Answer to Essential Question 3.6: While you are still in contact with the ground, but accelerating upward, you must have a net force directed up. This comes from an upward normal force on you, applied by the ground, which is larger in magnitude than the downward force of gravity applied on you. After you leave the ground, there is no longer a normal force acting on you, so the downward force of gravity acting on you is the net force in that situation.

3-7 Practice with Free-Body Diagrams

Let's start by looking at the forces involved when you are in an elevator.

EXAMPLE 3.7 – An elevator at rest

(a) You are standing in an elevator that is at rest. Draw three free-body diagrams. The first should show all the forces acting on you as you stand in the elevator; the second should show all the forces acting on the elevator as you stand in it, and the third should show all the forces acting on the system consisting of you and the elevator combined. Draw them to scale, assuming that the mass of the elevator (M) is twice as large as your mass (m).

(b) Use your free-body diagrams to help determine an expression for the tension in the cable.

SOLUTION

We should start by drawing a diagram, shown below as part a of Figure 3.17. This shows the cable attached to the top of the elevator.

(a) Your free-body diagram is the same as the free-body diagram we would draw if you were simply standing on the floor. We show a downward force of gravity and an upward normal force that is exerted on you by the floor of the elevator. These two forces balance one another, to give a net force of zero, consistent with your constant velocity (of zero).

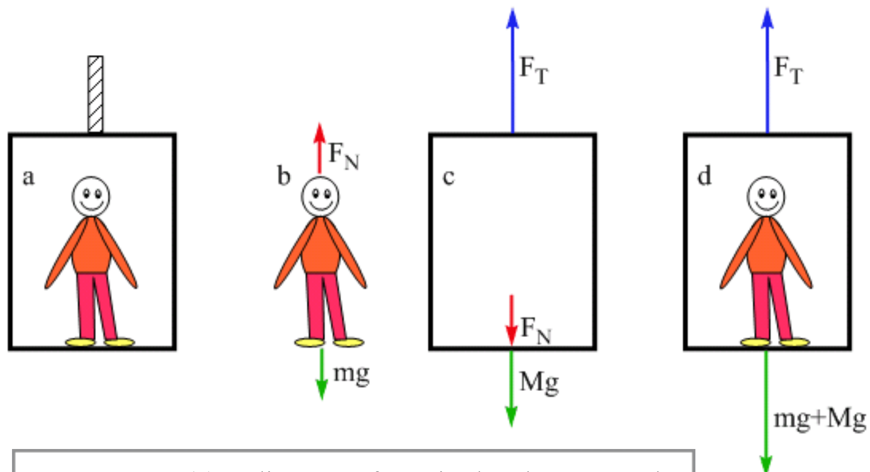

Figure 3.17: (a) A diagram of you in the elevator, and free-body diagrams for (b) you, (c) the elevator, and (d) the system consisting of you plus the elevator.

The free-body diagram of the elevator is a bit more challenging. Let's start by drawing a downward force of gravity and an upward tension force, which are the only forces that act on the elevator when the elevator is empty. Even though we draw what looks like an empty elevator, to construct the free-body diagram we have to remember that, in this case, you are in the elevator exerting a downward force on it. How do we represent this on the free-body diagram? Newton's third law is helpful. If the elevator applies an upward normal force on you, then you apply a downward normal force on the elevator of exactly the same magnitude.

A common mistake is to label the downward force the person applies to the elevator, in the elevator's free-body diagram, as mg instead of F_N. There are two reasons why doing so is not a good idea. First, the ***forces shown on an object's free-body diagram are forces exerted on that object by other things***. For the elevator, F_N is the force exerted on the elevator by you. mg is exerted on you by the Earth, so that force belongs on your free-body diagram but not the elevator's. Second, while mg and F_N are numerically equal in this situation, we will soon deal with a situation in which they are not, so using mg in place of F_N can actually lead to calculation errors.

The third free-body diagram, showing the forces acting on the system consisting of you and the elevator combined, is the combination of the first two free-body diagrams. We have the tension the cable exerts on the elevator, directed up, and the combined force of gravity acting on the system. When you combine the first two free-body diagrams, you also get the upward normal force the elevator exerts on you and the downward normal force you exert on the elevator. By Newton's third law, these forces are equal-and-opposite, so they cancel one another when they are combined. For this reason, as well as the fact that when we draw a free-body diagram, the forces we draw are exerted by objects external to the system we are considering, we don't include them on the free-body diagram of the combined system.

(b) *Use your free-body diagrams to determine an expression for the tension in the cable.* At this point, we apply Newton's second law. In general $\sum \vec{F} = m\vec{a}$, but, in this situation, the acceleration is zero, so we use the simplified equation $\sum \vec{F} = 0$. Choosing a coordinate system, let's define up to be positive. We will account for the fact that forces are vectors by using a plus sign if the force is directed up, and a minus sign if the force is directed down.

We could solve the problem by applying Newton's second law to the last free-body diagram, but let's consider all three diagrams to make sure everything is consistent.

Apply Newton's second law to your free-body diagram:
$\sum \vec{F} = 0$;

$+F_N - mg = 0$ which tells us that $F_N = mg$.

Apply Newton's second law to the elevator's free-body diagram:
$\sum \vec{F} = 0$;

$+F_T - Mg - F_N = 0$ which tells us that $F_T = Mg + F_N$.

Apply Newton's second law to the combined system's free-body diagram:
$\sum \vec{F} = 0$;

$+F_T - (M+m)g = 0$ which tells us that $F_T = Mg + mg$.

Everything is consistent. The second and third free-body diagrams give the same result for the tension because we know $F_N = mg$ from the first free-body diagram.

Related End-of-Chapter Exercises: 18, 43.

Essential Question 3.7: If the elevator is traveling up at constant velocity what, if anything, would change on the free-body diagrams? For example, would we need to add one or more forces to any of the free-body diagrams? Would any of the existing forces change in magnitude and/or direction?