CHAPTER 2

KINEMATICS: DESCRIPTION OF MOTION

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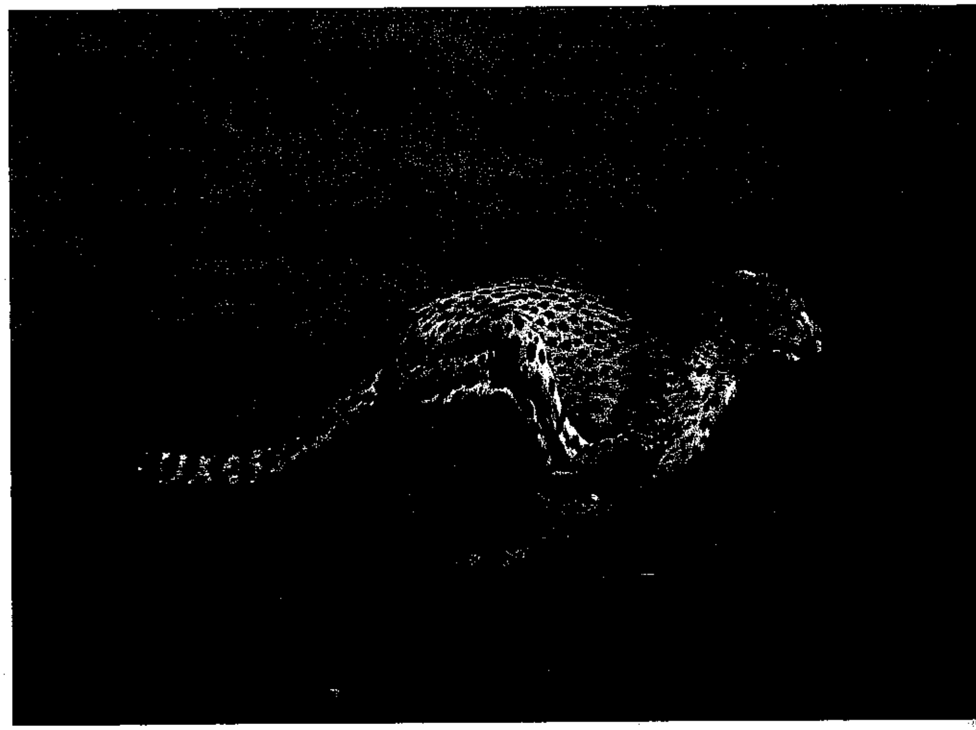


PHYSICS FACTS

- "Give me matter and motion and I will construct the universe." Rene Descartes (1640)
- Nothing can exceed the speed of light (in vacuum), 3.0×10^8 m/s (186 000 mi/s).
- NASA's X-43A uncrewed jet flew at a speed of 7700 km/h (4800 mi/h)—faster than a speeding bullet.
- A bullet from a high-powered rifle travels at a speed of about 2900 km/h (1800 mi/h).
- Electrical signals between your brain and muscles travel at about 435 km/h (270 mi/h).
- A person at the equator is traveling at a speed of 1600 km/h (1000 mi/h) due to the Earth's rotation.
- Fast and slow (approximate maximum speeds):
  - Cheetah 113 km/h (70 mi/h)
  - Horse 76 km/h (47 mi/h)
  - Greyhound 63 km/h (39 mi/h)
  - Rabbit 56 km/h (35 mi/h)
  - Cat 48 km/h (30 mi/h)
  - Human 45 km/h (28 mi/h)
  - Chicken 14 km/h (9 mi/h)
  - Snail 0.05 km/h (0.03 mi/h)
- Aristotle thought heavy objects fall faster than lighter ones. Galileo wrote, "Aristotle says that an iron ball falling from a height of one hundred cubits reaches the ground before a one-pound ball has fallen a single cubit. I say they arrive at the same time."

The cheetah is running at full stride. This fastest of all land animals is capable of attaining speeds up to 113 km/h, or 70 mi/h. The sense of motion in the chapter opening photograph is so strong that you can almost feel the air rushing by you. And yet this sense of motion is an illusion. Motion takes place in time, but the photo can "freeze" only a single instant. You'll find that without the dimension of time, you can hardly describe motion at all.

The description of motion involves the representation of a restless world. Nothing is ever perfectly still. You may sit, apparently at rest, but your blood flows, and air moves into and out of your lungs. The air is composed of gas molecules moving at different speeds and in different directions. And while you experience stillness, you, your chair, the building you are in, and the air you breathe are all revolving through space with the Earth, part of a solar system in a spiraling galaxy in an expanding universe.

The branch of physics concerned with the study of motion, and what produces and affects motion, is called **mechanics.** The roots of mechanics and of human interest in motion go back to early civilizations. The study of the motions of heavenly bodies, or *celestial mechanics*, grew out of the need to measure time and location. Several early Greek scientists, notably Aristotle, put forth theories of motion that were useful descriptions, but were later proved to be incomplete or incorrect. Our currently accepted concepts of motion were formulated in large part by Galileo (1564–1642) and Isaac Newton (1642–1727).

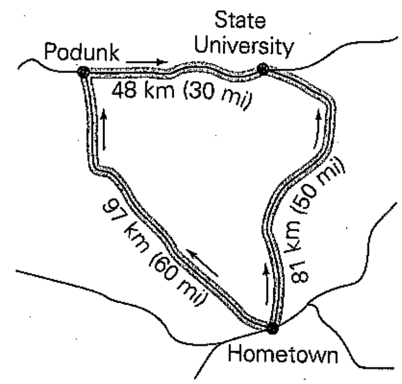
Mechanics is usually divided into two parts: (1) kinematics and (2) dynamics. **Kinematics** deals with the *description* of the motion of objects, without consideration of what causes the motion. **Dynamics** analyzes the *causes* of motion. This chapter covers kinematics and reduces the description of motion to its simplest terms by considering motion in a straight line. You'll learn to analyze changes in motion—speeding up, slowing down, and stopping. Along the way, we'll deal with a particularly interesting case of accelerated motion: free fall under the influence only of gravity.

