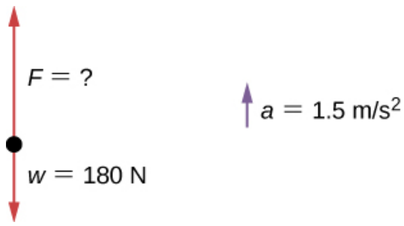


$$\begin{aligned}
w &= mg \\
m &= \frac{w}{g} = \frac{180\ \text{N}}{9.8\ \text{m/s}^2} = 18\ \text{kg} \\
\sum F &= ma \\
F - w &= ma \\
F - 180\ \text{N} &= (18\ \text{kg})(1.5\ \text{m/s}^2) \\
F - 180\ \text{N} &= 27\ \text{N} \\
F &= 207\ \text{N} = 210\ \text{N to two significant fig es}
\end{aligned}$$

Significance

To apply Newton’s second law as the primary equation in solving a problem, we sometimes have to rely on other equations, such as the one for weight or one of the kinematic equations, to complete the solution.

5.6 Check Your Understanding For **Example 5.8**, find the acceleration when the farmer’s applied force is 230.0 N.

Can you avoid the boulder field and land safely just before your fuel runs out, as Neil Armstrong did in 1969? This **version of the classic video game (https://openstaxcollege.org/l/21lunarlander)** accurately simulates the real motion of the lunar lander, with the correct mass, thrust, fuel consumption rate, and lunar gravity. The real lunar lander is hard to control.

Use this **interactive simulation (https://openstaxcollege.org/l/21gravityorbits)** to move the Sun, Earth, Moon, and space station to see the effects on their gravitational forces and orbital paths. Visualize the sizes and distances between different heavenly bodies, and turn off gravity to see what would happen without it.

5.5 | Newton’s Third Law

Learning Objectives

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

- State Newton’s third law of motion
- Identify the action and reaction forces in different situations
- Apply Newton’s third law to define systems and solve problems of motion

We have thus far considered force as a push or a pull; however, if you think about it, you realize that no push or pull ever occurs by itself. When you push on a wall, the wall pushes back on you. This brings us to **Newton’s third law**.

Newton’s Third Law of Motion

Whenever one body exerts a force on a second body, the first body experiences a force that is equal in magnitude and opposite in direction to the force that it exerts. Mathematically, if a body A exerts a force $\vec{\mathbf{F}}$ on body B, then B

simultaneously exerts a force $-\vec{\mathbf{F}}$ on *A*, or in vector equation form,

$$\vec{\mathbf{F}}_{AB} = -\vec{\mathbf{F}}_{BA}. \tag{5.10}$$

Newton's third law represents a certain symmetry in nature: Forces always occur in pairs, and one body cannot exert a force on another without experiencing a force itself. We sometimes refer to this law loosely as "action-reaction," where the force exerted is the action and the force experienced as a consequence is the reaction. Newton's third law has practical uses in analyzing the origin of forces and understanding which forces are external to a system.

We can readily see Newton's third law at work by taking a look at how people move about. Consider a swimmer pushing off the side of a pool (**Figure 5.16**). She pushes against the wall of the pool with her feet and accelerates in the direction opposite that of her push. The wall has exerted an equal and opposite force on the swimmer. You might think that two equal and opposite forces would cancel, but they do not *because they act on different systems*. In this case, there are two systems that we could investigate: the swimmer and the wall. If we select the swimmer to be the system of interest, as in the figure, then $F_{\text{wall on feet}}$ is an external force on this system and affects its motion. The swimmer moves in the direction of this force. In contrast, the force $F_{\text{feet on wall}}$ acts on the wall, not on our system of interest. Thus, $F_{\text{feet on wall}}$ does not directly affect the motion of the system and does not cancel $F_{\text{wall on feet}}$. The swimmer pushes in the direction opposite that in which she wishes to move. The reaction to her push is thus in the desired direction. In a free-body diagram, such as the one shown in **Figure 5.16**, we never include both forces of an action-reaction pair; in this case, we only use $F_{\text{wall on feet}}$, not $F_{\text{feet on wall}}$.

