Answer to Essential Question 3.1: The primary force acting on you once you have left the ground is the force of gravity. You are attracted toward the Earth by the force of gravity even though you are not in contact with the Earth.

3-2 Free-Body Diagrams

When analyzing a particular physical situation, it can be helpful to draw what is called a **free-body diagram**. This is a diagram in which arrows are attached to an object to represent the various forces applied to that object by external influences. The direction of an arrow is the same as the direction of the force the arrow represents, and the length of the arrow is proportional to the magnitude of that force. Each arrow is labeled with an appropriate symbol denoting the force the arrow represents.

When drawing a free-body diagram, it is helpful to keep two questions in mind:

1. For each force shown on the free-body diagram, what exerts the force?
2. Is the motion that would result from the set of forces acting on the object consistent with the actual motion of the object?

The following Explorations should help us learn how to answer those questions.

EXPLORATION 3.2A – Drawing a free-body diagram for an object at rest

Figure 3.3: Free-body diagram for an object that is not interacting with anything.

Step 1 – ***Sketch a free-body diagram for an object that is at rest in outer space, billions of kilometers away from anything.*** The free-body diagram in Figure 3.3 shows no forces, since the object does not interact with anything.

Step 2 - ***Sketch a free-body diagram for a book is at rest on a horizontal tabletop.*** The free-body diagram for this very common situation is shown in Figure 3.4. The Earth applies a downward force of gravity to the book, but the book remains at rest because there is an upward normal force applied to the book by the table. How do you think the magnitudes of these two forces compare? For the book to remain at rest, these two forces must cancel one another exactly, so the two forces have the same magnitude.

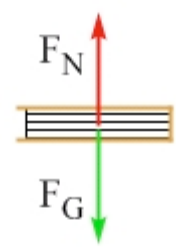

Figure 3.4: Free-body diagram for a book sitting at rest on a table.

Step 3 - ***Sketch a free-body diagram for a box that remains at rest on a horizontal tabletop even though you exert a horizontal force by pulling on a string tied to the box.*** The force you exert is transferred to the box by the string, so it is shown as a force of tension in Figure 3.5. When drawing the free-body diagram consider this question: Why doesn't the box move? If you pull hard enough, the box will move. In this case, though, the force you exert on the box is small enough that it can be balanced by another force in the opposite direction. This balancing force is the force of static friction, which we discuss in detail in chapter 5. Because the box does not move horizontally these two forces must cancel one another, so their magnitudes are equal.

As in step 2 the Earth applies a downward force of gravity to the box that is exactly balanced by the upward normal force applied to the box by the table.

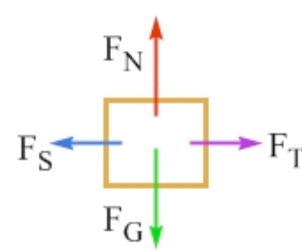

Figure 3.5: Free-body diagram for a box at rest on a table while you pull on a string to the right.

Step 4 – ***What, if anything, is common to the three situations discussed above?*** First, in each case, the object remains at rest – its motion does not change. Second, although the three free-body diagrams clearly are different, in each case there is no net force acting on the object. ***The net force is the sum of all the forces acting on an object.*** Because forces are vectors, we must account for both the directions and magnitudes of forces when we add them. There is no net force in any of the cases above because either there is no force acting at all or all the forces cancel out. Based on this, let's theorize that when no net force acts on an object that is at rest, the object remains at rest.

Key ideas for an object at rest: The net force is the vector sum of all the forces acting on an object. When no net force acts on an object that is at rest, the object remains at rest.
Related End-of-Chapter Exercises: 1, 15.

EXPLORATION 3.2B – The motion diagram and the free-body diagram

Let's now start connecting forces to the motion ideas from chapter 2.

Step 1 - ***Sketch a motion diagram for a ball you release from rest from some distance above the floor, showing its position at regular time intervals as it falls.*** The motion diagram in Figure 3.6 shows images of the ball that are close together near the top, where the ball moves slowly. As the ball speeds up, these images gradually get farther apart as the ball covers progressively larger distances in equal time intervals.

Step 2 - ***Sketch the ball's free-body diagram, showing the forces acting on the ball as it falls. Neglect air resistance.*** If we can neglect air resistance, the Earth is the only object applying a force to the ball, and that force is a downward force of gravity. The free-body diagram is shown near the bottom right of in Figure 3.6.

Step 3 - ***Does the free-body diagram show a net force acting on the ball as it falls? Does this net force increase substantially, decrease substantially, or stay reasonably constant as the ball falls?*** A downward net force acts on the ball because there is nothing to balance the force of gravity. This force is associated with the interaction between the ball and the Earth, and the strength of that interaction depends on the distance between the ball and the center of the Earth. If we drop a ball from a typical height of 1-2 meters, the distance between the ball and the center of the Earth changes by a very small fraction, so we can assume that the net force acting on the ball is constant.

Step 4 - ***What is the connection between the motion diagram and the free-body diagram?*** The motion diagram shows that the ball's motion changes, because the successive images of the ball are not drawn equally spaced. When a net force acts on an object, the motion of the object changes.

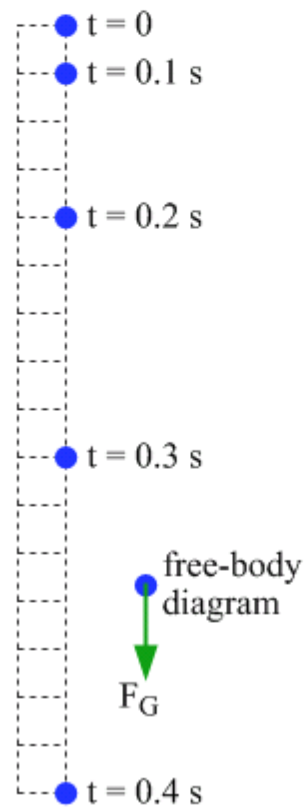

Figure 3.6: Motion diagram and free-body diagram for a ball dropped from rest.

Key idea for motion and force: When a net force acts on an object, the object's motion changes. **Related End-of-Chapter Exercises: 29, 30, 49.**

Essential Question 3.2: What if the ball in Exploration 3.2B had been thrown straight up, so it came to rest for an instant 0.4 s after leaving your hand? What would its motion diagram, and free-body diagram, look like?