2.1 Distance and Speed: Scalar Quantities

OBJECTIVES: To (a) define distance and calculate speed, and (b) explain what is meant by a scalar quantity.

Distance

We observe motion all around us. But what is motion? This question seems simple; however, you might have some difficulty giving an immediate answer (and it's not fair to use forms of the verb *to move* to describe motion). After a little thought, you should be able to conclude that **motion** (or moving) involves changing position. Motion can be described in part by specifying *how far* something travels in changing position—that is, the distance it travels. **Distance** is simply the *total path length* traversed in moving from one location to another. For example, you may drive to school from your hometown and express the distance traveled in miles or kilometers. In general, the distance between two points depends on the path traveled (▸Fig. 2.1).



▲ **FIGURE 2.1 Distance—total path length** In driving to State University from Hometown, one student may take the shortest route and travel a distance of 81 km (50 mi). Another student takes a longer route in order to visit a friend in Podunk before returning to school. The longer trip is in two segments, but the distance traveled is the total length, 97 km + 48 km = 145 km (90 mi).

Note: A scalar quantity has magnitude, but no direction.

Along with many other quantities in physics, distance is a scalar quantity. A **scalar quantity** is a quantity with only magnitude, or size. That is, a *scalar* has only a numerical value, such as 160 km or 100 mi. (Note that the magnitude includes units.) Distance tells you the magnitude only—how far, but not the direction. Other examples of scalars are quantities such as 10 s (time), 3.0 kg (mass), and 20°C (temperature). Some scalars may have negative values; for example, −10°F.

Speed

When something is in motion, its position changes with time. That is, it moves a certain distance in a given amount of time. Both length and time are therefore important quantities in describing motion. For example, imagine a car and a pedestrian moving down a street and traveling a distance of one block. You would expect the car to travel faster, and thus to cover the same distance in a shorter time than the person. A length-time relationship can be expressed by using the *rate* at which distance is traveled, or what we call **speed**.

Average speed ($\bar{s}$) is the distance d traveled, that is, the actual length of the path, divided by the total time Δt elapsed in traveling that distance:

$$\text{average speed} = \frac{\text{distance traveled}}{\text{total time to travel that distance}} \tag{2.1}$$

$$\bar{s} = \frac{d}{\Delta t} = \frac{d}{t_2 - t_1}$$

SI unit of speed: meters per second (m/s)

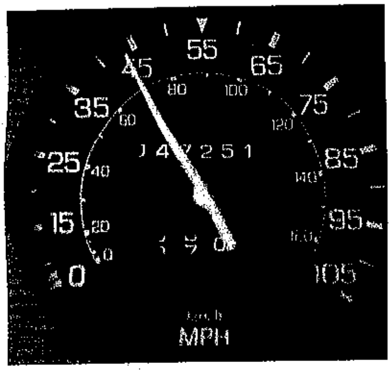
A symbol with a bar over it is commonly used to denote an average. The Greek letter delta, Δ, is used to represent a change or difference in a quantity, in this case the time difference between the beginning (t_1) and end (t_2) of a trip, or the elapsed time.

The SI standard unit of speed is meters per second (m/s, length/time), although kilometers per hour (km/h) is used in many everyday applications. The British standard unit is feet per second (ft/s), but we often use miles per hour (mi/h). Often, the initial time is taken to be zero, $t_1 = 0$, as in resetting a stopwatch, and thus the equation is written $\bar{s} = d/t$, where it is understood that t is the total time.

Since distance is a scalar (as is time), speed is also a scalar. The distance does *not* have to be in a straight line. (See Fig. 2.1.) For example, you probably have computed the average speed of an automobile trip by using the distance obtained from the starting and ending odometer readings. Suppose these readings were 17455 km and 17775 km, respectively, for a 4.0-h trip. (We'll assume that you have a car with odometer readings in kilometers.) Subtracting the readings gives a total traveled distance d of 320 km, so the average speed of the trip is $d/t = 320 \text{ km}/4.0 \text{ h} = 80 \text{ km/h}$ (or about 50 mi/h).

Average speed gives a general description of motion over a time interval Δt. In the case of the auto trip with an average speed of 80 km/h, the car's speed wasn't *always* 80 km/h. With various stops and starts on the trip, the car must have been moving more slowly than the average speed at various times. It therefore had to be moving more rapidly than the average speed another part of the time. With an average speed, you don't know how fast the car was moving at any particular instant of time during the trip. In analogy, the average test score of a class doesn't tell you the score of any particular student.

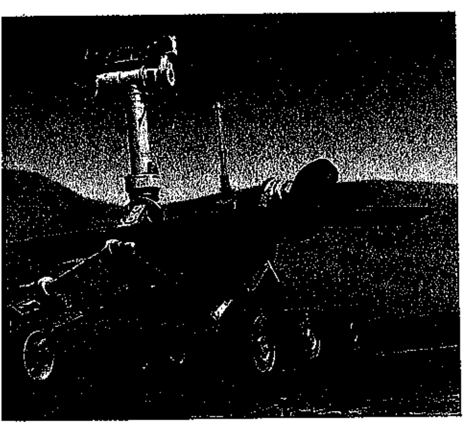
The **instantaneous speed** is a quantity that tells how fast something is moving *at a particular instant of time*. The speedometer of a car gives an approximate instantaneous speed. For example, the speedometer shown in ◂Fig. 2.2 indicates a speed of about 44 mi/h, or 70 km/h. If the car travels with constant speed (so the speedometer reading does not change), then the average and instantaneous speeds will be equal. (Do you agree? Think of the previous average test score analogy. What if all of the students got the same score?)



