Newton's Third Law of Motion

Key Ideas

- Newton's third law states that the force that one object exerts on a second object is equal in magnitude and opposite in direction to the force that the second exerts on the first.
- The two forces in a third-law pair act on different objects, not on the same object, and may have different effects on the objects they act upon.
- Internal forces within a chosen system cancel due to Newton's second law.
- Choosing different systems when analyzing a problem can help determine different forces.
- Newton's third law applies to both contact and long-range forces.

Learning Objectives

After completing this section, you should be able to...

- state Newton's third law of motion,
- identify third-law pairs of forces acting on two interacting objects, and
- apply Newton's third law to different systems to determine different forces.

As we stated in Section 5.1 (Forces), a force on an object is always caused by another object, whether it is by contact or through a long-range interaction. So far, when analyzing forces, we have chosen a single object (or collection of objects) as our system, and focused only on the forces that objects in the environment exert on that system. Now, we wish to consider the relationship between forces by the environment on the system and forces by the system on the environment. If one object exerts a force on a second, does the second exert a force on the first? How are these two forces related? The answer is given by Newton's third law of motion.

Newton's Third Law of Motion

The force that one object exerts on a second object is equal in magnitude and opposite in direction to the force the second object exerts on the first. Mathematically, if A and B are two objects, where $\vec{\mathrm{F}}_{\mathrm{A\ on\ B}}$ is the force that A exerts on B, and $\vec{\mathrm{F}}_{\mathrm{B\ on\ A}}$ is the force that B exerts on A, then:

$$\vec{\mathrm{F}}_{\mathrm{A\ on\ B}} = -\vec{\mathrm{F}}_{\mathrm{B\ on\ A}} \tag{5.9}$$

Newton's third law shows that forces always come in pairs, with each force in a pair acting on one of a pair of objects. One object cannot exert a force on another without itself experiencing a force caused by the second object. We will refer to these pairs of forces as "third-law pairs." Each force in a third-law pair has the same magnitude, but they are in opposite directions. It is extremely important to realize that each force in a third-law pair acts on a different object. They do *not* both act on the same object. So, when determining the net force on a system, we never include both forces of a third-law pair, because each force in the pair acts on a different system. Furthermore, Newton's third law holds true regardless of whether one or both objects in the pair is stationary, moving at constant velocity, or accelerating. The relative size of the two objects in the pair also does not matter. The force that a large object exerts on a small object is the same magnitude as the force the small object exerts on the large object.

As an example, consider the swimmer in Figure 5.25 pushing off the side of a pool. She pushes against the wall of the pool with her feet, exerting a force on the wall, $\vec{F}_{S\text{ on }W}$. By Newton's third law, the wall exerts a force on the swimmer, $\vec{F}_{W\text{ on }S}$, which is equal in magnitude but in the opposite direction of $\vec{F}_{S\text{ on }W}$. It is tempting to think that these two forces somehow "cancel out," leading to a net force of zero on the swimmer. But we cannot add these two forces *because they act on different systems*. In this case, there are two systems we could investigate: the swimmer and the wall. If we select the swimmer as the system of interest, then $\vec{F}_{W\text{ on }S}$ is an external force on this system that affects its motion. It is not the only force on the system: as shown in the free body diagram in Figure 5.25 at right, there is also a gravitational force, $\vec{F}_g$, due to the Earth downward, and a force upward on the swimmer due to the water (called a "buoyant" force), $\vec{F}_B$. We observe the swimmer's acceleration is horizontal, so the two vertical forces add to zero. The net force is then in the horizontal direction and equal to $\vec{F}_{W\text{ on }S}$, which causes the swimmer to accelerate to the left.

