

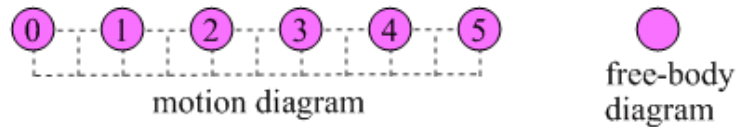
**Answer to Essential Question 3.2:** After the ball leaves your hand, the only force acting on the ball is the force of gravity, so the free-body diagram would be the same as in Figure 3.6. The successive locations of the ball on the motion diagram would also be the same, with the times increasing from bottom to top instead of from top to bottom.

### 3-3 Constant Velocity, Acceleration, and Force

If an object is moving at constant velocity, is there a net force acting in the direction of motion? Let's explore that idea.

#### EXPLORATION 3.3A – Forces in a constant-velocity situation

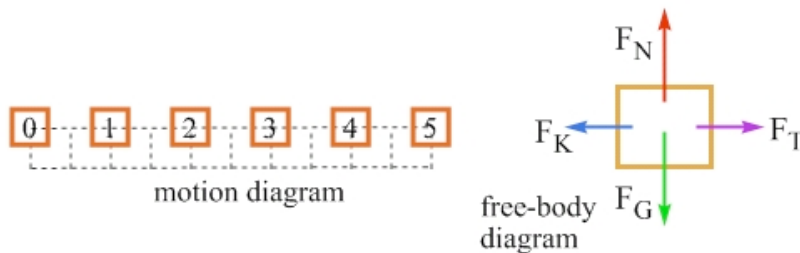
**Step 1 - Sketch a motion diagram for an object that is drifting through space with a constant velocity to the right, billions of kilometers from anything.** The motion diagram in Figure 3.7 shows images of the object that are equally spaced along a straight line.



**Figure 3.7:** Motion diagram and free-body diagram for an object drifting to the right through space.

**Step 2 - Sketch the object's free-body diagram, showing all the forces acting on the object as it drifts through space.** Many people think that the free-body diagram should show a force acting to the right. Here is where you ask yourself, though, "What would apply that force?" The object is not interacting with anything, so there are no forces to show on the free-body diagram in Figure 3.7.

**Step 3 - Repeat parts 1 and 2 for a box you drag with a constant velocity to the right across a horizontal table. You drag the box by pulling on a string tied to the box. The string is horizontal because of the force you exert on it. There is some friction acting on the box.** The motion diagram for the box, which is shown in Figure 3.8, is similar to that for the object drifting through space – the images of the object that are equally spaced. The free-body diagram is similar to that for the box at rest on the table, when you pulled on the string to the right, except that in this case the friction force is the kinetic force of friction. If the box was initially at rest, the tension force you exert via the string would have to be larger than the friction force to start the box moving. Once the box is moving, the tension force simply has to balance the kinetic friction force to maintain the motion.



**Figure 3.8:** Motion diagram and free-body diagram for a box being dragged to the right, by means of a string, across a flat surface.

**Step 4 - Compare and contrast the free-body diagrams you drew in parts 2 and 3.** The free-body diagrams are quite different, with one having no forces and the other having four. However, the net force in both cases is zero, because for the box the vertical forces cancel one another and the horizontal forces cancel one another.

**Step 5 - What is the connection between the motion diagrams in these cases and the free-body diagrams?** Even though we considered objects in motion, the free-body diagrams here are equivalent to those we drew in Exploration 3.2A for objects at rest. In all cases, here and in Exploration 3.2A, the net force is zero. The lesson for us is that when no net force acts on an object the object's velocity is unchanged.

**Key ideas for constant-velocity motion:** Again, we see the connection between an object at rest and an object in motion with constant velocity – as far as forces are concerned the situations are the same, with no net force in either case. When no net force acts on an object, its velocity is constant. **Related End-of-Chapter Exercises: 2, 5.**

In Explorations 3.2A and 3.3A, we learned that when an object experiences no net force its velocity is constant, which means its acceleration is zero. An object with a net force has an acceleration. To see how force is connected to acceleration, let's start by doing some dimensional analysis. The SI unit of force is the newton (N).  $1 \text{ N} = 1 \text{ kg m/s}^2$ . The SI unit of acceleration is  $\text{m/s}^2$ , so the units differ by a factor of kilograms. The mass of an object has units of kg, so we can speculate that force and acceleration are connected by a factor a mass.

This connection is easy to verify experimentally. When we apply a particular net force to an object of mass  $m$  and measure the acceleration  $\vec{a}$ , the acceleration turns out to be given by:

$$\vec{a} = \frac{\sum \vec{F}}{m} \quad (\text{Equation 3.1: Connecting acceleration and force})$$

The symbol  $\Sigma$  represents a sum, so  $\sum \vec{F}$  is the net force (the sum of all the forces) acting on the object. Note that the right-hand side of Equation 3.1 has units of N/kg, so the units of acceleration can be stated as N/kg or as  $\text{m/s}^2$ .

### EXPLORATION 3.3B – A race

Take two objects of different mass and hold one in one hand and one in the other. If you simultaneously release them from rest from the same distance above the floor, which object hits the ground first? Be sure to use objects that will not be affected much by air resistance, such as a pen and a ball. A piece of paper is a poor choice, for instance, unless you crumple it into a tight ball.

When you do the experiment, you should observe that the objects reach the ground at the same time. This contradicts a common belief (and a belief that was held by Greek thinkers such as Aristotle) that objects with more mass fall faster.

**Key idea for an object moving under the influence of gravity alone:** If air resistance can be neglected, the acceleration of an object moving under the influence of gravity is independent of the mass of the object. **Related End-of-Chapter Exercises: 34, 35.**

**Essential Question 3.3:** If a free-body diagram shows a net force acting on an object at all times, can the object be at rest?