▲ **FIGURE 2.2 Instantaneous speed** The speedometer of a car gives the speed over a very short interval of time, so its reading approaches the instantaneous speed.

Example 2.1 ■ Slow Motion: Rover Moves Along

In January 2004, the Mars Exploration Rover touched down on the surface of Mars and rolled out for exploration (◂Fig. 2.3). The average speed of a rover on flat, hard ground is 5.0 cm/s. (a) Assuming the rover traveled continuously over this terrain at its average speed, how much time would it take to travel 2.0 m in a straight line? (b) However, in order to ensure a safe drive, the rover was equipped with hazard avoidance software that cause it to stop and assess its location every few seconds. It was programmed to drive at average speed for 10 s, then stop and observe the terrain for 20 s before moving onward for another 10 s and repeating the cycle. Taking its programming into account, what would be the rover's average speed in traveling the 2.0 m?



▲ **FIGURE 2.3 Mars Exploration Rovers** Twin Rover landed on opposite sides of the Martian planet in search of answers about the history of water on Mars.

Thinking It Through. (a) Knowing the average speed and the distance, the time can be computed from the equation for average speed (Eq. 2.1). (b) Here, to calculate the average speed, the total time, which includes stops, must be used.

Solution. Listing the data in symbol form: (cm/s is converted directly to m/s)

Given:
(a) $\bar{s} = 5.0 \text{ cm/s} = 0.050 \text{ m/s}$
$d = 2.0 \text{ m}$
(b) cycles of 10 s travel, 20 s stops

Find:
(a) Δt (time to travel distance)
(b) $\bar{s}$ (average speed)

(a) From Eq. 2.1, we have $\bar{s} = \dfrac{d}{\Delta t}$

Rearranging,

$$\Delta t = \frac{d}{\bar{s}} = \frac{2.0 \text{ m}}{0.050 \text{ m/s}} = 40 \text{ s}$$

(b) Here we need the total time for the 2.0-m distance. In each 10-s interval, a distance of $0.050 \text{ m/s} \times 10 \text{ s} = 0.50 \text{ m}$ would be traveled. So, the total time would be four 10-s intervals for actual travel, and three 20-s intervals of stopping, giving $\Delta t = 4 \times 10 \text{ s} + 3 \times 20 \text{ s} = 100 \text{ s}$. Then

$$\bar{s} = \frac{d}{\Delta t} = \frac{d}{t_2 - t_1} = \frac{2.0 \text{ m}}{100 \text{ s}} = 0.020 \text{ m/s}$$

Follow-Up Exercise. Suppose the Rover's programming was for 5.0 s of travel and for 10-s stops. How long would it take to travel the 2.0 m in this case? *(Answers to all Follow-Up Exercises are at the back of the text.)*

2.2 One-Dimensional Displacement and Velocity: Vector Quantities

OBJECTIVES: To (a) define displacement and calculate velocity, and (b) explain the difference between scalar and vector quantities.

Displacement

For straight-line, or linear, motion, it is convenient to specify position by using the familiar two-dimensional Cartesian coordinate system, with x- and y-axes at right angles. A straight-line path can be in any direction relative to the axes, but for convenience, we usually orient the coordinate axes so that the motion is along one of them. (See the accompanying Learn by Drawing.)

As we have seen, distance is a scalar quantity with only magnitude (and units). However, to more completely describe motion, more information should be given by adding a *direction*. This information is particularly easy to convey for a change of position in a straight line. We define **displacement** as the straight-line distance between two points, along with the *direction* from the starting point to the final position. Unlike distance (a scalar), displacement can have either positive or negative values, with the signs indicating the directions along a coordinate axis.

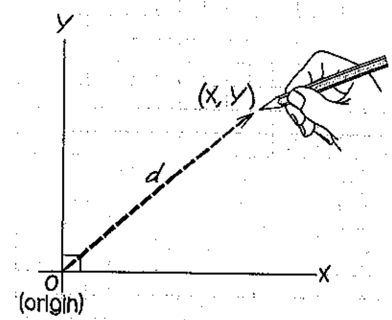
As such, displacement is a **vector quantity**. In other words, a *vector* has both magnitude and direction. For example, when we describe the displacement of an airplane as 25 km north, we are giving a *vector* description (magnitude and direction). Other vector quantities include velocity and acceleration, as will be seen.

There is an algebra that applies to vectors, but we have to know how to specify and deal with the direction part of the vector. This process is relatively simple in one dimension by using + and − signs to indicate directions. To illustrate this with displacements, consider the situation shown in ▾Fig. 2.4, where x_1 and x_2 indicate the initial and final positions, respectively, on the x-axis as a student moves in a straight line from his locker to the physics lab. As can be seen in Fig. 2.4a, the scalar distance he travels is 8.0 m. To specify displacement (a vector) between x_1 and x_2, we use the expression

