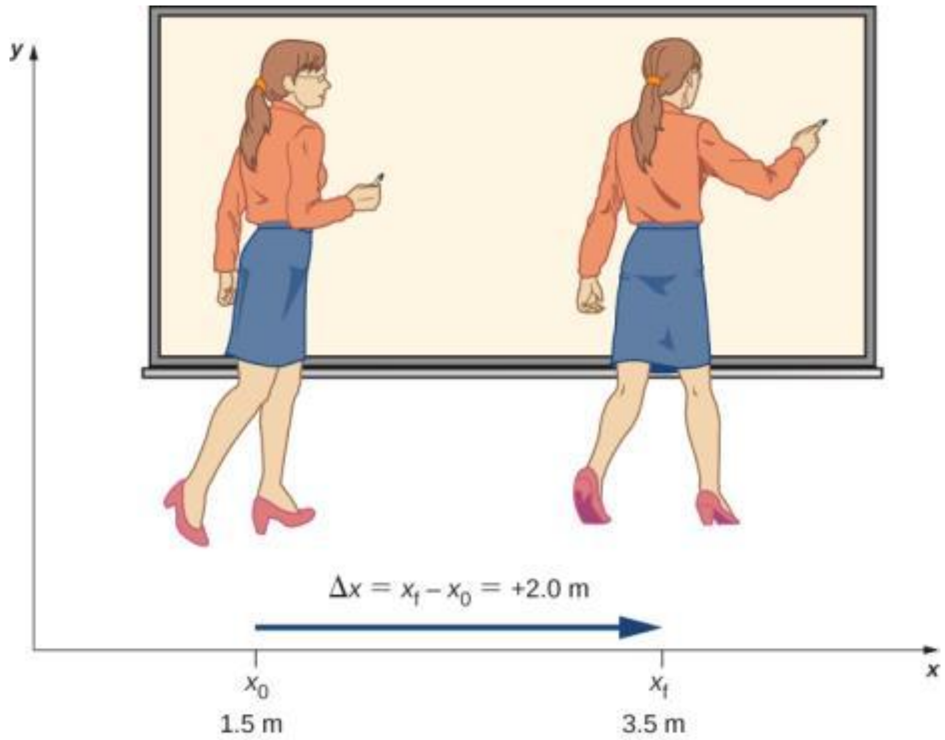
FIGURE 3.1

A JR Central L0 series five-car maglev (magnetic levitation) train undergoing a test run on the Yamanashi Test Track. The maglev train's motion can be described using kinematics, the subject of this chapter. (credit: modification of work by "Maryland GovPics"/Flickr)

FIGURE 3.2

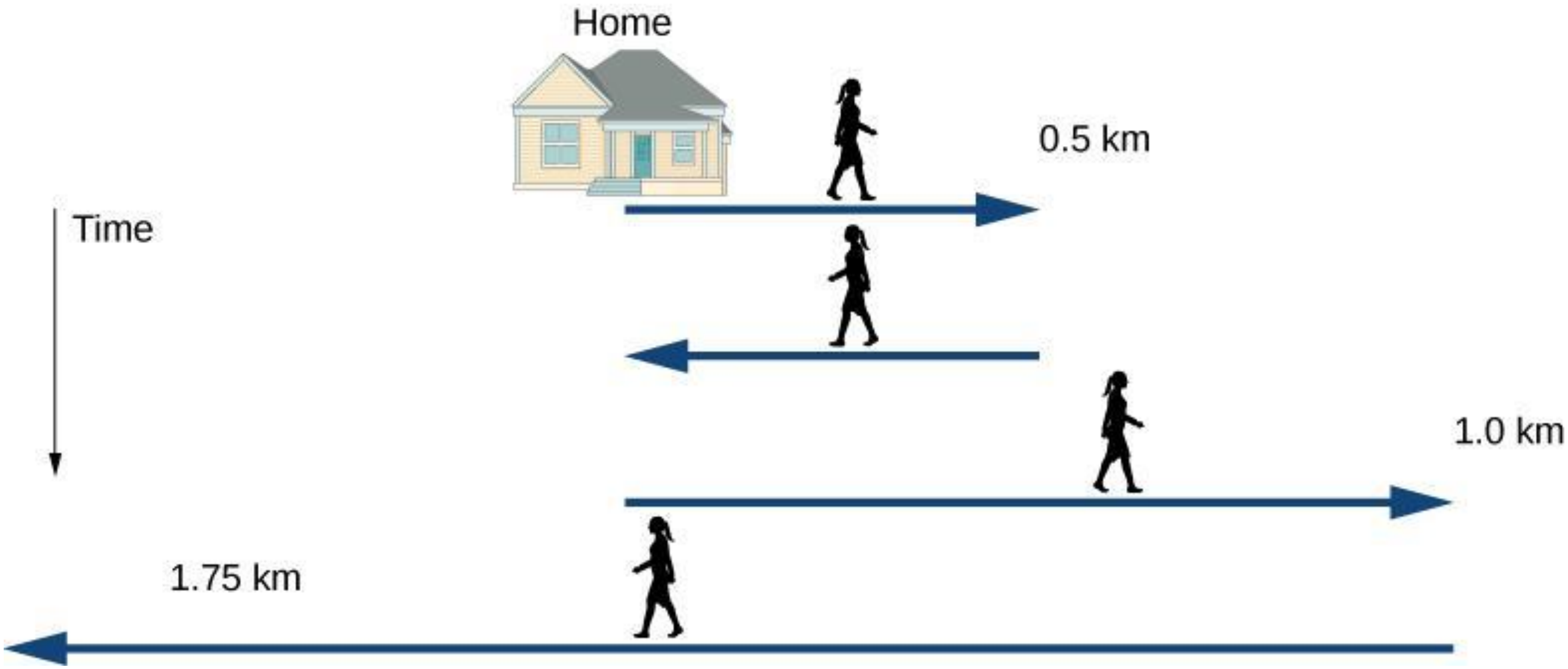
These cyclists in Vietnam can be described by their position relative to buildings or a canal. Their motion can be described by their change in position, or displacement, in a frame of reference. (credit: Suzan Black)

FIGURE 3.3



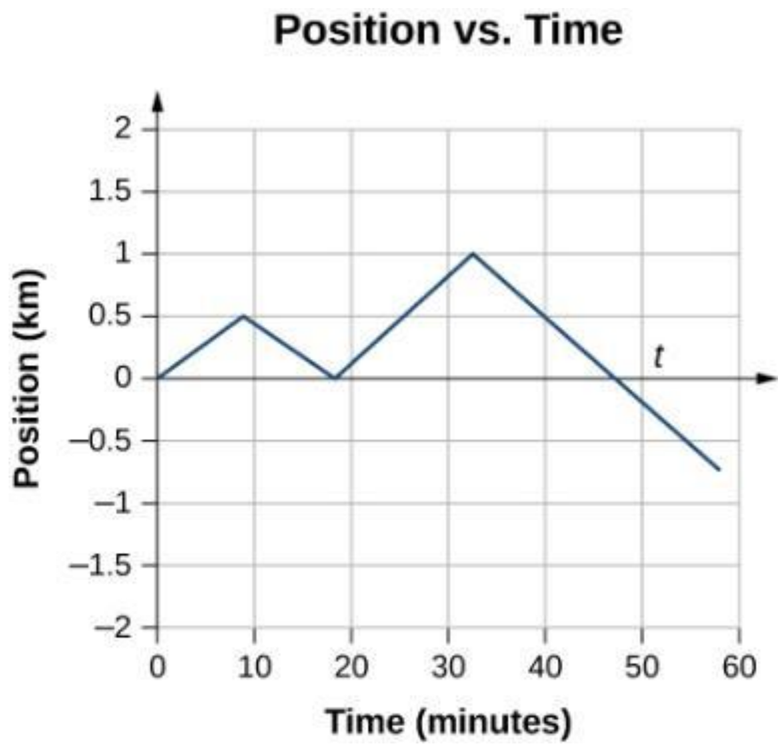
A professor paces left and right while lecturing. Her position relative to Earth is given by *x*. The +2.0-m displacement of the professor relative to Earth is represented by an arrow pointing to the right.

FIGURE 3.4



Timeline of Jill's movements.

FIGURE 3.5



This graph depicts Jill’s position versus time. The average velocity is the slope of a line connecting the initial and final points.