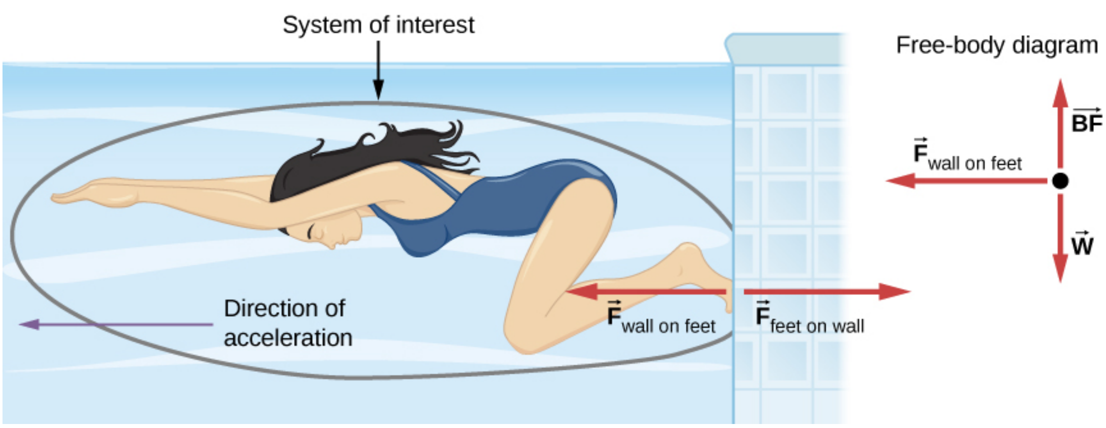


Figure 5.16 When the swimmer exerts a force on the wall, she accelerates in the opposite direction; in other words, the net external force on her is in the direction opposite of $F_{\text{feet on wall}}$. This opposition occurs because, in accordance with Newton's third law, the wall exerts a force $F_{\text{wall on feet}}$ on the swimmer that is equal in magnitude but in the direction opposite to the one she exerts on it. The line around the swimmer indicates the system of interest. Thus, the free-body diagram shows only $F_{\text{wall on feet}}$, w (the gravitational force), and *BF*, which is the buoyant force of the water supporting the swimmer's weight. The vertical forces *w* and *BF* cancel because there is no vertical acceleration.

Other examples of Newton's third law are easy to find:

- As a professor paces in front of a whiteboard, he exerts a force backward on the floor. The floor exerts a reaction force forward on the professor that causes him to accelerate forward.
- A car accelerates forward because the ground pushes forward on the drive wheels, in reaction to the drive wheels pushing backward on the ground. You can see evidence of the wheels pushing backward when tires spin on a gravel road and throw the rocks backward.
- Rockets move forward by expelling gas backward at high velocity. This means the rocket exerts a large backward force on the gas in the rocket combustion chamber; therefore, the gas exerts a large reaction force forward on the rocket. This reaction force, which pushes a body forward in response to a backward force, is called **thrust**. It is a common misconception that rockets propel themselves by pushing on the ground or on the air behind them. They

actually work better in a vacuum, where they can more readily expel the exhaust gases.

- Helicopters create lift by pushing air down, thereby experiencing an upward reaction force.
- Birds and airplanes also fly by exerting force on the air in a direction opposite that of whatever force they need. For example, the wings of a bird force air downward and backward to get lift and move forward.
- An octopus propels itself in the water by ejecting water through a funnel from its body, similar to a jet ski.
- When a person pulls down on a vertical rope, the rope pulls up on the person (**Figure 5.17**).