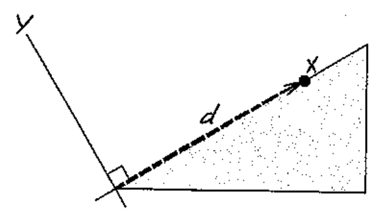
$$\Delta x = x_2 - x_1 \tag{2.2}$$

LEARN BY DRAWING

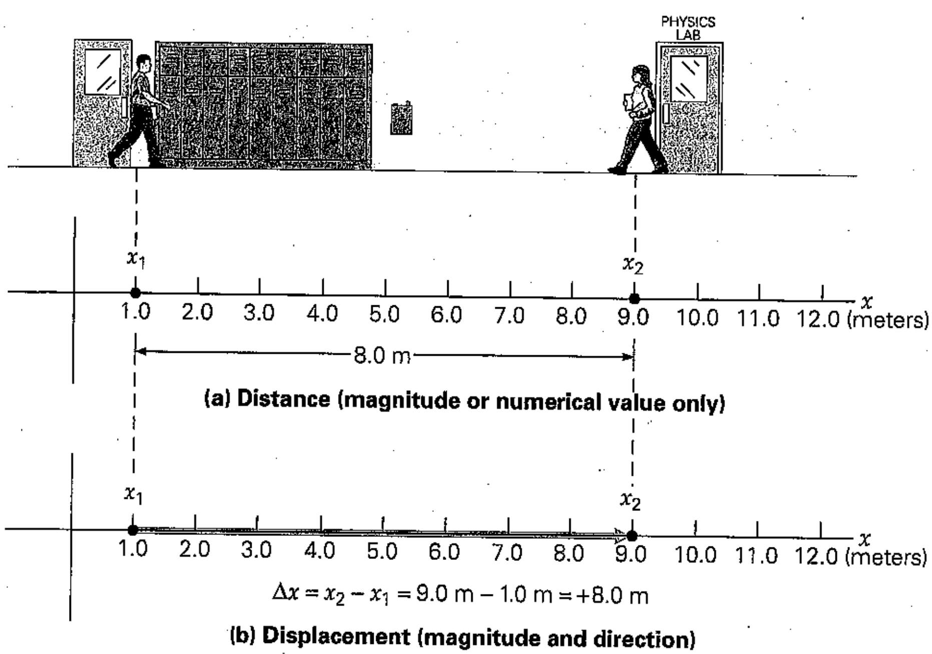
Cartesian Coordinates and One-Dimensional Displacement



(a) A two-dimensional Cartesian coordinate system. A displacement vector d locates a point (x, y).



(b) For one-dimensional, or straight-line, motion, it is convenient to orient one of the coordinate axes along the direction of motion.



◂ **FIGURE 2.4 Distance (scalar) and displacement (vector)** (a) The distance (straight-line path) between the student and the physics lab is 8.0 m and is a scalar quantity. (b) To indicate displacement, x_1 and x_2 specify the initial and final positions, respectively. The displacement is then $\Delta x = x_2 - x_1 = 9.0\text{ m} - 1.0\text{ m} = +8.0\text{ m}$—that is, 8.0 m in the positive x-direction.

where Δ is again used to represent a change in a quantity. Then, as in Fig. 2.4b, we have

$$\Delta x = x_2 - x_1 = +9.0\text{ m} - (+1.0\text{ m}) = +8.0\text{ m}$$

Note: Δ always means *final minus initial*, just as a *change* in your bank account is the final balance minus the initial balance.

where the + signs indicate the positions on the axis. Hence, the student's displacement (magnitude and direction) is 8.0 m in the positive x-direction, as indicated by the positive (+) result in Fig. 2.4b. (As in "regular" mathematics, the plus sign is often omitted, as it is understood, so this displacement can be written as $\Delta x = 8.0$ m instead of $\Delta x = +8.0$ m.)

Note: For displacement in *one direction*, the distance is the magnitude of the displacement.

Vector quantities in this book are usually indicated by boldface type with an overarrow; for example, a displacement vector is indicated by $\vec{\mathbf{d}}$ or $\vec{\mathbf{x}}$, and a velocity vector is indicated by $\vec{\mathbf{v}}$. However, when working in one dimension, this notation is not needed and can be simplified by using plus and minus signs to indicate the only two possible directions. The x-axis is commonly used for horizontal motions, and a plus (+) sign is taken to indicate the direction to the right, or in the "positive x-direction," and a minus (−) sign indicates the direction to the left, or in the "negative x-direction."

Keep in mind that these signs only "point" in *particular directions*. An object moving along the negative x-axis toward the origin would be moving in the positive x-direction, even though its value is negative. How about an object moving along the positive x-axis toward the origin? If you said in the negative x-direction, you are correct. (In art figures, vector arrows indicate directions with the associated magnitudes alongside.)

Suppose the other student in Fig. 2.4 walks from the physics lab (her initial position is different, $x_1 = +9.0$ m) to the end of the lockers (the final position is now $x_2 = +1.0$ m). Her displacement would be

$$\Delta x = x_2 - x_1 = +1.0\text{ m} - (+9.0\text{ m}) = -8.0\text{ m}$$

The minus sign indicates that the direction of the displacement was in the negative x-direction or to the left in the figure. In this case, we say that the two students' displacements are equal (in magnitude) and opposite (in direction).

Note: Don't confuse velocity (a vector) with speed (a scalar).

Velocity

As we have seen, speed, like the distance it incorporates, is a scalar quantity—it has magnitude only. Another more descriptive quantity used to describe motion is *velocity*. Speed and velocity are often used synonymously in everyday conversation, but the terms have different meanings in physics. Speed is a scalar, and velocity is a vector—velocity has both magnitude and direction. Unlike speed (but like displacement), one-dimensional velocities can have both positive and negative values, indicating the only two possible directions.

