \quad (9.1.1)$$

Note that if net  $F$  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

$$\text{net } F_x \text{ and } F_y = 0 \quad (9.1.2)$$

Figures 9.1.1 and 9.1.2 illustrate situations where  $\text{net } F = 0$  for both static equilibrium (motionless), and dynamic equilibrium (constant velocity).

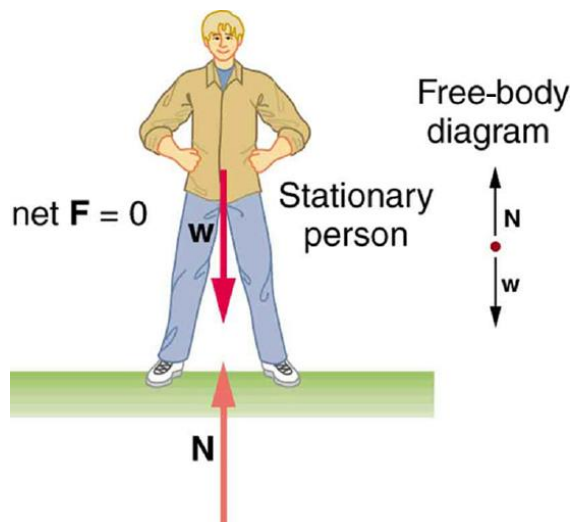


Figure 9.1.1: This motionless person is in static equilibrium. The forces acting on him add up to zero. Both forces are vertical in this case.

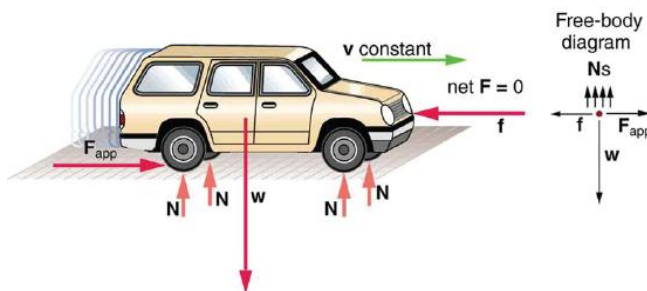


Figure 9.1.2: This car is in dynamic equilibrium because it is moving at constant velocity. There are horizontal and vertical forces, but the net external force in any direction is zero. The applied force  $F_{app}$  between the tires and the road is balanced by air friction, and the weight of the car 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 Figures 9.1.3 and 9.1.4 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 9.1.3, the ice hockey stick remains motionless. But in Figure 9.1.4, 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.

Equilibrium: remains stationary

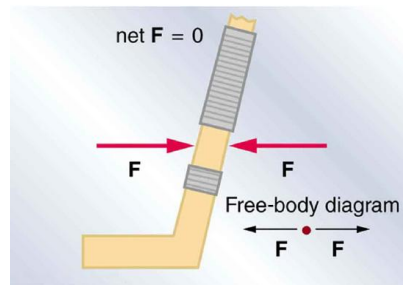


Figure 9.1.3: An ice hockey stick lying flat on ice with two equal and opposite horizontal forces applied to it. Friction is negligible, and the gravitational force is balanced by the support of the ice (a normal force). Thus,  $net F = 0$ . Equilibrium is achieved, which is static equilibrium in this case.

Nonequilibrium: rotation accelerates

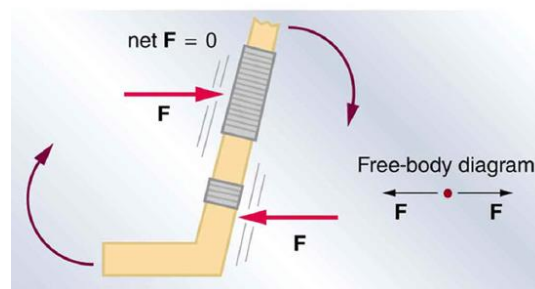


Figure 9.1.4: The same forces are applied at other points and the stick rotates—in fact, it experiences an accelerated rotation. Here  $net F = 0$  but the system is not at equilibrium. Hence, the  $net F = 0$  is a necessary—but not sufficient—condition for achieving equilibrium.

### PhET Explorations: Torque

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

## Summary

- Statics is the study of forces in equilibrium.
- Two conditions must be met to achieve equilibrium, which is defined to be motion without linear or rotational acceleration.
- The first condition necessary to achieve equilibrium is that the net external force on the system must be zero, so that  $F = 0$ .

## Glossary

### static equilibrium

a state of equilibrium in which the net external force and torque acting on a system is zero

### dynamic equilibrium

a state of equilibrium in which the net external force and torque on a system moving with constant velocity are zero

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