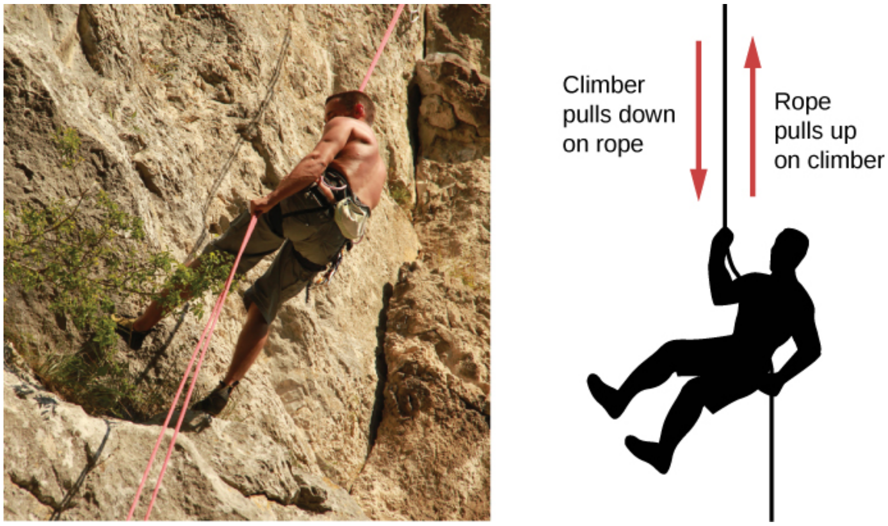


Figure 5.17 When the mountain climber pulls down on the rope, the rope pulls up on the mountain climber. (credit left: modification of work by Cristian Bortes)

There are two important features of Newton’s third law. First, the forces exerted (the action and reaction) are always equal in magnitude but opposite in direction. Second, these forces are acting on different bodies or systems: *A*’s force acts on *B* and *B*’s force acts on *A*. In other words, the two forces are distinct forces that do not act on the same body. Thus, they do not cancel each other.

For the situation shown in **Figure 5.6**, the third law indicates that because the chair is pushing upward on the boy with force $\vec{\mathbf{C}}$, he is pushing downward on the chair with force $-\vec{\mathbf{C}}$. Similarly, he is pushing downward with forces $-\vec{\mathbf{F}}$ and $-\vec{\mathbf{T}}$ on the floor and table, respectively. Finally, since Earth pulls downward on the boy with force $\vec{\mathbf{w}}$, he pulls upward on Earth with force $-\vec{\mathbf{w}}$. If that student were to angrily pound the table in frustration, he would quickly learn the painful lesson (avoidable by studying Newton’s laws) that the table hits back just as hard.

A person who is walking or running applies Newton’s third law instinctively. For example, the runner in **Figure 5.18** pushes backward on the ground so that it pushes him forward.

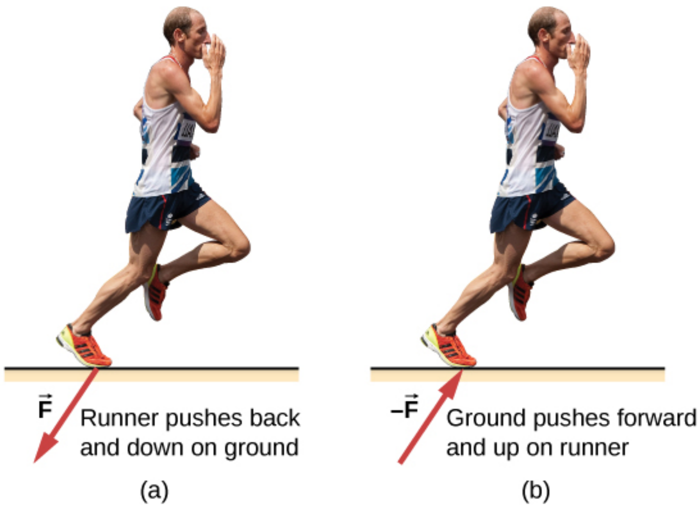


Figure 5.18 The runner experiences Newton’s third law. (a) A force is exerted by the runner on the ground. (b) The reaction force of the ground on the runner pushes him forward. (credit "runner": modification of work by "Greenwich Photography"/Flickr)

Example 5.9

Forces on a Stationary Object

The package in **Figure 5.19** is sitting on a scale. The forces on the package are $\vec{S}$, which is due to the scale, and $-\vec{w}$, which is due to Earth’s gravitational field. The reaction forces that the package exerts are $-\vec{S}$ on the scale and $\vec{w}$ on Earth. Because the package is not accelerating, application of the second law yields

$$\vec{S} - \vec{w} = m\vec{a} = \vec{0},$$

so

$$\vec{S} = \vec{w}.$$

Thus, the scale reading gives the magnitude of the package’s weight. However, the scale does not measure the weight of the package; it measures the force $-\vec{S}$ on its surface. If the system is accelerating, $\vec{S}$ and $-\vec{w}$ would not be equal, as explained in **Applications of Newton’s Laws**.