Velocity tells you how fast something is moving *and* in which direction it is moving. And just as we can speak of average and instantaneous speeds, there are average and instantaneous velocities involving vector displacements. The **average velocity** is the displacement divided by the total travel time. In one dimension, this involves just motion along one axis, which we take to be the x-axis. In this case,

$$\text{average velocity} = \frac{\text{displacement}}{\text{total travel time}} \qquad (2.3)^*$$

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1}$$

SI unit of velocity: meters per second (m/s)*

*Another common form of this equation is

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{(x_2 - x_1)}{(t_2 - t_1)} = \frac{(x - x_o)}{(t - t_o)} = \frac{(x - x_o)}{t}$$

or, after rearranging,

$$x = x_o + \bar{v}t, \qquad (2.3)$$

where x_o is the initial position, x is the final position, and $\Delta t = t$ with $t_o = 0$. See Section 2.3 for more on this notation.

In the case of more than one displacement (such as for successive displacements), the average velocity is equal to the total or net displacement divided by the total time. The total displacement is found by adding the displacements algebraically according to the directional signs.

You might be wondering whether there is a relationship between average speed and average velocity. A quick look at Fig. 2.4 will show you that if all the motion is in one direction, that is, there is no reversal of direction, the distance is equal to the magnitude of the displacement. Then the average speed is equal to the magnitude of the average velocity. *However, be careful.* This set of relationships is not true if there is a reversal of direction, as Example 2.2 shows.

Example 2.2 ■ There and Back: Average Velocities

A jogger jogs from one end to the other of a straight 300-m track in 2.50 min and then jogs back to the starting point in 3.30 min. What was the jogger's average velocity (a) in jogging to the far end of the track, (b) coming back to the starting point, and (c) for the total jog?

Note: For displacements in both the + and − directions (reversal of direction), the distance is not the magnitude of the total displacement.

Thinking It Through. The average velocities are computed from the defining equation. Note that the times given are the Δt's associated with the particular displacements.

Solution. From the problem, we have:

Given: $\Delta x_1 = 300$ m (taking the initial direction as positive)
$\Delta x_2 = -300$ m (taking the direction of the return trip as negative)
$\Delta t_1 = 2.50 \text{ min } (60 \text{ s/min}) = 150 \text{ s}$
$\Delta t_2 = 3.30 \text{ min } (60 \text{ s/min}) = 198 \text{ s}$

Find: Average velocities for
(a) the first leg of the jog,
(b) the return jog,
(c) the total jog

(a) The jogger's average velocity for the trip down the track is found from Eq. 2.3:

$$\bar{v}_1 = \frac{\Delta x_1}{\Delta t_1} = \frac{+300 \text{ m}}{150 \text{ s}} = +2.00 \text{ m/s}$$

(b) Similarly, for the return trip, we have

$$\bar{v}_2 = \frac{\Delta x_2}{\Delta t_2} = \frac{-300 \text{ m}}{198 \text{ s}} = -1.52 \text{ m/s}$$

(c) For the total trip, there are two displacements to consider, down and back, so these are added together to get the total displacement, and then divided by the total time:

$$\bar{v}_3 = \frac{\Delta x_1 + \Delta x_2}{\Delta t_1 + \Delta t_2} = \frac{300 \text{ m} + (-300 \text{ m})}{150 \text{ s} + 198 \text{ s}} = 0 \text{ m/s}$$

The average velocity for the total trip is zero! Do you see why? Recall from the definition of displacement that the magnitude of displacement is the straight-line distance between two points. The displacement from one point back to the same point is zero; hence the average velocity is zero. (See ▸Fig. 2.5.)

The total or net displacement could have been found by simply taking $\Delta x = x_{\text{final}} - x_{\text{initial}} = 0 - 0 = 0$, where the initial and final positions are taken to be the origin, but it was done in parts here for illustration purposes.

Follow-Up Exercise. Find the jogger's average speed for each of the cases in this Example, and compare it with the magnitudes of the respective average velocities. [Will the average speed for part (c) be zero?] *(Answers to all Follow-Up Exercises are at the back of the text.)*

▲ **FIGURE 2.5 Back home again!** Despite having covered nearly 110 m on the base paths, at the moment the runner slides through the batter's box (his original position) into home plate, his displacement is zero—at least, if he is a right-handed batter. No matter how fast he ran the bases, his average velocity for the round trip is also zero.

As Example 2.2 shows, average velocity provides only an overall description of motion. One way to take a closer look at motion is to take smaller time intervals; that is, to let the observation time interval (Δt) become smaller and smaller. As with speed, when Δt approaches zero, we obtain the **instantaneous velocity**, which describes how fast something is moving and in which direction *at a particular instant of time.*

Instantaneous velocity is defined mathematically as

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} \tag{2.4}$$

This expression is read as "the instantaneous velocity is equal to the limit of $\Delta x/\Delta t$ as Δt goes to zero." The time interval does not ever equal zero (why?), but *approaches* zero. Instantaneous velocity is technically still an average velocity, but over such a small Δt that it is essentially an average "at an instant in time," which is why we call it the *instantaneous* velocity.

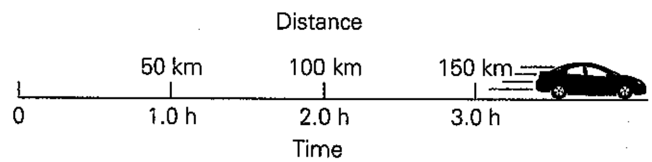
Note: The word *uniform* means "constant."

Uniform motion means motion with a constant velocity (constant magnitude *and* constant direction). As a one-dimensional example of this, the car in ▼Fig. 2.6 has a uniform velocity. It travels the same distance and experiences the same displacement in equal time intervals (50 km each hour), and the direction of its motion does not change.