EXAMPLE 3.1

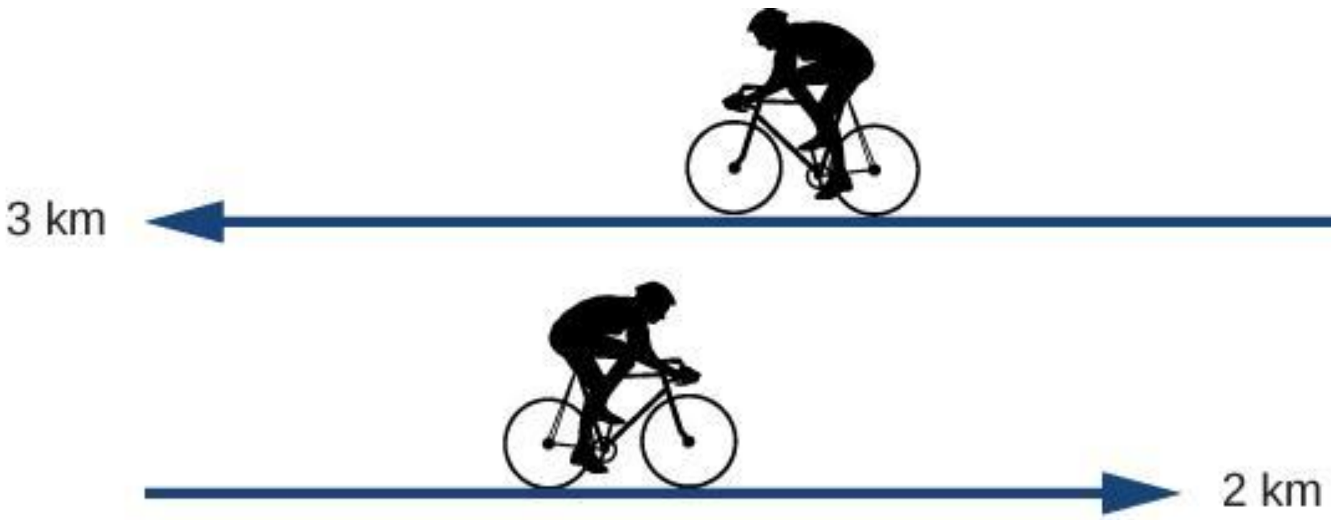
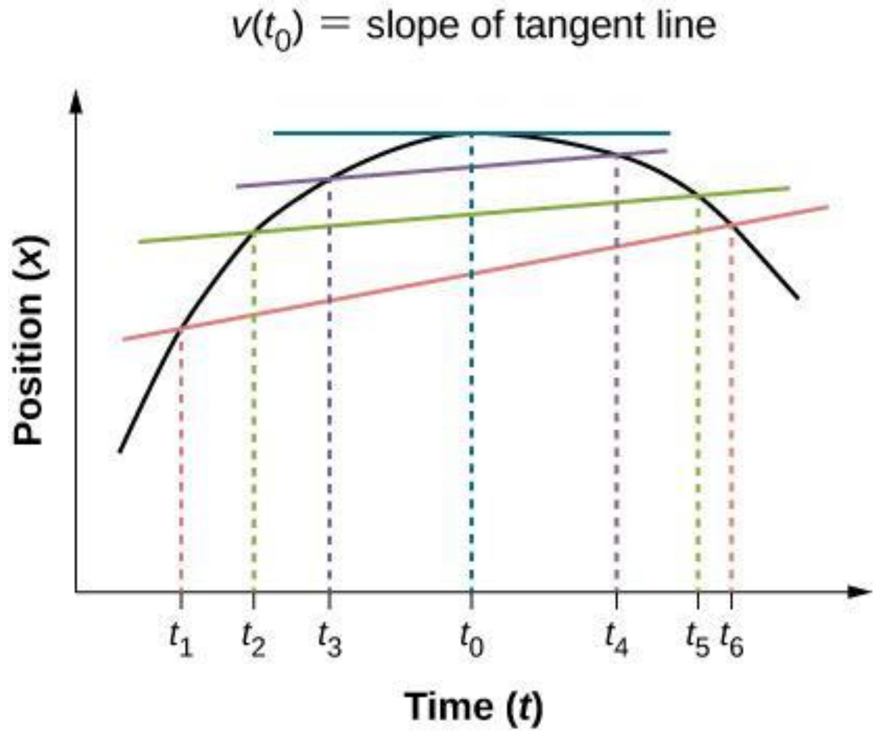
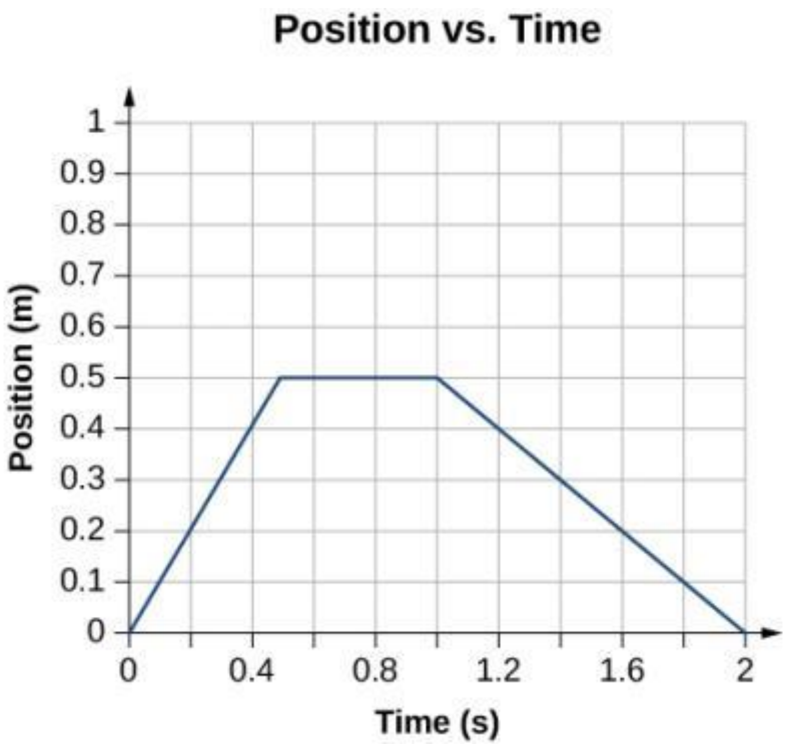


FIGURE 3.6



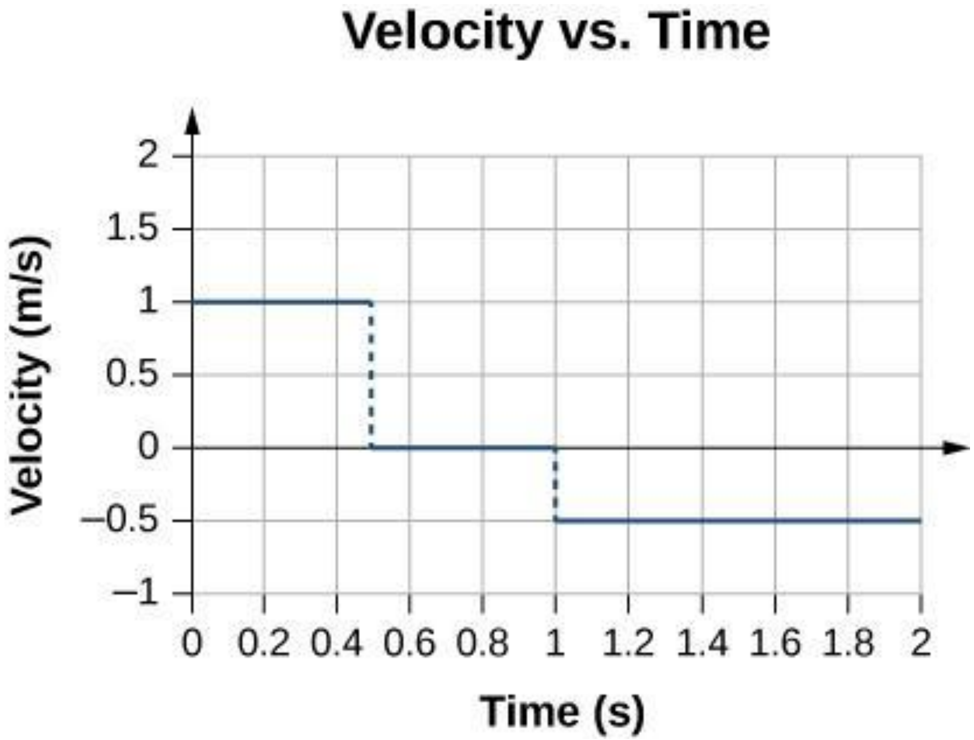
In a graph of position versus time, the instantaneous velocity is the slope of the tangent line at a given point. The average velocities $\bar{v} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$ between times $\Delta t = t_6 - t_1$, $\Delta t = t_5 - t_2$, and $\Delta t = t_4 - t_3$ are shown. When $\Delta t \to 0$, the average velocity approaches the instantaneous velocity at $t = t_0$.