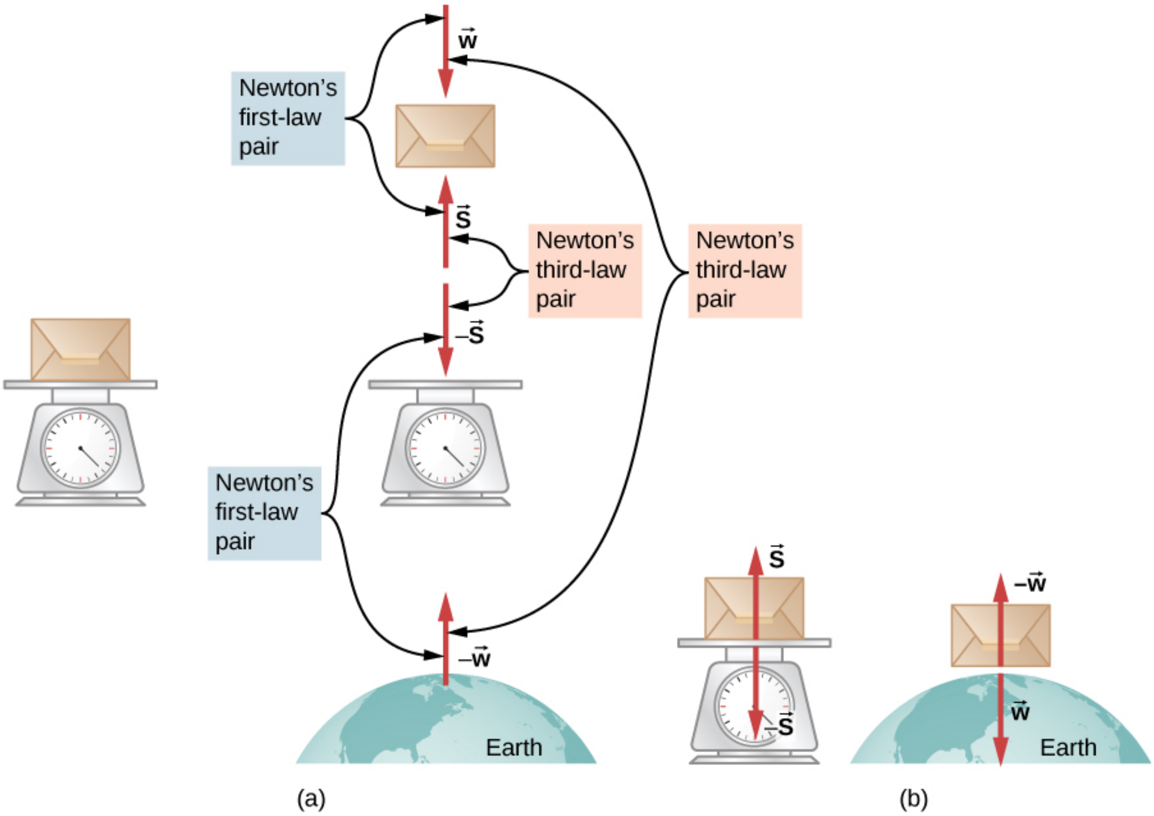


Figure 5.19 (a) The forces on a package sitting on a scale, along with their reaction forces. The force $\vec{w}$ is the weight of the package (the force due to Earth's gravity) and $\vec{S}$ is the force of the scale on the package. (b) Isolation of the package-scale system and the package-Earth system makes the action and reaction pairs clear.

Example 5.10

Getting Up to Speed: Choosing the Correct System

A physics professor pushes a cart of demonstration equipment to a lecture hall (**Figure 5.20**). Her mass is 65.0 kg, the cart's mass is 12.0 kg, and the equipment's mass is 7.0 kg. Calculate the acceleration produced when the professor exerts a backward force of 150 N on the floor. All forces opposing the motion, such as friction on the cart's wheels and air resistance, total 24.0 N.