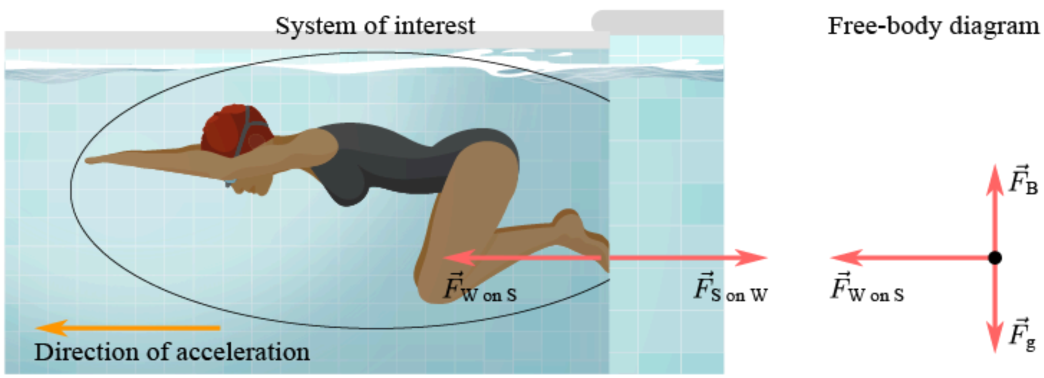

Figure 5.25 The swimmer pushes against the wall with force $\vec{F}_{S\text{ on }W}$ to the right. By Newton's third law, the wall then pushes on the swimmer with force $\vec{F}_{W\text{ on }S}$, which has the same magnitude as $\vec{F}_{S\text{ on }W}$ but is directed to the left. Examining the system of the swimmer, three forces act on her: $\vec{F}_{W\text{ on }S}$, a buoyant force $\vec{F}_B$ due to the water upward, and a gravitational force $\vec{F}_g$ due to the Earth downward. The two vertical forces balance, leaving a net force equal to $\vec{F}_{W\text{ on }S}$ to the left, and resulting in an acceleration to the left, by Newton's second law.

So, in the free body diagram of the system of the swimmer, only $\vec{F}_{W\text{ on }S}$ is included, and not $\vec{F}_{S\text{ on }W}$. We could draw a second free body diagram choosing the wall as our system. This diagram would include $\vec{F}_{S\text{ on }W}$ as well as any other forces acting on the wall, such as its weight and the force on it by the concrete floor, but it would not include $\vec{F}_{W\text{ on }S}$. Note that it does not matter that the swimmer is accelerating while the wall remains stationary. Both forces in the third-law pair, $\vec{F}_{W\text{ on }S}$ and $\vec{F}_{S\text{ on }W}$, are still equal in magnitude and opposite in direction.

Like the example of the swimmer, many applications of Newton's third law involve propulsion.

- When walking or running, a person exerts a force downward and backward on the ground. The ground in turn exerts a force upward and forward on the person, causing the person to accelerate forward, as shown in Figure 5.26.

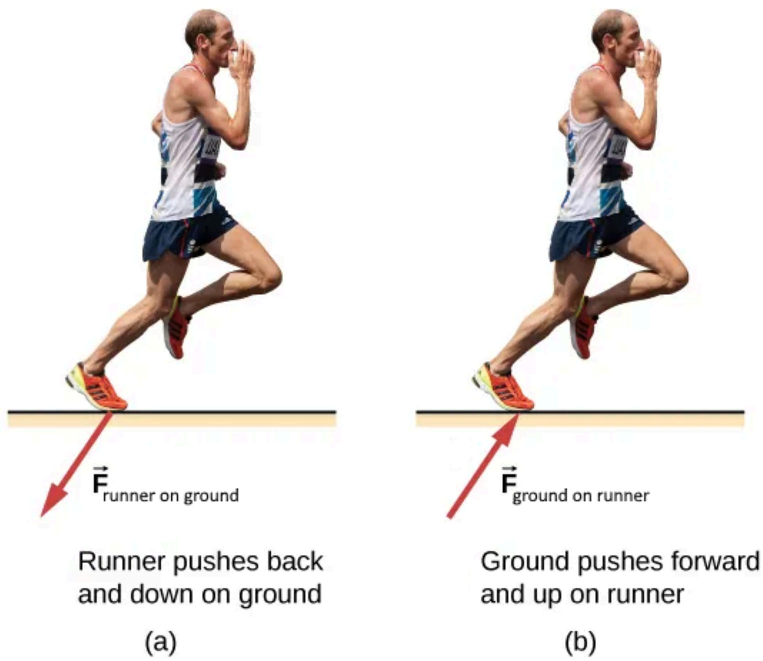

Figure 5.26 (NOTE: Image Not Finalized)The runner experiences Newton's third law. (a) The runner exerts a force on the ground. (b) The ground in turn exerts a force on the runner of equal magnitude and opposite direction. The vertical component of this force balances his weight, while the horizontal component accelerates him forward. (credit "runner": modification of work by "Greenwich Photography"/Flickr)