FIGURE 3.7



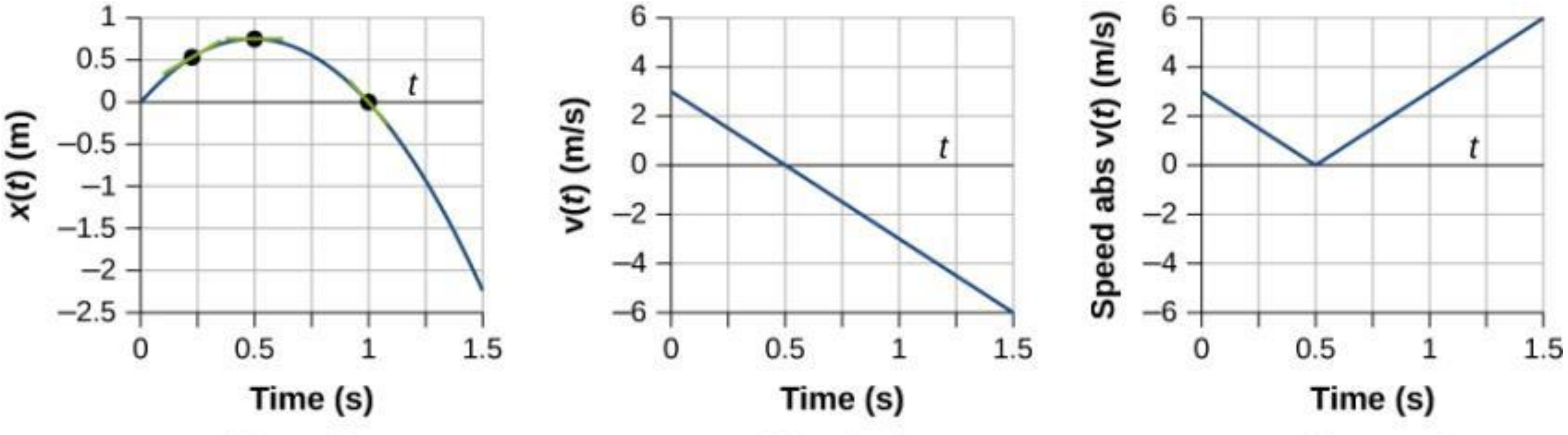
The object starts out in the positive direction, stops for a short time, and then reverses direction, heading back toward the origin. Notice that the object comes to rest instantaneously, which would require an infinite force. Thus, the graph is an approximation of motion in the real world. (The concept of force is discussed in **Newton's Laws of Motion**.)

FIGURE 3.8



The velocity is positive for the first part of the trip, zero when the object is stopped, and negative when the object reverses direction.

FIGURE 3.9



(a) Position (b) Velocity (c) Speed

(a) Position: $x(t)$ versus time.

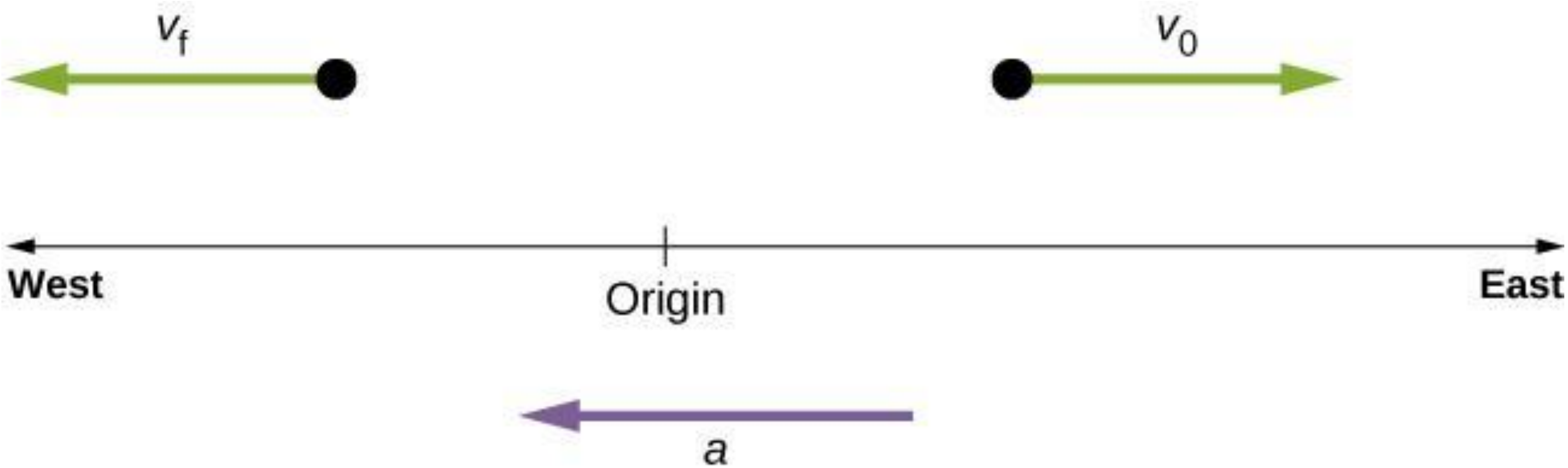
(b) Velocity: $v(t)$ versus time. The slope of the position graph is the velocity. A rough comparison of the slopes of the tangent lines in (a) at 0.25 s, 0.5 s, and 1.0 s with the values for velocity at the corresponding times indicates they are the same values.

(c) Speed: $|v(t)|$ versus time. Speed is always a positive number.

FIGURE 3.10

A subway train in Sao Paulo, Brazil, decelerates as it comes into a station. It is accelerating in a direction opposite to its direction of motion. (credit: Yusuke Kawasaki)

FIGURE 3.11

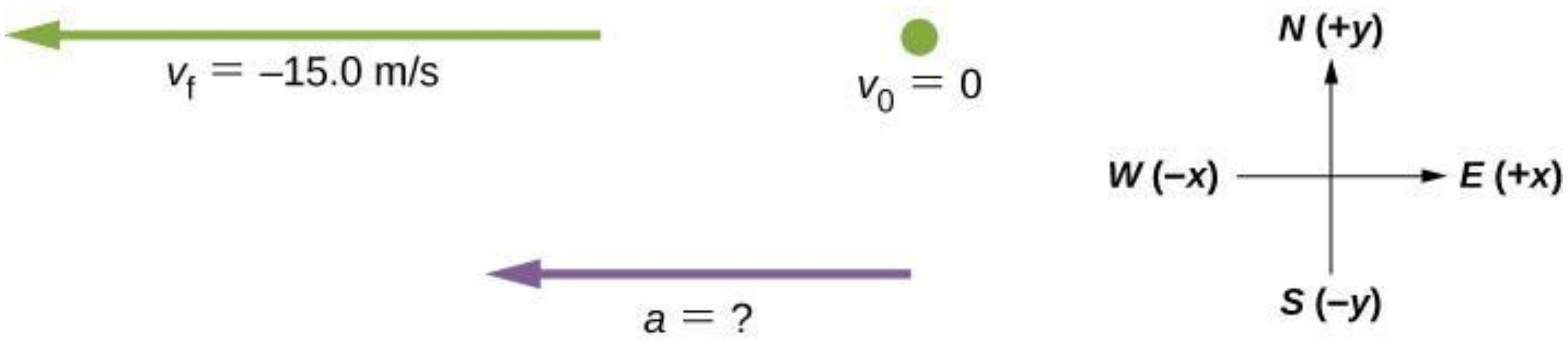


An object in motion with a velocity vector toward the east under negative acceleration comes to a rest and reverses direction. It passes the origin going in the opposite direction after a long enough time.

FIGURE 3.12

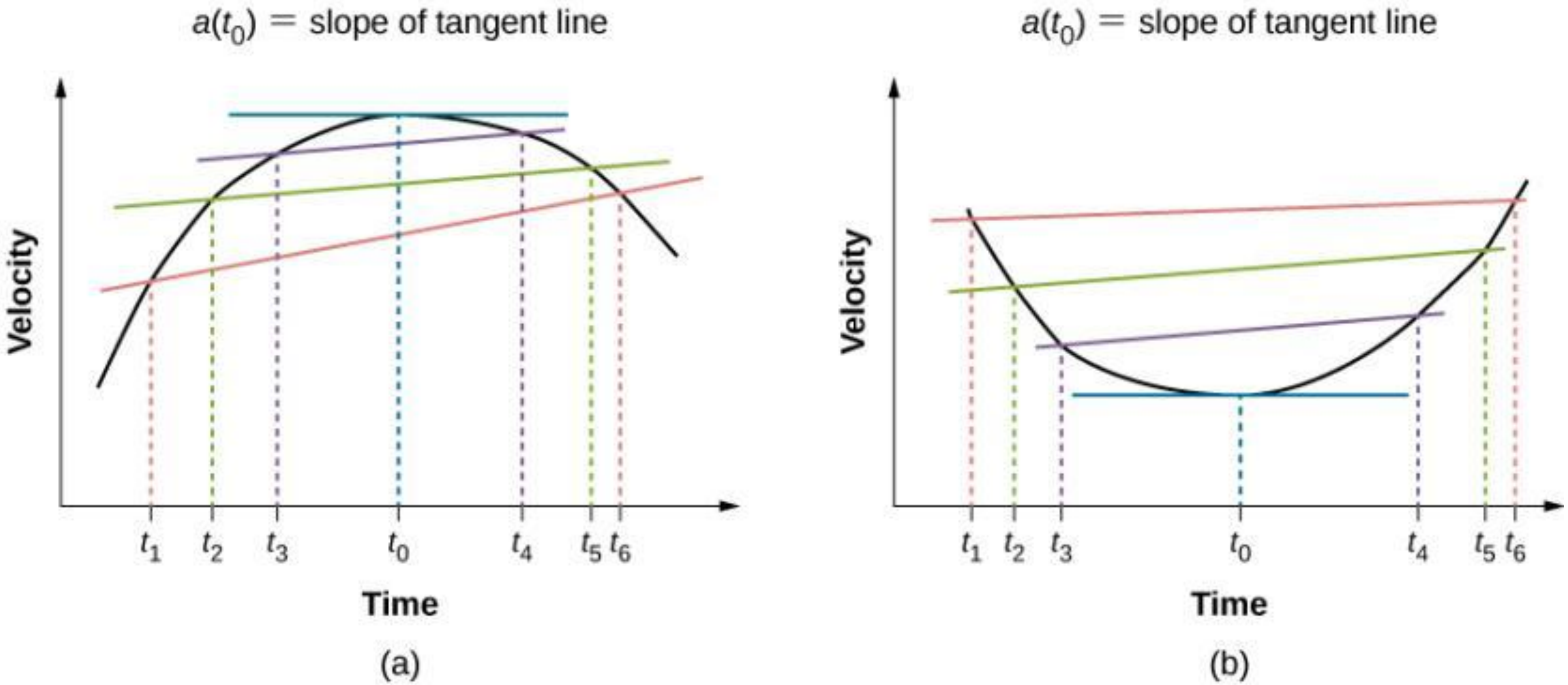
Racehorses accelerating out of the gate. (credit: Jon Sullivan)

FIGURE 3.13



Identify the coordinate system, the given information, and what you want to determine.