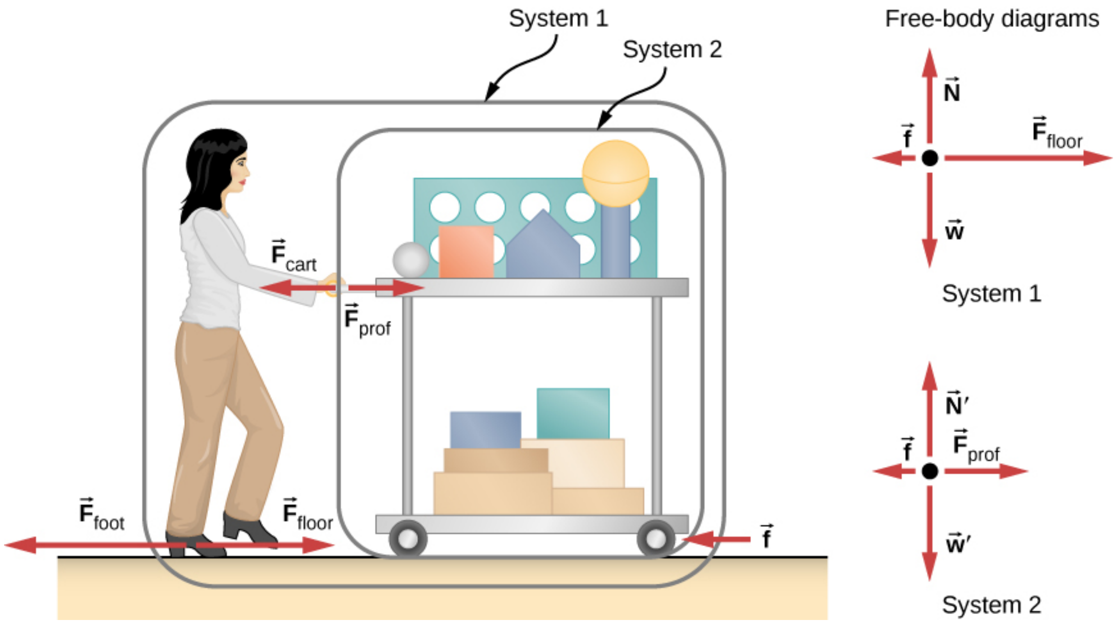


Figure 5.20 A professor pushes the cart with her demonstration equipment. The lengths of the arrows are proportional to the magnitudes of the forces (except for $\vec{\mathbf{f}}$, because it is too small to drawn to scale). System 1 is appropriate for this example, because it asks for the acceleration of the entire group of objects. Only $\vec{\mathbf{F}}_{\text{floo}}$ and $\vec{\mathbf{f}}$ are external forces acting on System 1 along the line of motion. All other forces either cancel or act on the outside world. System 2 is chosen for the next example so that $\vec{\mathbf{F}}_{\text{prof}}$ is an external force and enters into Newton's second law. The free-body diagrams, which serve as the basis for Newton's second law, vary with the system chosen.

Strategy

Since they accelerate as a unit, we define the system to be the professor, cart, and equipment. This is System 1 in **Figure 5.20**. The professor pushes backward with a force F_{foot} of 150 N. According to Newton's third law, the floor exerts a forward reaction force F_{floo} of 150 N on System 1. Because all motion is horizontal, we can assume there is no net force in the vertical direction. Therefore, the problem is one-dimensional along the horizontal direction. As noted, friction *f* opposes the motion and is thus in the opposite direction of F_{floo}. We do not include the forces F_{prof} or F_{cart} because these are internal forces, and we do not include F_{foot} because it acts on the floor, not on the system. There are no other significant forces acting on System 1. If the net external force can be found from all this information, we can use Newton's second law to find the acceleration as requested. See the free-body diagram in the figure.

Solution

Newton's second law is given by

$$a = \frac{F_{\text{net}}}{m}.$$

The net external force on System 1 is deduced from **Figure 5.20** and the preceding discussion to be

$$F_{\text{net}} = F_{\text{floo}} - f = 150\ \text{N} - 24.0\ \text{N} = 126\ \text{N}.$$

The mass of System 1 is

$$m = (65.0 + 12.0 + 7.0)\ \text{kg} = 84\ \text{kg}.$$

These values of F_{net} and m produce an acceleration of

$$a = \frac{F_{\text{net}}}{m} = \frac{126\ \text{N}}{84\ \text{kg}} = 1.5\ \text{m/s}^2.$$

Significance

None of the forces between components of System 1, such as between the professor's hands and the cart, contribute to the net external force because they are internal to System 1. Another way to look at this is that forces between components of a system cancel because they are equal in magnitude and opposite in direction. For example, the force exerted by the professor on the cart results in an equal and opposite force back on the professor. In this case, both forces act on the same system and therefore cancel. Thus, internal forces (between components of a system) cancel. Choosing System 1 was crucial to solving this problem.

Example 5.11

Force on the Cart: Choosing a New System

Calculate the force the professor exerts on the cart in **Figure 5.20**, using data from the previous example if needed.