- Similarly, the tires on a car's drive wheels rotate and apply a frictional force on the pavement directed backwards. The third-law pair to this force is the frictional force by the pavement on the tires directed forward, causing the car to accelerate forward. You can see evidence of the wheels pushing backward when tires spin on a gravel road, throwing rocks backward.
- A rocket exerts a force on exhaust gas within its combustion chamber, expelling the gas backward. By Newton's third law, the gas exerts a force on the rocket forward, causing it to accelerate forward. The force that expelled gas exerts on a rocket is the **thrust** force mentioned earlier.
- Airplanes, helicopters, drones, and birds all exert forces on the air through surfaces like wings and propellers. The force by the wings or propellers on the air has a downward component. By Newton's third law, the air exerts a force on the wings that has an upward component. This force is called **lift** and is needed to either balance the object's weight or accelerate it upward.
- When a person pulls down on a vertical rope, the tension force of the rope pulls up on the person (Figure 5.27).

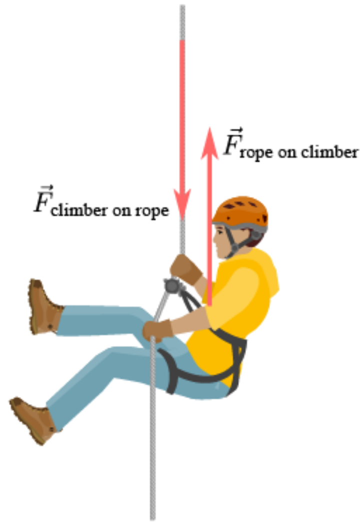

Figure 5.27 When the mountain climber pulls down on the rope, the rope pulls up on the mountain climber.

Example 5.13

Forces on a Stationary Object

The package in Figure 5.28 is sitting motionless on a spring scale. Technically, a spring scale measures the force that is applied to it by whatever is resting on top of it. How can we be sure this force is the same as the weight of the package? Show that the scale gives an accurate reading by proving the force it exerts on the package is equal in magnitude to the package's weight.

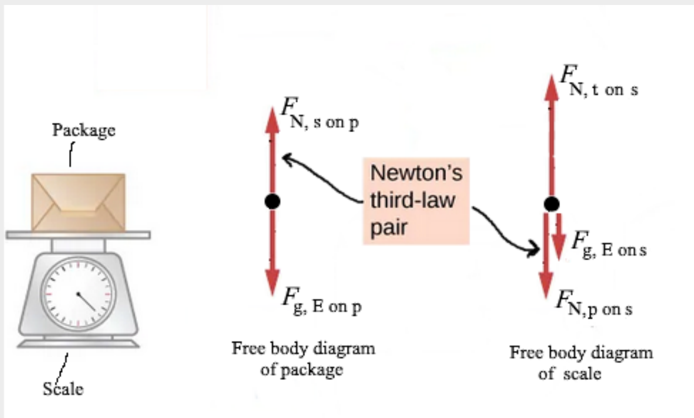

Figure 5.28 (NOTE: Image Not Finalized) A package sits motionless on a scale. Free-body diagrams of the package and the scale are shown, with the force by the scale on the package and the force by the package on the scale are indicated as a Newton's third law pair.

Strategize

Figure 5.28 shows two free body diagrams, one for the package and one for the scale. The package has two forces on it: its weight $\vec{F}_{g,\text{ E on p}}$, due to the Earth, and the normal force due to the scale, $\vec{F}_{N,\text{ s on p}}$. The scale has three forces on it: its weight $\vec{F}_{g,\text{ E on s}}$, the normal force due to the package $\vec{F}_{N,\text{ p on s}}$, and the normal force due to the table that the package sits upon, $\vec{F}_{N,\text{ t on s}}$.

We will apply Newton's second law to the system of the package to relate its weight to the force applied to it by the scale, then apply Newton's third law to relate this force to the force by the package on the scale. Using Newton's second law, we can relate the forces acting on the package.

Develop and Solve

The acceleration of the package is zero. Applying Newton's second law to this system, we have

$$\begin{aligned} \vec{F}_{net} &= m\vec{a} \\ \vec{F}_{N,\text{ s on p}} + \vec{F}_{g,\text{ E on p}} &= 0 \\ \vec{F}_{N,\text{ s on p}} &= -\vec{F}_{g,\text{ E on p}} \end{aligned}$$

So, the magnitudes of the forces are equal:

$$F_{N,\text{ s on p}} = F_{g,\text{ E on p}}$$