Answer to Essential Question 2.1: The magnitude of the net displacement is always less than or equal to the total distance. The two quantities are equal when the motion occurs without any change in direction. In that case, the individual displacements point in the same direction, so the magnitude of the net displacement is equal to the sum of the magnitudes of the individual displacements (the total distance). If there is a change of direction, however, the magnitude of the net displacement is less than the total distance, as in Example 2.1.

2-2 Velocity and Speed

In describing motion, we are not only interested in where an object is and where it is going, but we are also generally interested in how fast the object is moving and in what direction it is traveling. This is measured by the object's velocity.

Average velocity: a vector representing the average rate of change of position with respect to time. The SI unit for velocity is m/s (meters per second).

Because the change in position is the displacement, we can express the average velocity as:

$$\bar{\vec{v}} = \frac{\Delta \vec{x}}{\Delta t} = \frac{\text{net displacement}}{\text{time interval}} . \quad \text{(Equation 2.2: \textbf{Average velocity})}$$

The bar symbol ($\bar{}$) above a quantity means the average of that quantity. The direction of the average velocity is the direction of the displacement.

"Velocity" and "speed" are often used interchangeably in everyday speech, but in physics we distinguish between the two. Velocity is a vector, so it has both a magnitude and a direction, while speed is a scalar. Speed is the magnitude of the instantaneous velocity (see the next page). Let's define average speed.

Average Speed = $\bar{v} = \frac{\text{total distance covered}}{\text{time interval}}$ (Equation 2.3: **Average speed**)

In Section 2-1, we discussed how the magnitude of the displacement can be different from the total distance traveled. This is why the magnitude of the average velocity can be different from the average speed.

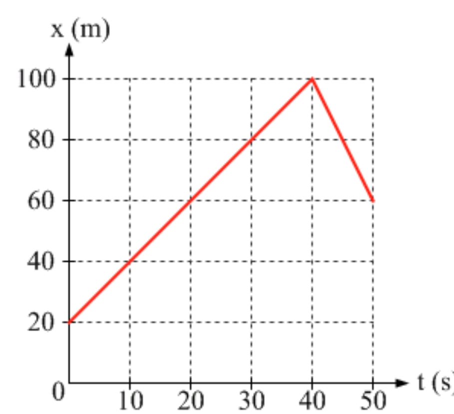

Figure 2.6: A graph of your position versus time over a 50-second period as you move along a sidewalk.

EXAMPLE 2.2A – Average velocity and average speed

Consider Figure 2.6, the graph of position-versus-time we looked at in the previous section. Over the 50-second interval, find:

(a) the average velocity, and (b) the average speed.

SOLUTION

(a) Applying Equation 2.2, we find that the average velocity is:

$$\bar{\vec{v}} = \frac{\Delta \vec{x}}{\Delta t} = \frac{+40\,\text{m}}{50\,\text{s}} = +0.80\ \text{m/s} .$$

The net displacement is shown in Figure 2.7. We can also find the net displacement by adding, as vectors, the displacement of +80 meters, in the first 40 seconds, to the displacement of –40 meters, which occurs in the last 10 seconds.

(b) Applying Equation 2.3 to find the average speed,

$$\bar{v} = \frac{\text{total distance covered}}{\text{time interval}} = \frac{80\,\text{m} + 40\,\text{m}}{50\,\text{s}} = \frac{120\,\text{m}}{50\,\text{s}} = 2.4\,\text{m/s}\,.$$

The average speed and average velocity differ because the motion involves a change of direction. Let's now turn to finding instantaneous values of velocity and speed.

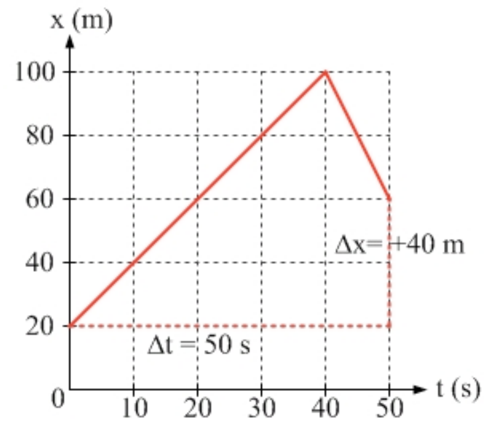

Figure 2.7: The net displacement of +40 m is shown in the graph.

Instantaneous velocity: a vector representing the rate of change of position with respect to time at a particular instant in time. A practical definition is that the instantaneous velocity is the slope of the position-versus-time graph at a particular instant. Expressing this as an equation:

$$\vec{v} = \frac{\Delta \vec{x}}{\Delta t}\,. \qquad \text{(Equation 2.4: \textbf{Instantaneous velocity})}$$

Δt is sufficiently small that the velocity can be considered to be constant over that time interval.

Instantaneous speed: the magnitude of the instantaneous velocity.

EXAMPLE 2.2B – Instantaneous velocity

Once again, consider the motion represented by the graph in Figure 2.6. What is the instantaneous velocity at (a) $t = 25$ s? (b) $t = 45$ s?

SOLUTION

(a) Focus on the slope of the graph, as in Figure 2.8, which represents the velocity. The position-versus-time graph is a straight line for the first 40 seconds, so the slope, and the velocity, is constant over that time interval. Because of this, we can use the entire 40-second interval to find the value of the constant velocity at any instant between $t = 0$ and $t = 40$ s.
Thus, the velocity at t = 25 s is

$$\vec{v}_1 = \frac{\text{rise}}{\text{run}} = \frac{\text{displacement}}{\text{time}} = \frac{+80\text{ m}}{40\text{ s}} = +2.0\text{ m/s}\,.$$

(b) We use a similar method to find the constant velocity between $t = 40$ s and $t = 50$ s:
At $t = 45$ s, the velocity is

$$\vec{v}_2 = \frac{\text{displacement}}{\text{time}} = \frac{-40\text{ m}}{10\text{ s}} = -4.0\text{ m/s}\,.$$

Related End-of-Chapter Exercises: 2, 3, 8, 10, and 11

***Essential Question 2.2*:** For the motion represented by the graph in Figure 2.6, is the average velocity over the entire 50-second interval equal to the average of the velocities we found in Example 2.2B for the two different parts of the motion? Explain.

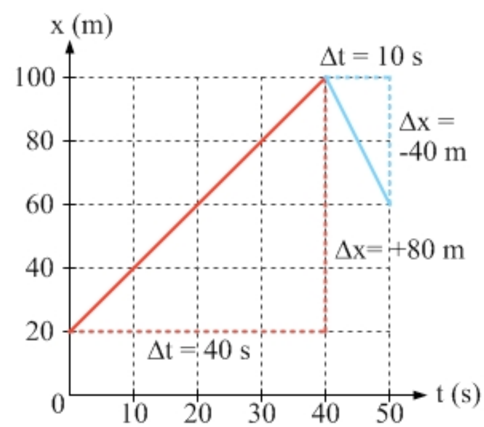

Figure 2.8: The velocity at any instant in time is determined by the slope of the position-versus-time graph at that instant.