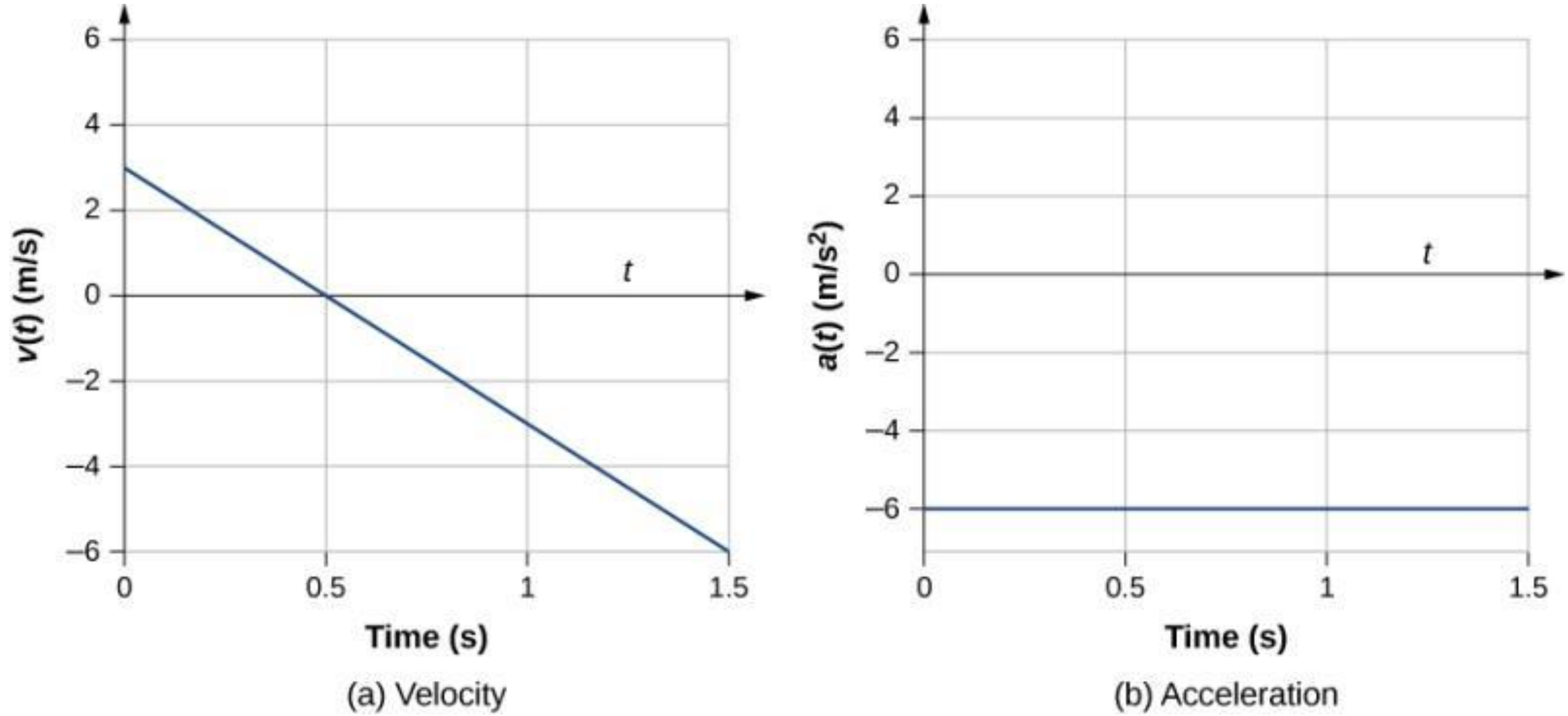
FIGURE 3.14



In a graph of velocity versus time, instantaneous acceleration is the slope of the tangent line.

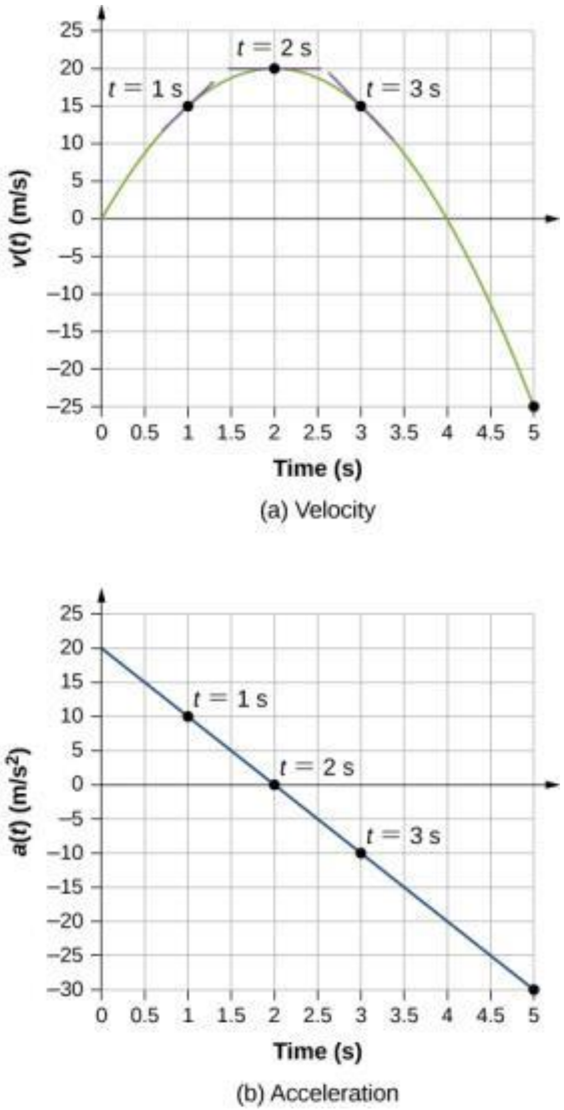
(a) Shown is average acceleration $\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$ between times $\Delta t = t_6 - t_1$, $\Delta t = t_5 - t_2$, and $\Delta t = t_4 - t_3$. When $\Delta t \to 0$, the average acceleration approaches instantaneous acceleration at time t_0 . In view (a), instantaneous acceleration is shown for the point on the velocity curve at maximum velocity. At this point, instantaneous acceleration is the slope of the tangent line, which is zero. At any other time, the slope of the tangent line—and thus instantaneous acceleration—would not be zero.

FIGURE 3.15



(a, b) The velocity-versus-time graph is linear and has a negative constant slope (a) that is equal to acceleration, shown in (b).

