Answer to Essential Question 3.5: Even though the Sun is enormous compared to the Earth, Newton's third law tells us that the force the Sun exerts on the Earth is equal in magnitude, and opposite in direction, to the force the Earth exerts on the Sun.

3-6 Exploring Forces and Free-Body Diagrams

A force is simply a push or a pull. A force is a vector, so it has a direction. Also, a force represents an interaction between objects. Let's build on these facts and learn more about forces.

EXPLORATION 3.6A – The normal force

Step 1 - ***Sketch free-body diagrams for the following situations: (a) a book rests on a table; (b) you exert a downward force on the book as it sits on the table; (c) you tie a helium-filled balloon to the book, which remains on the table.***

The diagrams are shown in Figure 3.13. In (a), the normal force applied by the table on the book has to balance the force of gravity acting on the book. If you push down on the book, the normal force increases – it has to balance the force of gravity as well as the force you exert. Tying a helium balloon to the book reduces the normal force because the normal force and the tension in the string combine to balance the force of gravity. The normal force depends on the situation – the magnitude of the normal force is whatever is necessary to prevent the book from falling through the table.

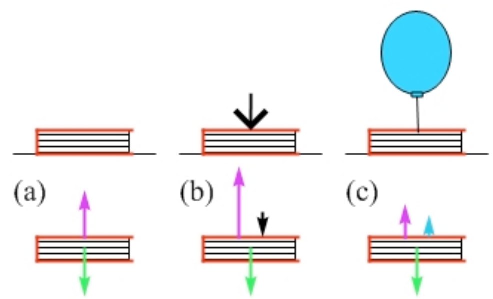

Figure 3.13: The upward normal force the table exerts on the book is larger when you exert a downward force (b) and is smaller when a string tied to a helium balloon exerts an upward force (c).

Let's say we have a scale calibrated in force units. The magnitude of the normal force is the force the scale reads if the scale is placed between the objects in contact.

Step 2 - ***When does one object lose contact with another? For instance, how many helium balloons would we have to tie to the book to make it lift off the table?*** Objects lose contact when the normal force between them goes to zero. The minimum number of balloons is the number needed to reduce the normal force the table exerts on the book (and the normal force the book exerts on the table) to zero.

Key ideas about the normal force: The magnitude of the normal force in a particular situation is whatever is required to prevent one object from passing through another, and is equal to the scale reading if a scale were placed between the objects in contact. Objects lose contact when the normal force between them goes to zero. **Related End-of-Chapter Exercises: 4, 17.**

EXAMPLE 3.6 – Calculating the normal force

As shown in Figure 3.14, a large box (box 1), with a weight of $m_1 g = 20$ N, is at rest on the floor. A smaller box (box 2), with a weight of $m_2 g = 10$ N, sits on top of the large box. (a) Draw free-body diagrams for each box. Calculate the normal force (b) exerted on box 2 by box 1, (c) exerted on box 1 by box 2, and (d) exerted on box 1 by the floor.

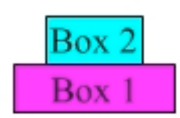

Figure 3.14: Two boxes, one on top of the other, at rest on the floor.

SOLUTION

(a) The free-body diagrams are shown in Figure 3.15. For box 2, the upward normal force applied by box 1 balances the downward force of gravity acting on box 2. For box 1, the table balances both the force of gravity on box 1 and the downward normal force applied on box 1 by box 2.

(b) For the forces to balance, the normal force applied on box 2 by box 1 is 10 N up.
(c) By Newton's third law, box 2 applies a normal force on box 1 of 10 N down.
(d) For the forces on box 1 to balance, the table applies a normal force of 30 N up.

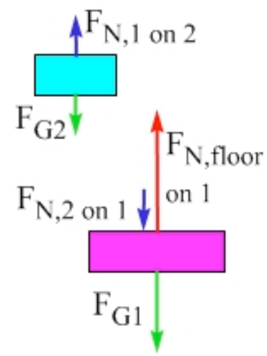

Figure 3.15: Free-body diagrams for the two boxes of Example 3.6

The Contact Force (F_C)

In general, when two objects are in contact with one another, they exert contact forces that are equal in magnitude but opposite in direction. We usually split the contact force into two components, a normal force perpendicular to the surfaces in contact, and a force of friction that is parallel to the surfaces in contact. It can be useful to look at the whole vector, however.

EXPLORATION 3.6B – A whole-vector approach

While unloading a truck, you place a box on a ramp leading from the truck.

Step 1 - ***The box remains at rest on the ramp. What is the net force acting on the box?*** The velocity of the box remains constant (at $v = 0$, in this case), so there is no net force on the box.

Step 2 - ***Sketch a diagram of the situation and a free-body diagram showing the forces acting on the box. What is the magnitude and direction of the force the ramp exerts on the box?*** In this case, it is simpler to use the whole contact force, rather than using the two components (a normal force perpendicular to the ramp and a static force of friction directed up the ramp). The net force on the box is zero, so the contact force is directed straight up with a magnitude equal to the force of gravity, as shown in Figure 3.16.

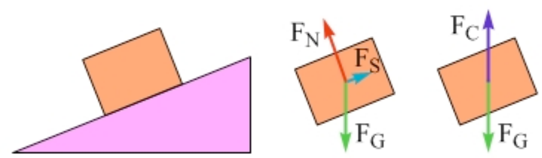

Figure 3.16: A diagram and two equivalent free-body diagrams for the box at rest on the ramp.

Key idea: It can be helpful to view the contact force as one vector, instead of breaking it into its components, a normal force and a force of friction. **Related End-of-Chapter Exercises: 38, 39.**

The Force of Gravity, Weight, and Apparent Weight

The force of gravity, F_G, does not require objects to be in contact but acts at a distance. The force of gravity is always attractive, directed toward the object exerting the force. In Chapter 8, we will look at situations in which the distance between objects changes, changing the force of gravity. For now, we will deal with situations in which the force of gravity is constant, as it is at the Earth's surface, where we use $\vec{F}_G = m\vec{g}$, with $\vec{g}$ the acceleration due to gravity. In this book, we generally use the term "force of gravity," but $m\vec{g}$ is often called the **weight**.

Your mass is the same no matter where you are. Near the surface of the Earth, the force of gravity acting on you is also constant. However, you have probably experienced feeling that you weigh more or less than usual, such as when you're on a roller coaster, or in a car going over a hill. Your weight (the force of gravity acting on you) is constant, but your apparent weight is different. Your apparent weight is, in many cases, equal in magnitude to the normal force acting on you, so you often feel a change in your apparent weight when the normal force changes.

Essential Question 3.6: Jump straight up into the air. While you are still in contact with the ground, but accelerating upward, how does the normal force applied on you by the ground compare to the force of gravity applied on you by the Earth? In what direction is the net force on you after you lose contact with the ground?