PHYSLET® Illustration 1.3 *Getting Data Out*

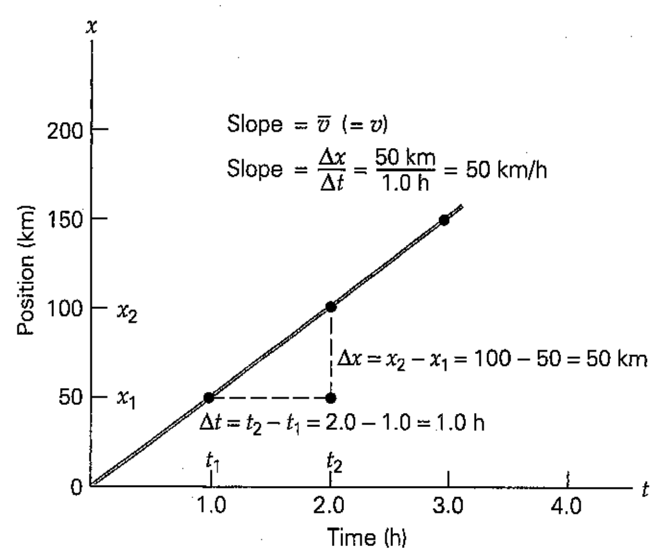
Graphical Analysis

Graphical analysis is often helpful in understanding motion and its related quantities. For example, the motion of the car in Fig. 2.6a may be represented on a plot of position versus time, or x versus t. As can be seen from Fig. 2.6b, a straight line is obtained for a uniform, or constant, velocity on such a graph.



Δx (km)	Δt (h)	$\Delta x/\Delta t$
50	1.0	50 km/1.0 h = 50 km/h
100	2.0	100 km/2.0 h = 50 km/h
150	3.0	150 km/3.0 h = 50 km/h

(a)



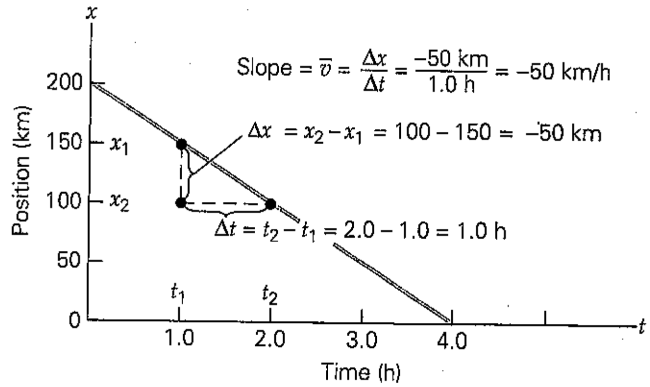
Uniform velocity

(b)

▶ **FIGURE 2.6 Uniform linear motion—constant velocity** In uniform linear motion, an object travels at a constant velocity, covering the same distance in equal time intervals. **(a)** Here, a car travels 50 km each hour. **(b)** An x-versus-t plot is a straight line, since equal displacements are covered in equal times. The numerical value of the slope of the line is equal to the magnitude of the velocity, and the sign of the slope gives its direction. (The average velocity equals the instantaneous velocity in this case. Why?)

PHYSLET® Illustration 2.1 *Position and Displacement*

PHYSLET® Exploration 2.1 *Compare Position vs. Time and Velocity vs. Time Graphs*



◀ **FIGURE 2.7 Position-versus-time graph for an object in uniform motion in the negative *x*-direction** A straight line on an x-versus-t plot with a negative slope indicates uniform motion in the negative x-direction. Note that the object's location changes at a constant rate. At $t = 4.0$ h, the object is at $x = 0$. How would the graph look if the motion continues for $t > 4.0$ h?

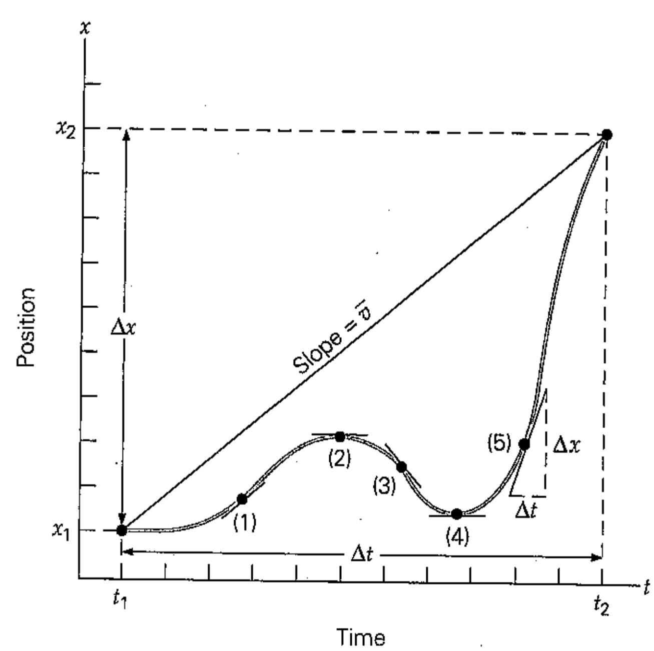
Recall from Cartesian graphs of y versus x that the slope of a straight line is given by $\Delta y/\Delta x$. Here, with a plot of x versus t, the slope of the line, $\Delta x/\Delta t$, is therefore equal to the average velocity $\bar{v} = \Delta x/\Delta t$. For uniform motion, this value is equal to the instantaneous velocity. That is, $\bar{v} = v$. (Why?) The numerical value of the slope is the magnitude of the velocity, and the sign of the slope gives the direction. A positive slope indicates that x increases with time, so the motion is in the positive x-direction. (The plus sign is often omitted as being understood, which we will do in general from here on.)