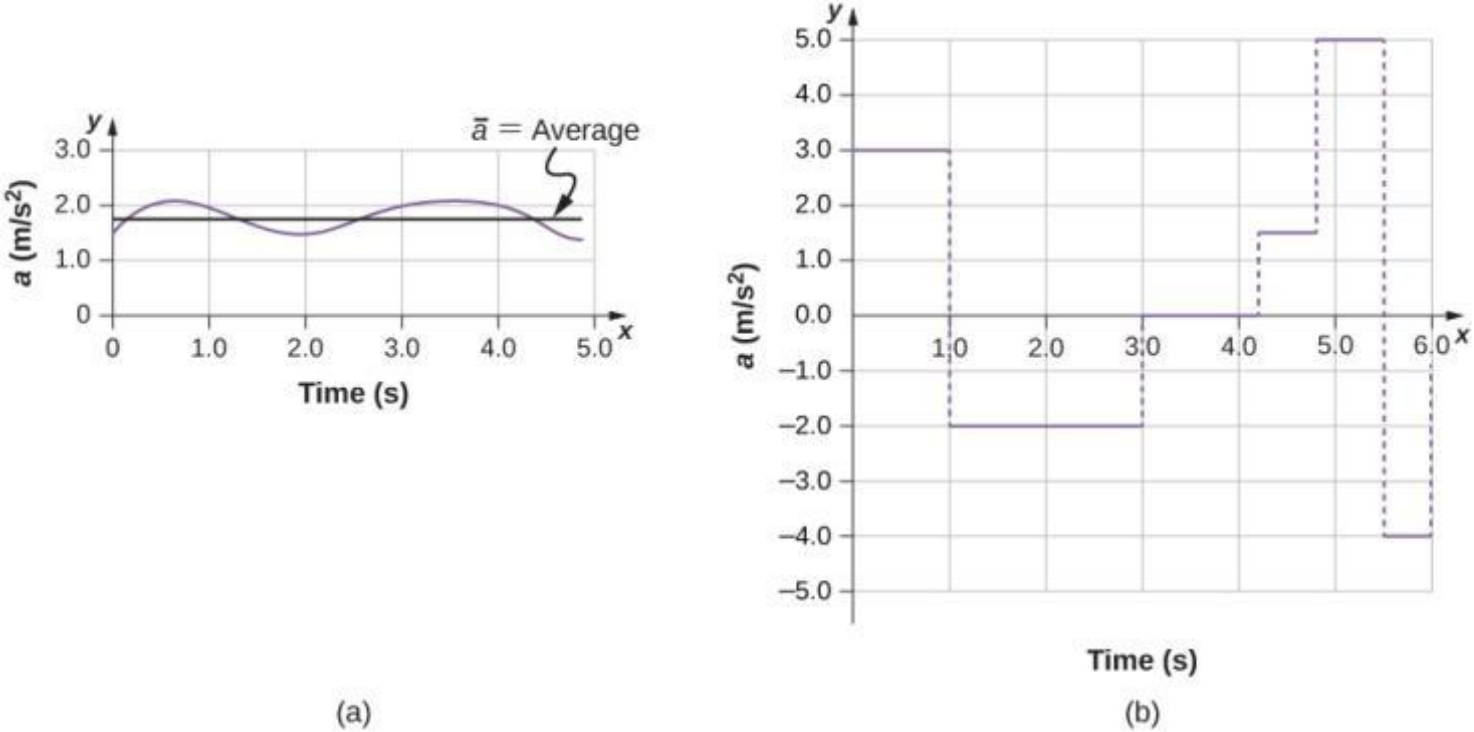
FIGURE 3.16



(a) Velocity versus time. Tangent lines are indicated at times 1, 2, and 3 s. The slopes of the tangents lines are the accelerations. At t = 3 s, velocity is positive. At t = 5 s, velocity is negative, indicating the particle has reversed direction.

(b) Acceleration versus time. Comparing the values of accelerations given by the black dots with the corresponding slopes of the tangent lines (slopes of lines through black dots) in (a), we see they are identical.

FIGURE 3.17

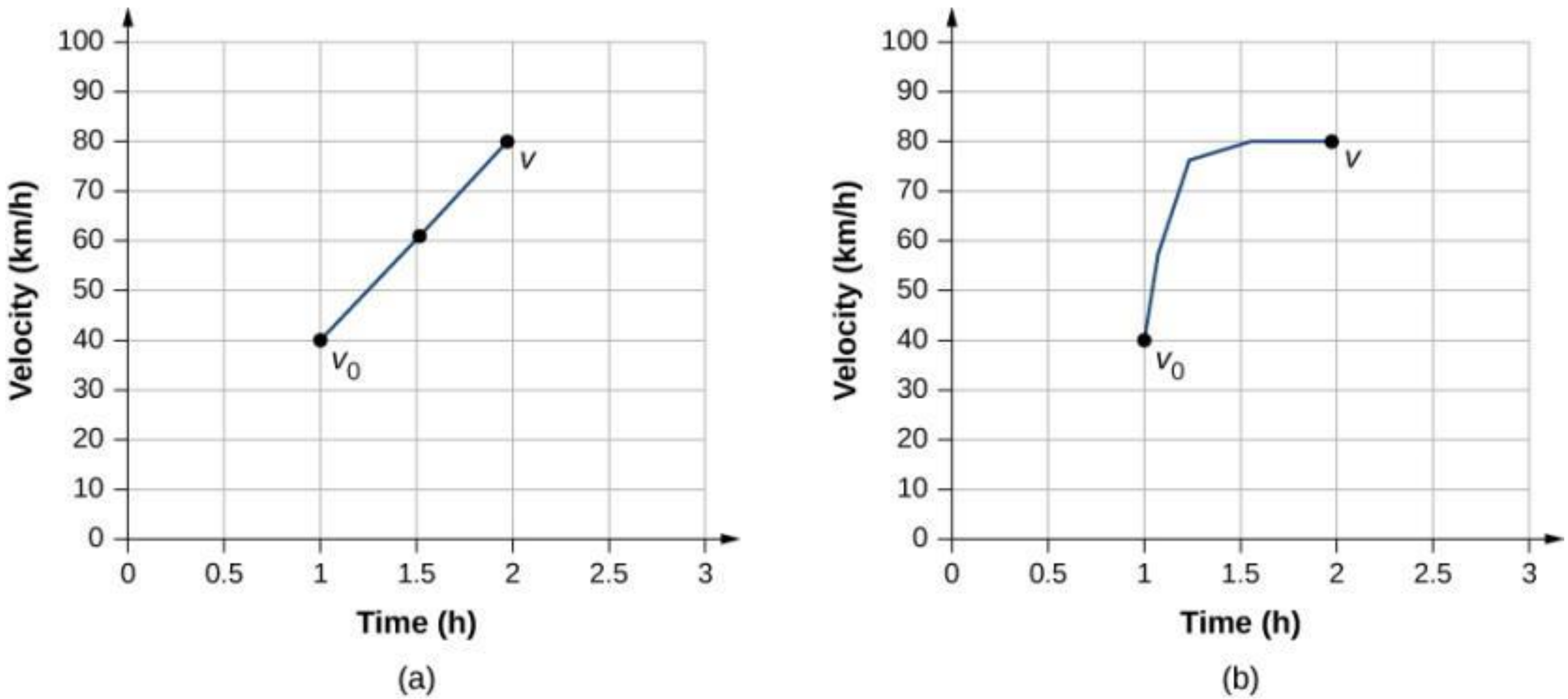


Graphs of instantaneous acceleration versus time for two different one-dimensional motions.

(a) Acceleration varies only slightly and is always in the same direction, since it is positive. The average over the interval is nearly the same as the acceleration at any given time.

(b) Acceleration varies greatly, perhaps representing a package on a post office conveyor belt that is accelerated forward and backward as it bumps along. It is necessary to consider small time intervals (such as from 0–1.0 s) with constant or nearly constant acceleration in such a situation.

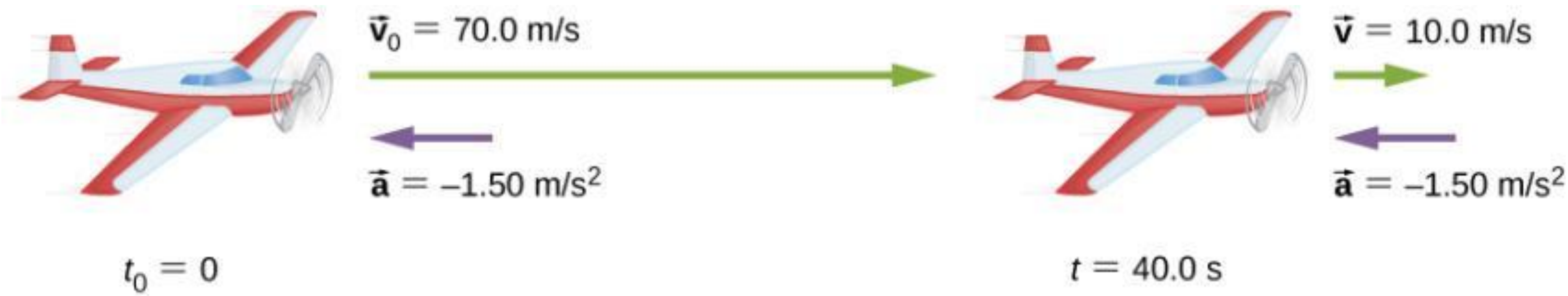
FIGURE 3.18



(a) Velocity-versus-time graph with constant acceleration showing the initial and final velocities v_0 and v. The average velocity is $\frac{1}{2}(v_0 + v) = 60$ km/h.

(b) Velocity-versus-time graph with an acceleration that changes with time. The average velocity is not given by $\frac{1}{2}(v_0 + v)$, but is greater than 60 km/h.