Strategy

If we define the system of interest as the cart plus the equipment (System 2 in **Figure 5.20**), then the net external force on System 2 is the force the professor exerts on the cart minus friction. The force she exerts on the cart, F_{prof}, is an external force acting on System 2. F_{prof} was internal to System 1, but it is external to System 2 and thus enters Newton's second law for this system.

Solution

Newton's second law can be used to find $F_{\text{prof}}.$ We start with

$$a = \frac{F_{\text{net}}}{m}.$$

The magnitude of the net external force on System 2 is

$$F_{\text{net}} = F_{\text{prof}} - f.$$

We solve for F_{prof}, the desired quantity:

$$F_{\text{prof}} = F_{\text{net}} + f.$$

The value of f is given, so we must calculate net $F_{\text{net}}.$ That can be done because both the acceleration and the mass of System 2 are known. Using Newton's second law, we see that

$$F_{\text{net}} = ma,$$

where the mass of System 2 is 19.0 kg ($m = 12.0\ \text{kg} + 7.0\ \text{kg}$) and its acceleration was found to be $a = 1.5\ \text{m/s}^2$ in the previous example. Thus,

$$F_{\text{net}} = ma = (19.0\ \text{kg})\left(1.5\ \text{m/s}^2\right) = 29\ \text{N}.$$

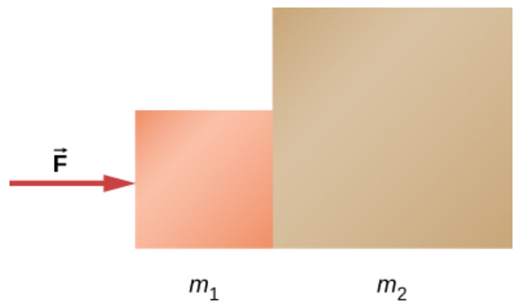
Now we can find the desired force:

$$F_{\text{prof}} = F_{\text{net}} + f = 29\ \text{N} + 24.0\ \text{N} = 53\ \text{N}.$$

Significance

This force is significantly less than the 150-N force the professor exerted backward on the floor. Not all of that 150-N force is transmitted to the cart; some of it accelerates the professor. The choice of a system is an important analytical step both in solving problems and in thoroughly understanding the physics of the situation (which are not necessarily the same things).

5.7 Check Your Understanding Two blocks are at rest and in contact on a frictionless surface as shown below, with $m_1 = 2.0\,\text{kg}$, $m_2 = 6.0\,\text{kg}$, and applied force 24 N. (a) Find the acceleration of the system of blocks. (b) Suppose that the blocks are later separated. What force will give the second block, with the mass of 6.0 kg, the same acceleration as the system of blocks?



View this **video (https://openstaxcollege.org/l/21actionreact)** to watch examples of action and reaction.

View this **video (https://openstaxcollege.org/l/21NewtonsLaws)** to watch examples of Newton's laws and internal and external forces.

5.6 | Common Forces

Learning Objectives

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

- Define normal and tension forces
- Distinguish between real and fictitious forces
- Apply Newton's laws of motion to solve problems involving a variety of forces

Forces are given many names, such as push, pull, thrust, and weight. Traditionally, forces have been grouped into several categories and given names relating to their source, how they are transmitted, or their effects. Several of these categories are discussed in this section, together with some interesting applications. Further examples of forces are discussed later in this text.

A Catalog of Forces: Normal, Tension, and Other Examples of Forces

A catalog of forces will be useful for reference as we solve various problems involving force and motion. These forces include normal force, tension, friction, and spring force.

Normal force

Weight (also called the force of gravity) is a pervasive force that acts at all times and must be counteracted to keep an object from falling. You must support the weight of a heavy object by pushing up on it when you hold it stationary, as illustrated in **Figure 5.21**(a). But how do inanimate objects like a table support the weight of a mass placed on them, such as shown in **Figure 5.21**(b)? When the bag of dog food is placed on the table, the table sags slightly under the load. This would be noticeable if the load were placed on a card table, but even a sturdy oak table deforms when a force is applied to it. Unless an object is deformed beyond its limit, it will exert a restoring force much like a deformed spring (or a trampoline or diving board). The greater the deformation, the greater the restoring force. Thus, when the load is placed on the table, the table