PHYSLET® Exploration 2.2 *Determine the Correct Graph*

Suppose that a plot of position versus time for a car's motion is a straight line with a negative slope, as in ▲Fig. 2.7. What does this indicate? As the figure shows, the position (x) values get smaller with time at a constant rate, indicating that the car is traveling in uniform motion, but now in the negative x-direction which correlates with the negative value of the slope.

In most instances, the motion of an object is *nonuniform*, meaning that different distances are covered in equal intervals of time. An x-versus-t plot for such motion in one dimension is a curved line, as illustrated in ▼Fig. 2.8. The average velocity of the object during any interval of time is the slope of a straight line between the two points on the curve that correspond to the starting and ending times of the interval. In the figure, since $\bar{v} = \Delta x/\Delta t$, the average velocity of the total trip is the slope of the straight line joining the beginning and ending points of the curve.

PHYSLET® Illustration 2.2 *Average Velocity*



◀ **FIGURE 2.8 Position-versus-time graph for an object in nonuniform linear motion** For a nonuniform velocity, an x-versus-t plot is a curved line. The slope of the line between two points is the average velocity between those positions, and the instantaneous velocity is the slope of a line tangent to the curve at any point. Five tangent lines are shown, with the intervals for $\Delta x/\Delta t$ in the fifth. Can you describe the object's motion in words?

4. **MC** What can be said about average speed relative to the magnitude of the average velocity? (a) greater than, (b) equal to, (c) both a and b.

5. **CQ** Can the displacement of a person's trip be zero, yet the distance involved in the trip be nonzero? How about the reverse situation? Explain.

6. **CQ** You are told that a person has walked 750 m. What can you safely say about the person's final position relative to the starting point?

7. **CQ** If the displacement of an object is 300 m north, what can you say about the distance traveled by the object?

8. **CQ** Speed is the magnitude of velocity. Is average speed the magnitude of average velocity? Explain.

9. **CQ** The average velocity of a jogger on a straight track is computed to be +5 km/h. Is it possible for the jogger's instantaneous velocity to be negative at any time during the jog? Explain.

10. ● What is the magnitude of the displacement of a car that travels half a lap along a circle that has a radius of 150 m? How about when the car travels a full lap?

11. ● A student throws a rock straight upward at shoulder level, which is 1.65 m above the ground. What is the displacement of the rock when it hits the ground?

12. ● In 1999, the Moroccan runner Hicham El Guerrouj ran the 1-mi race in 3 min, 43.13 s. What was his average speed during the race in m/s?

13. ● A senior citizen walks 0.30 km in 10 min, going around a shopping mall. (a) What is her average speed in meters per second? (b) If she wants to increase her average speed by 20% in walking a second lap, what would her travel time in minutes have to be?

14. ●● A hospital patient is given 500 cc of saline by IV. If the saline is received at a rate of 4.0 mL/min, how long will it take for the half liter to run out?

15. ●● A hospital nurse walks 25 m to a patient's room at the end of the hall in 0.50 min. She talks with the patient for 4.0 min, and then walks back to the nursing station at the same rate she came. What was the nurse's average speed?

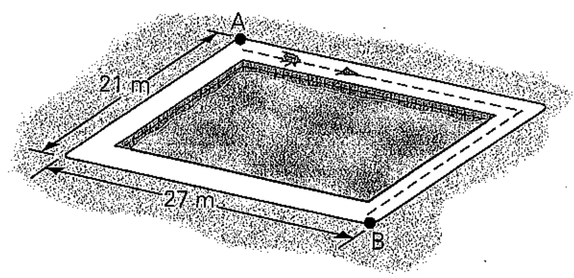
16. ●● On a cross-country trip, a couple drives 500 mi in 10 h on the first day, 380 mi in 8.0 h on the second day, and 600 mi in 15 h on the third day. What was the average speed for the whole trip?

17. **IE** ●● A car travels three quarters of a lap on a circular track of radius R. (a) The magnitude of the displacement is (1) less than R, (2) greater than R, but less than $2R$, (3) greater than $2R$. (b) If $R = 50$ m, what is the magnitude of the displacement?

18. **IE** ●● A race car travels a complete lap on a circular track of radius 500 m in 50 s. (a) The average velocity of the race car is (1) zero, (2) 100 m/s, (3) 200 m/s, (4) none of the preceding. Why? (b) What is the average speed of the race car?

19. **IE** ●● A student runs 30 m east, 40 m north, and 50 m west. (a) The magnitude of the student's net displacement is (1) between 0 and 20 m, (2) between 20 m and 40 m, (3) between 40 m and 60 m. (b) What is his net displacement?

20. ●● A student throws a ball vertically upward such that it travels 7.1 m to its maximum height. If the ball is caught at the initial height 2.4 s after being thrown, (a) what is the ball's average speed, and (b) what is its average velocity?



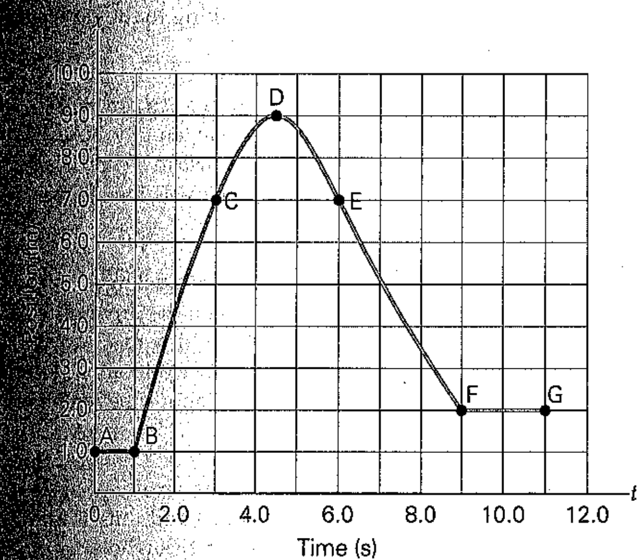
▲ **FIGURE 2.17 Speed versus velocity** See Exercise 21. (Not drawn to scale; insect is displaced for clarity.)