FIGURE 3.19

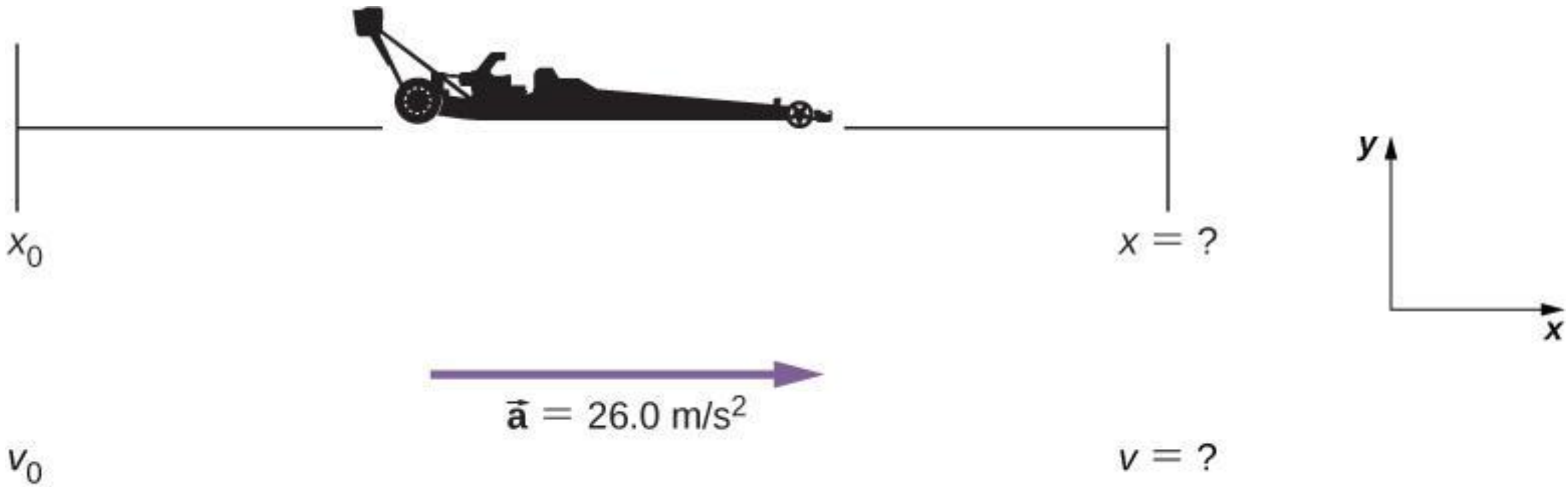


The airplane lands with an initial velocity of 70.0 m/s and slows to a final velocity of 10.0 m/s before heading for the terminal. Note the acceleration is negative because its direction is opposite to its velocity, which is positive.

FIGURE 3.20

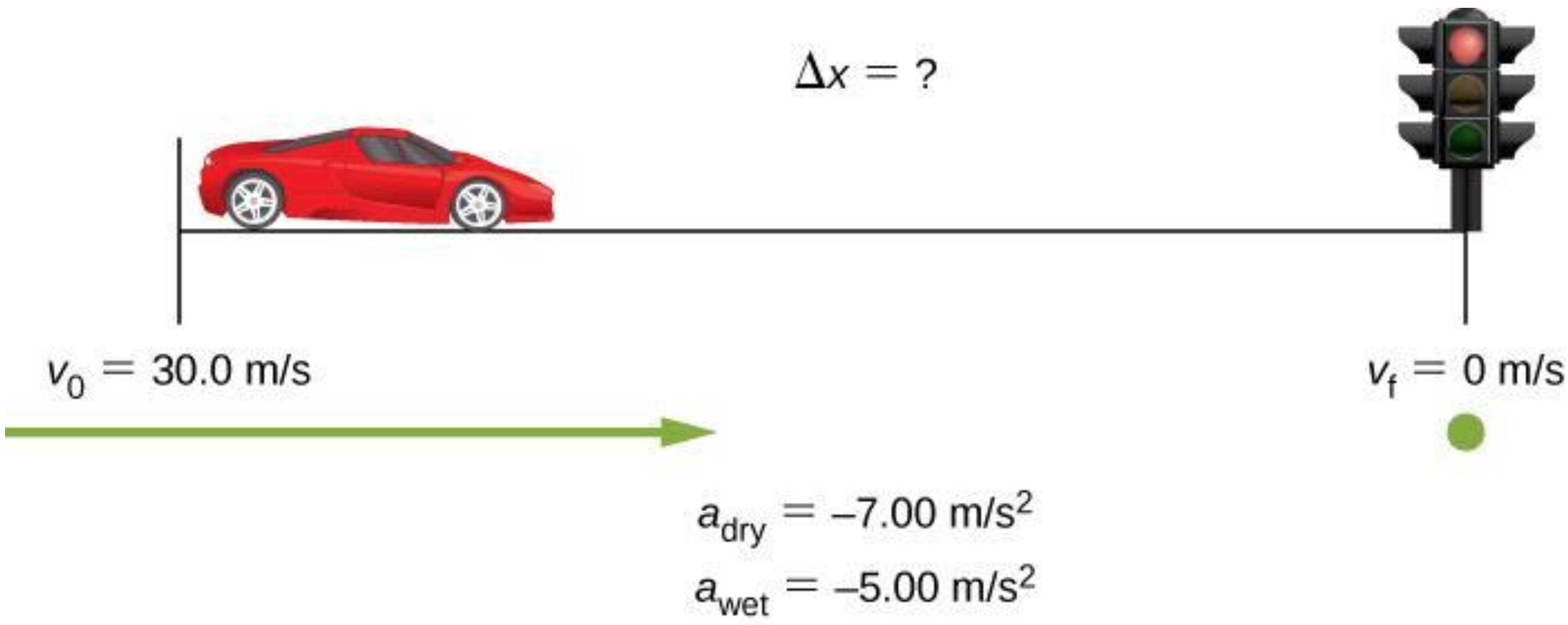
U.S. Army Top Fuel pilot Tony “The Sarge” Schumacher begins a race with a controlled burnout. (credit: Lt. Col. William Thurmond. Photo Courtesy of U.S. Army.)

FIGURE 3.21



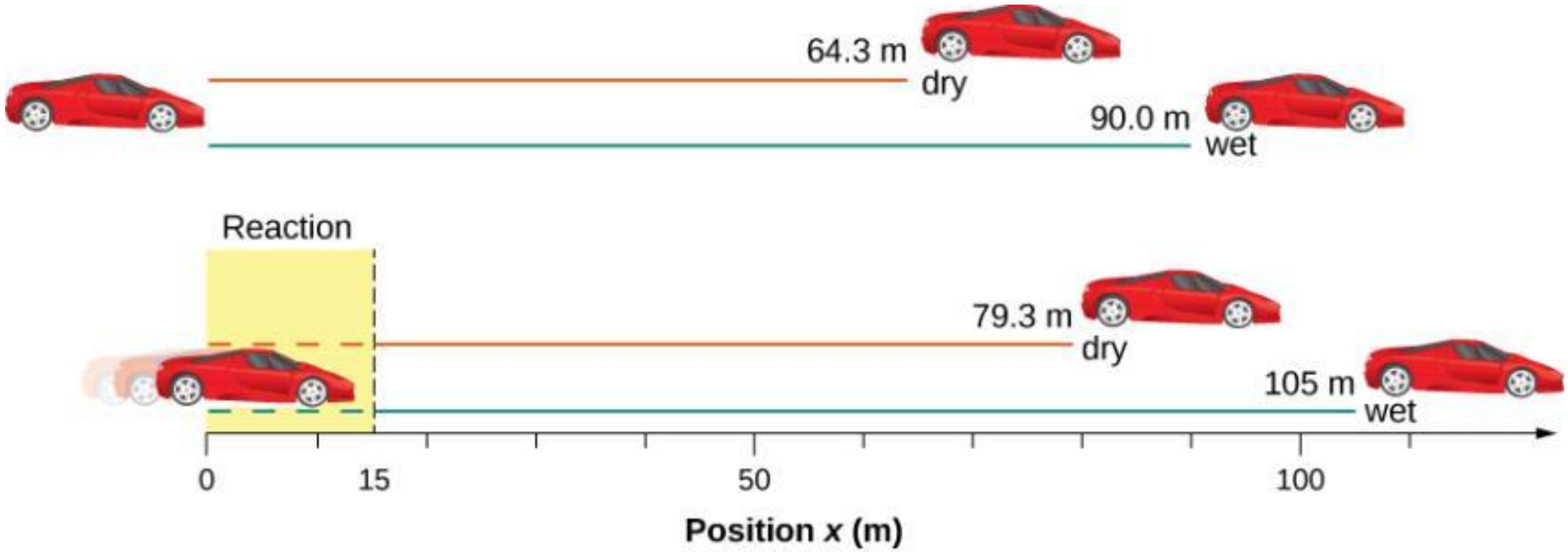
Sketch of an accelerating dragster.

