Answer to Essential Question 2.2: If we take the average of the two velocities we found in Example 2.2B, $\vec{v}_1 = +2.0\,\text{m/s}$ and $\vec{v}_2 = -4.0\,\text{m/s}$, we get $-1.0\,\text{m/s}$. This is clearly not the average velocity, because we found the average velocity to be +0.80 m/s in Example 2.2A . The reason the average velocity differs from the average of the velocities of the two parts of the motion is that one part of the motion takes place over a longer time interval than the other (4 times longer, in this case). If we wanted to find the average velocity by averaging the velocity of the different parts, we could do a weighted average, weighting the velocity of the first part of the motion four times more heavily because it takes four times as long, as follows:

$$\bar{\vec{v}} = \frac{4\times(+2.0\,\text{m/s}) + 1\times(-4.0\,\text{m/s})}{4+1} = \frac{+4.0\,\text{m/s}}{5} = +0.8\,\text{m/s}.$$

2-3 Different Representations of Motion

There are several ways to describe the motion of an object, such as explaining it in words, or using equations to describe the motion mathematically. Different representations give us different perspectives on how an object moves. In this section, we'll focus on two other ways of representing motion, drawing motion diagrams and drawing graphs. We'll do this for motion with constant velocity - motion in a constant direction at a constant speed.

EXPLORATION 2.3A – Learning about motion diagrams

A motion diagram is a diagram in which the position of an object is shown at regular time intervals as the object moves. It's like taking a video and over-laying the frames of the video.

Step 1 - ***Sketch a motion diagram for an object that is moving at a constant velocity.*** An object with constant velocity travels the same distance in the same direction in each time interval. The motion diagram in Figure 2.9 shows equally spaced images along a straight line. The numbers correspond to times, so this object is moving to the right with a constant velocity.

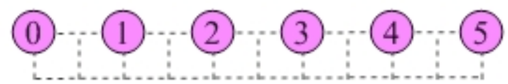

Figure 2.9: Motion diagram for an object that has a constant velocity to the right.

Step 2 - ***Draw a second motion diagram next to the first, this time for an object that is moving parallel to the first object but with a larger velocity.*** To be consistent, we should record the positions of the two objects at the same times. Because the second object is moving at constant velocity, the various images of the second object on the motion diagram will also be equally spaced. Because the second object is moving faster than the first, however, there will be more space between the images of the second object on the motion diagram – the second object covers a greater distance in the same time interval. The two motion diagrams are shown in Figure 2.10.

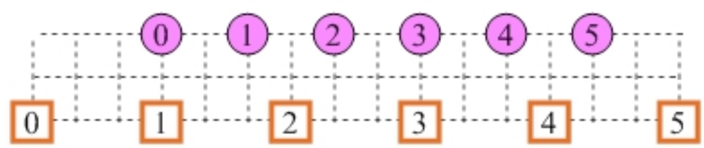

Figure 2.10: Two motion diagrams side by side. These two motion diagrams show objects with a constant velocity to the right but the lower object (marked by the square) has a higher speed, and it passes the one marked by the circles at time-step 3.

Key ideas: A motion diagram can tell us whether or not an object is moving at constant velocity. The farther apart the images, the higher the speed. Comparing two motion diagrams can tell us which object is moving fastest and when one object passes another.

Related End-of-Chapter Exercises: 23 and 24

EXPLORATION 2.3B – Connecting velocity and displacement using graphs
As we have investigated already with position-versus-time graphs, another way to represent motion is to use graphs, which can give us a great deal of information. Let's now explore a velocity-versus-time graph, for the case of a car traveling at a constant velocity of +25 m/s.

Step 1 - ***How far does the car travel in 2.0 seconds***? The car is traveling at a constant speed of 25 m/s, so it travels 25 m every second. In 2.0 seconds the car goes 25 m/s × 2.0 s, which is 50 m.

Step 2 – ***Sketch a velocity-versus-time graph for the motion. What on the velocity-versus-time graph tells us how far the car travels in 2.0 seconds?*** Because the velocity is constant, the velocity-versus-time graph is a horizontal line, as shown in Figure 2.11.

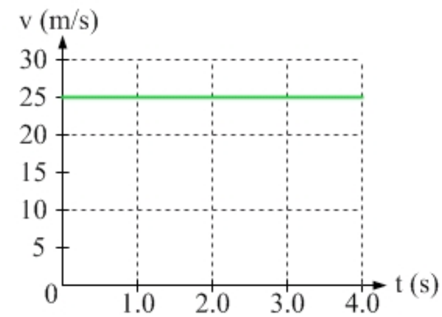

Figure 2.11: The velocity-versus-time graph for a car traveling at a constant velocity of +25 m/s.

To answer the second question, let's re-arrange Equation 2.2, $\bar{\vec{v}} = \frac{\Delta \vec{x}}{\Delta t}$, to solve for the displacement from the average velocity.

$\Delta \vec{x} = \bar{\vec{v}}\, \Delta t$.   (Equation 2.5: **Finding displacement from average velocity**)

When the velocity is constant, the average velocity is the value of the constant velocity. This method of finding the displacement can be visualized from the velocity-versus-time graph. The displacement in a particular time interval is the area under the velocity-versus-time graph for that time interval. "The area under a graph" means the area of the region between the line or curve on the graph and the *x*-axis. As shown in Figure 2.12, this area is particularly easy to find in a constant-velocity situation because the region we need to find the area of is rectangular, so we can simply multiply the height of the rectangle (the velocity) by the width of the rectangle (the time interval) to find the area (the displacement).

Key idea: The displacement is the area under the velocity-versus-time graph. This is true in general, not just for constant-velocity motion.

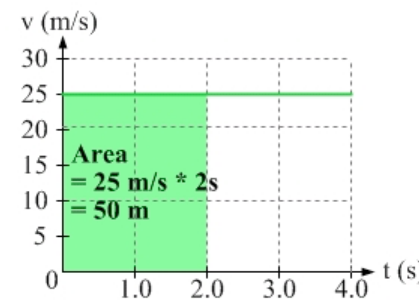

Figure 2.12: The area under the velocity-versus-time graph in a particular time interval equals the displacement in that time interval.

Deriving an equation for position when the velocity is constant

Substitute Equation 2.1, $\Delta \vec{x} = \vec{x}_f - \vec{x}_i$, into Equation 2.5, $\Delta \vec{x} = \vec{v}\, \Delta t$.

This gives: $\vec{x}_f - \vec{x}_i = \vec{v}\, \Delta t = \vec{v}\left(t_f - t_i\right)$.

Generally, we define the initial time t_i to be zero: $\vec{x}_f - \vec{x}_i = \vec{v}\, t_f$.

Remove the "f" subscripts to make the equation as general as possible: $\vec{x} - \vec{x}_i = \vec{v}\, t$.

$\vec{x} = \vec{x}_i + \vec{v}\, t$.   (Equation 2.6: **Position for constant-velocity motion**)

Such a position-as-a-function-of-time equation is known as an **equation of motion**.

Related End-of-Chapter Exercises: 3, 17, and 48.

Essential Question 2.3: What are some examples of real-life objects experiencing constant-velocity motion? *(The answer is at the top of the next page.)*