21. ●● An insect crawls along the edge of a rectangular swimming pool of length 27 m and width 21 m (▼Fig. 2.17). If it crawls from corner A to corner B in 30 min, (a) what is its average speed, and (b) what is the magnitude of its average velocity?

22. ●● Consider motion on the Earth's surface during one complete day. (a) What is the average velocity of a person on the Earth's equator? (b) What is the average speed of a person on the Earth's equator? (c) Compare these two results to a person located exactly at the Earth's North Pole.

23. ●● A high school kicker makes a 30.0-yd field goal attempt (in American football) and hits the crossbar at a height of 10.0 ft. (a) What is the net displacement of the football from the time it leaves the ground until it hits the crossbar? (b) Assuming the football took 2.5 s to hit the crossbar, what was its average velocity? (c) Explain why you *cannot* determine its average speed from this data.

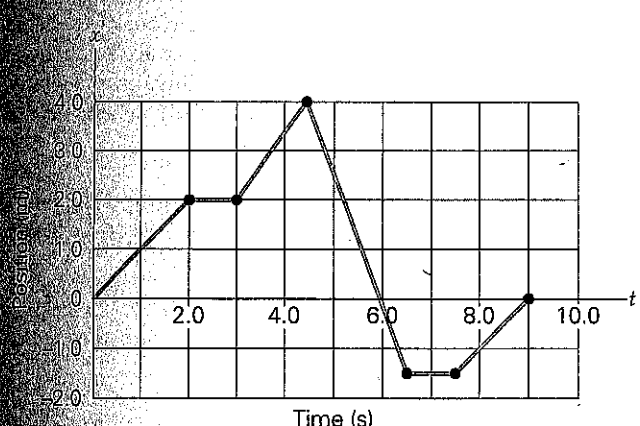
24. ●● A plot of position versus time is shown in ▸Fig. 2.18 for an object in linear motion. (a) What are the average velocities for the segments AB, BC, CD, DE, EF, FG,



▲ **FIGURE 2.18 Position versus time** See Exercise 24.

and BC? (b) State whether the motion is uniform or nonuniform in each case. (c) What is the instantaneous velocity at point D?

25. ●● In demonstrating a dance step, a person moves in one dimension, as shown in ▼Fig. 2.19. What are (a) the average speed and (b) the average velocity for each phase of the motion? (c) What are the instantaneous velocities at $t = 1.0$ s, 2.5 s, 4.5 s, and 6.0 s? (d) What is the average velocity for the interval between $t = 4.5$ s and $t = 9.0$ s? [*Hint*: Recall that the overall displacement is the displacement between the starting point and the ending point.]



▲ **FIGURE 2.19 Position versus time** See Exercise 25.

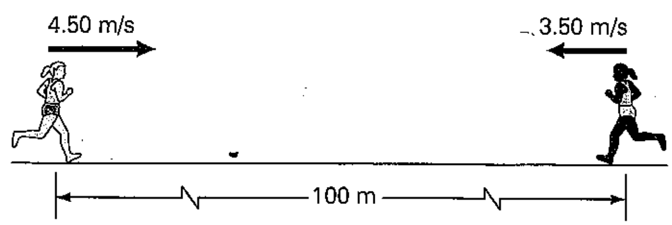
26. ●● You can determine the speed of a car by measuring the time it takes to travel between mile markers on a highway. (a) How many seconds should elapse between two consecutive mile markers if the car's average speed is 70 mi/h? (b) What is the car's average speed if it takes 65 s to travel between the mile markers?

27. ●● Short hair grows at a rate of about 2.0 cm/month. A college student has his hair cut to a length of 1.5 cm. He will have it cut again when the length is 3.5 cm. How long will it be until his next trip to the barber shop?

28. ●●● A student driving home for the holidays starts at 8:00 AM to make the 675-km trip, practically all of which is on nonurban interstate highway. If she wants to arrive home no later than 3:00 PM, what must be her minimum average speed? Will she have to exceed the 65-mi/h speed limit?

29. ●●● A regional airline flight consists of two legs with an intermediate stop. The airplane flies 400 km due north from airport A to airport B. From there, it flies 300 km due east to its final destination at airport C. (a) What is the plane's displacement from its starting point? (b) If the first leg takes 45 min and the second leg 30 min, what is the average velocity for the trip? (c) What is the average speed for the trip? (d) Why is the average speed not the same as the magnitude for the average velocity?

30. ●●● Two runners approaching each other on a straight track have constant speeds of 4.50 m/s and 3.50 m/s, respectively, when they are 100 m apart (▼Fig. 2.20). How long will it take for the runners to meet, and at what position will they meet if they maintain these speeds?



▲ **FIGURE 2.20 When and where do they meet?** See Exercise 30.

2.3 Acceleration

31. **MC** On a position-versus-time plot for an object that has a constant acceleration, the graph is (a) a horizontal line, (b) a nonhorizontal and nonvertical straight line, (c) a vertical line, (d) a curve.

32. **MC** An acceleration may result from (a) an increase in speed, (b) a decrease in speed, (c) a change of direction, (d) all of the preceding.

33. **MC** A negative acceleration can cause (a) an increase in speed, (b) a decrease in speed, (c) either a or b.

34. **MC** The gas pedal of an automobile is commonly referred to as the *accelerator*. Which of the following might also be called an accelerator: (a) the brakes; (b) the steering wheel; (c) the gear shift; or (d) all of the preceding? Explain.