FIGURE 3.22



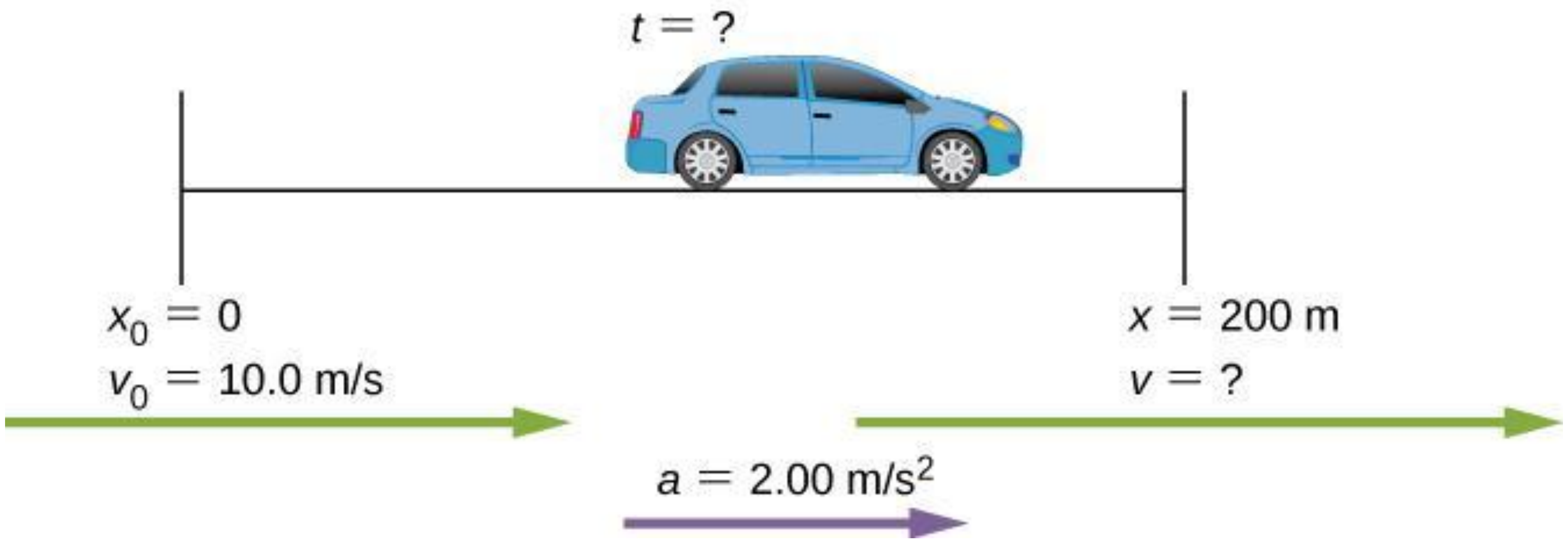
Sample sketch to visualize deceleration and stopping distance of a car.

FIGURE 3.23



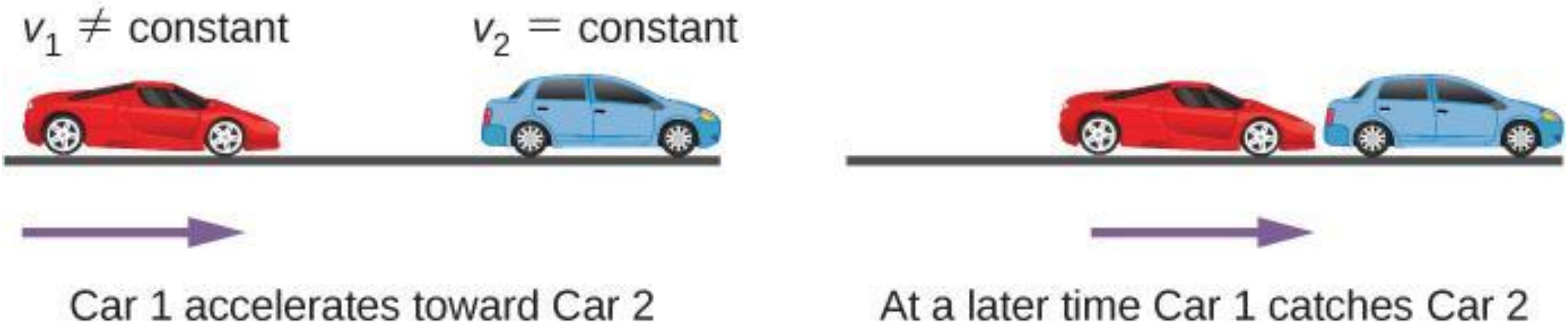
The distance necessary to stop a car varies greatly, depending on road conditions and driver reaction time. Shown here are the braking distances for dry and wet pavement, as calculated in this example, for a car traveling initially at 30.0 m/s. Also shown are the total distances traveled from the point when the driver first sees a light turn red, assuming a 0.500-s reaction time.

FIGURE 3.24



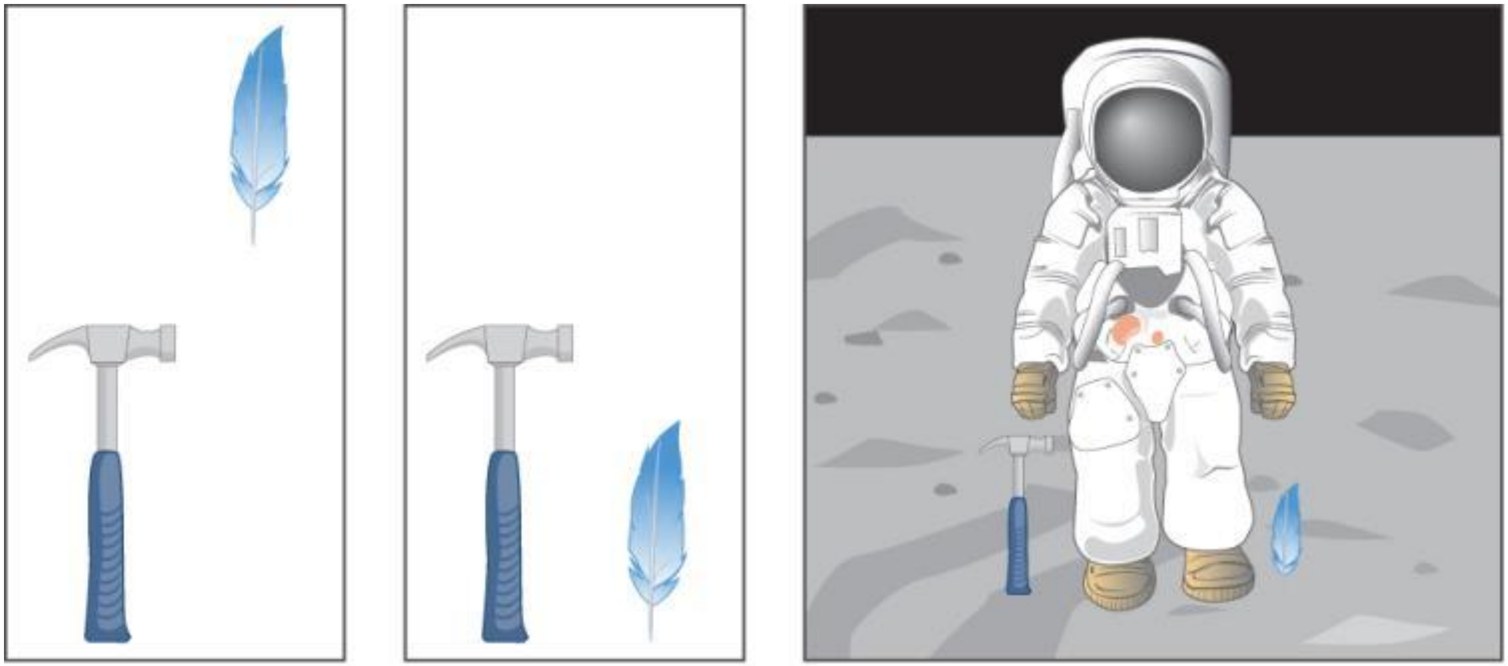
Sketch of a car accelerating on a freeway ramp.

FIGURE 3.25



A two-body pursuit scenario where car 2 has a constant velocity and car 1 is behind with a constant acceleration. Car 1 catches up with car 2 at a later time.

FIGURE 3.26



In air

In a vacuum

In a vacuum (the hard way)

A hammer and a feather fall with the same constant acceleration if air resistance is negligible. This is a general characteristic of gravity not unique to Earth, as astronaut David R. Scott demonstrated in 1971 on the Moon, where the acceleration from gravity is only 1.67 m/s^2 and there is no atmosphere.

FIGURE 3.27

The positions and velocities at 1-s intervals of a ball thrown downward from a tall building at 4.9 m/s.

