

Answer to Essential Question 3.7: If the velocity is constant, there is no acceleration. The situation is the same as in part (a). As far as forces are concerned “at rest” and “constant velocity” are equivalent. Nothing changes on any of the free-body diagrams.

3-8 A Method for Solving Problems Involving Newton’s Laws

Now that we have explored some of the basic steps involved in solving a typical problem that relies on Newton’s laws, let’s summarize a general method that we can apply to all such problems. We have not yet addressed all the issues covered by the method (such as the various coordinate systems mentioned in step 3), but we will continue to address these issues in the remaining examples of this chapter as well as in chapter 5.

A General Method for Solving a Problem Involving Newton’s Laws, in One Dimension

1. Draw a diagram of the situation.
2. Draw one or more free-body diagrams, with each free-body diagram showing all the forces acting on an object.
3. For each free-body diagram, choose an appropriate coordinate system. The different coordinate systems should be consistent with one another. A good rule of thumb is to align each coordinate system with the direction of the acceleration.
4. Apply Newton’s second law to each free-body diagram.
5. Put the resulting force equations together and solve.

Let’s apply the general method in the following Example.

EXAMPLE 3.8 – An elevator accelerating up

Let’s say the elevator from Example 3.7, with you in it, has a constant acceleration directed up.

- (a) What, if anything, would change on the free-body diagrams we drew in Example 3.7? Determine an expression for the tension in the cable now.
- (b) If we know the elevator’s acceleration is directed up, with a magnitude of $g/2$, what can we say about the direction the elevator is moving?

SOLUTION

(a) By Newton’s second law, $\sum \vec{F} = m\vec{a}$, an upward acceleration requires a net upward force. Something must change on each free-body diagram to give us a net upward force. We have already accounted for all the interactions, so we don’t add or subtract forces. Instead, one or more of the forces on each free-body diagram (see Figure 3.18) must change in magnitude.

The force of gravity cannot change, so to get a net upward force on the first free-body diagram, the normal force must increase. The normal force now has two jobs. It prevents you from falling through the floor of the elevator, and it also provides the extra upward force needed for the upward acceleration. Applying Newton’s second law gives:

$$\sum \vec{F} = m\vec{a} = +\frac{1}{2}mg .$$

$$F_N - mg = +\frac{1}{2}mg \quad \text{which tells us that } F_N = \frac{3}{2}mg .$$

On the free-body diagram of just the elevator, our previous results mean that the downward normal force increases. Applying Newton's second law gives:

$$\sum \vec{F} = M\vec{a} = +\frac{1}{2}Mg .$$

$$F_T - Mg - F_N = +\frac{1}{2}Mg$$

which tells us that

$$F_T = +\frac{3}{2}Mg + F_N .$$

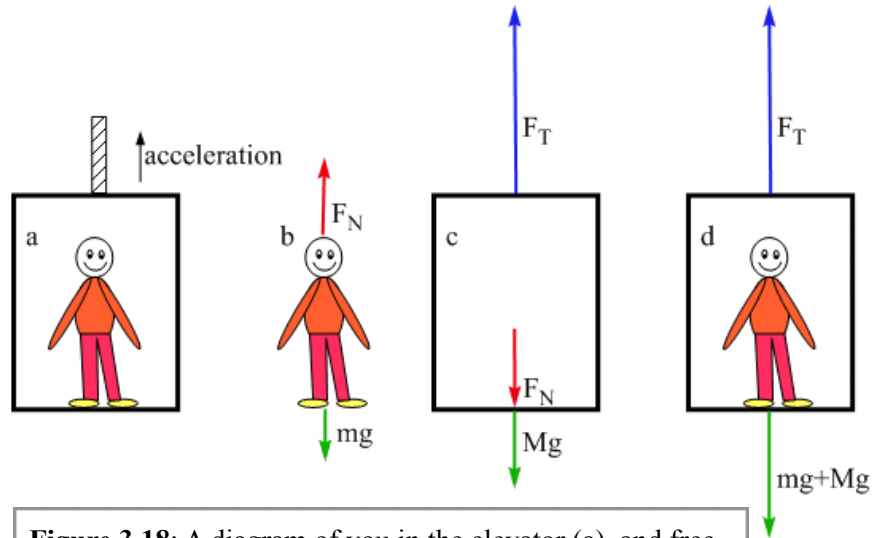


Figure 3.18: A diagram of you in the elevator (a), and free-body diagrams for you (b), the elevator (c), and the system consisting of you plus the elevator (d), when the elevator has an upward acceleration with a magnitude of $g/2$.

Here, it is critical to show the force that you exert on the elevator as a normal force, not a force of gravity, because the normal force is larger in magnitude than the force of gravity acting on you. Note that the increase in the tension offsets the increased normal force and also provides the net force required to accelerate the system upwards.

Applying Newton's second law to the third free-body diagram gives:

$$\sum \vec{F} = (M + m)\vec{a} = +\frac{1}{2}(M + m)g$$

$$F_T - (M + m)g = +\frac{1}{2}(M + m)g , \text{ which tells us that } F_T = \frac{3}{2}(Mg + mg) .$$

The only change here is an increase in the tension. Check the two expressions for tension to make sure that they are consistent with one another.

(b) The elevator could actually be moving in any direction and have an upward acceleration. For instance, if the elevator is gaining speed while moving up, the acceleration is directed up. However, if the elevator is slowing while moving down, the acceleration is also directed up. A similar situation is a ball thrown straight up into the air. Whether the ball is moving up or down, once you release the ball, the acceleration is directed down because the force of gravity is the only force acting and is directed down. For one instant at the very top, the acceleration is down, yet the ball is at rest. Knowing the direction of the acceleration is not enough to determine the direction of motion.

Related End-of-Chapter Exercises: 19, 44.

We'll do another example to become more familiar with applying the method of solving a typical problem involving Newton's laws. First, we'll start with a conceptual question.

Essential Question 3.8: Three boxes are placed side-by-side on the floor (see Figure 3.19). The red box has a weight of 40 N, the green box a weight of 60 N, and the blue box a weight of 50 N. When you exert a constant force to the right on the red box, the entire system accelerates to the right. Which box experiences the largest-magnitude net force?

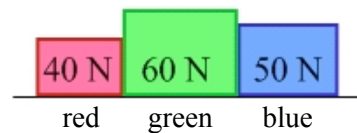


Figure 3.19: Three boxes placed side-by-side.