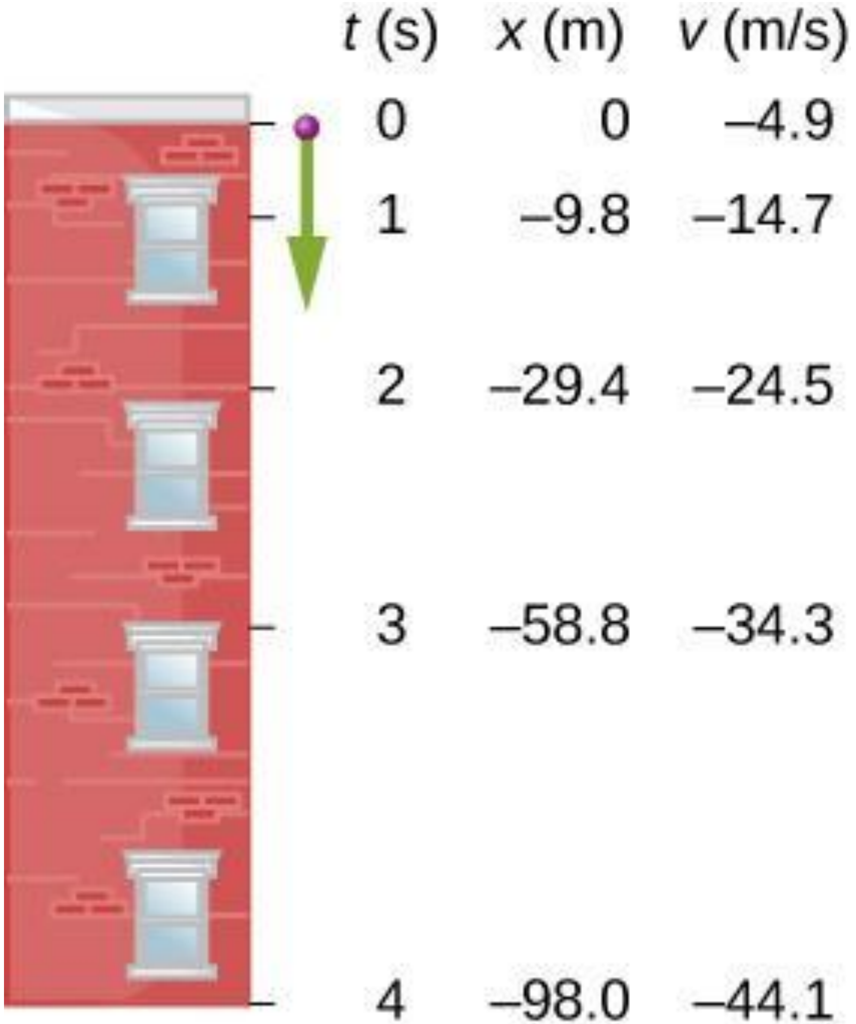
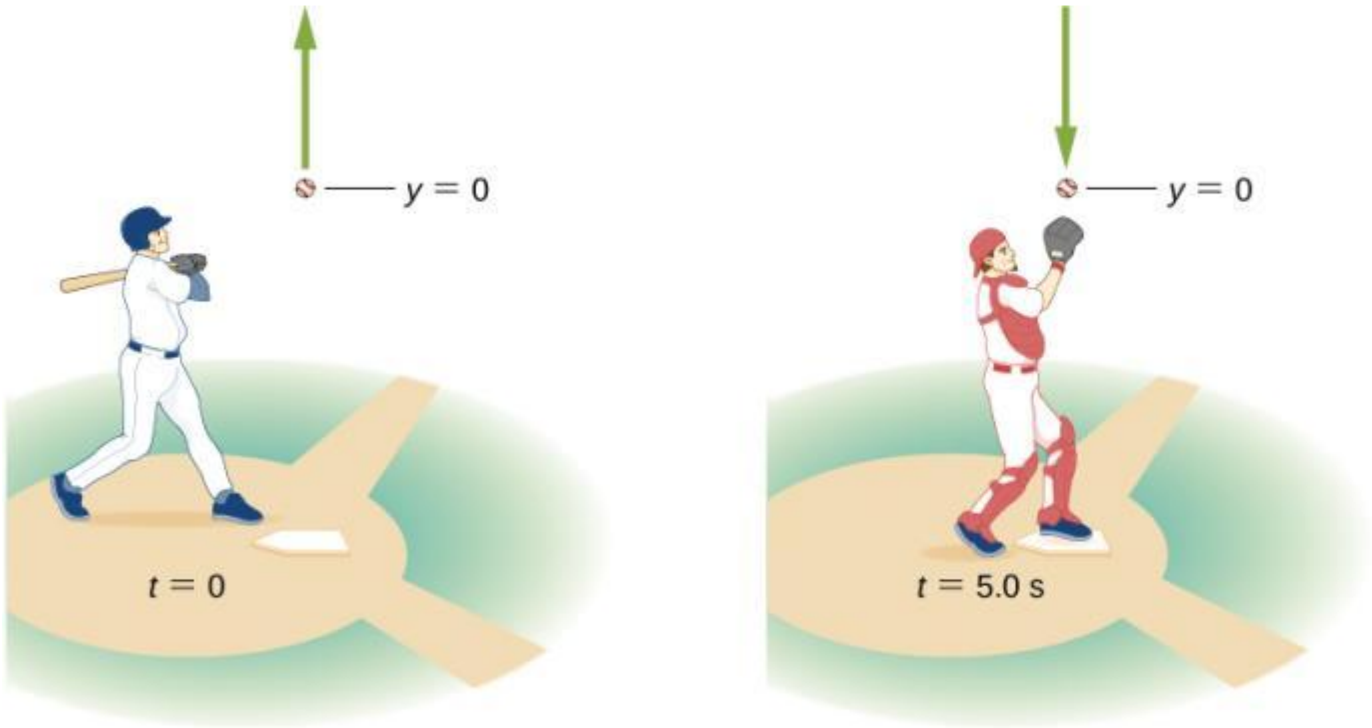
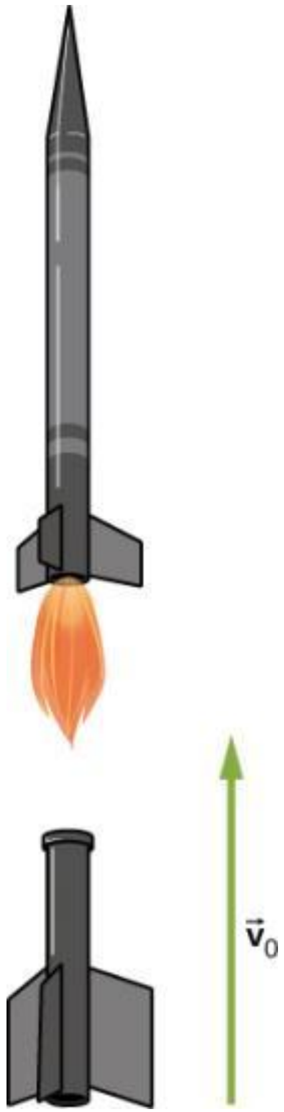


FIGURE 3.28



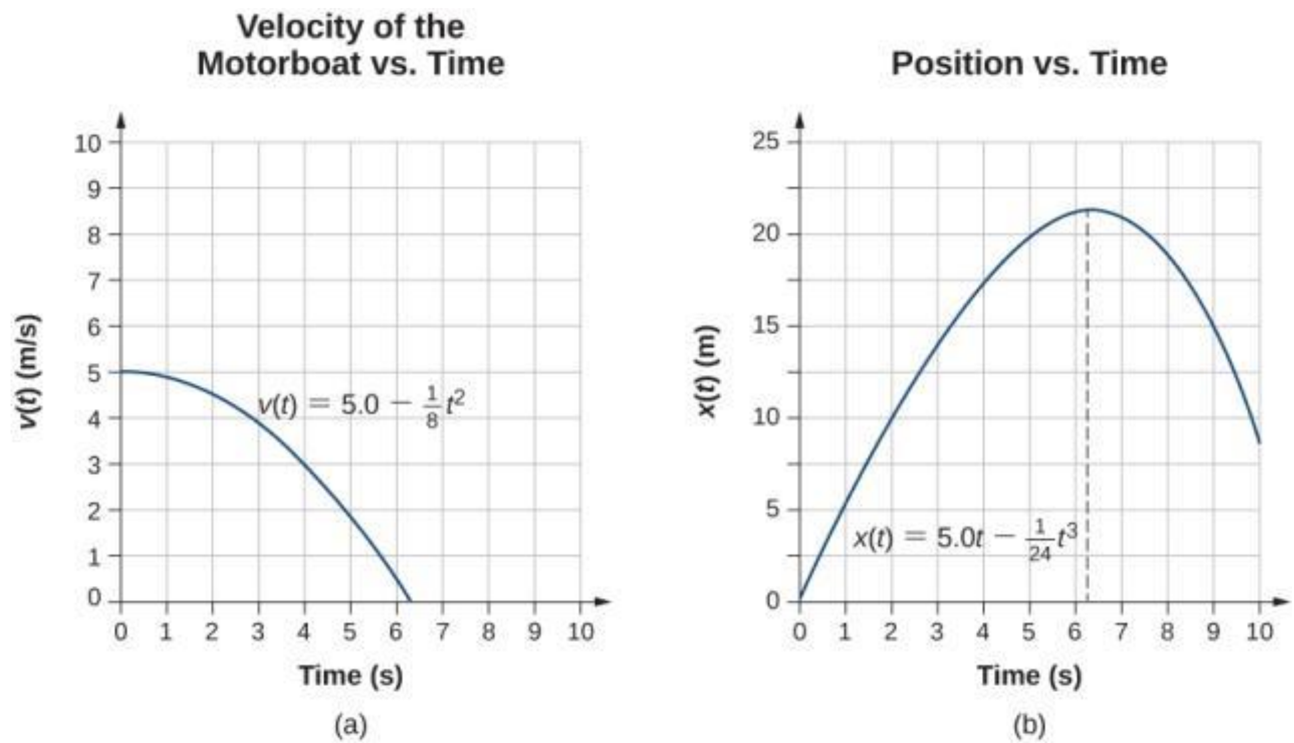
A baseball hit straight up is caught by the catcher 5.0 s later.

FIGURE 3.29



A rocket releases its booster at a given height and velocity. How high and how fast does the booster go?

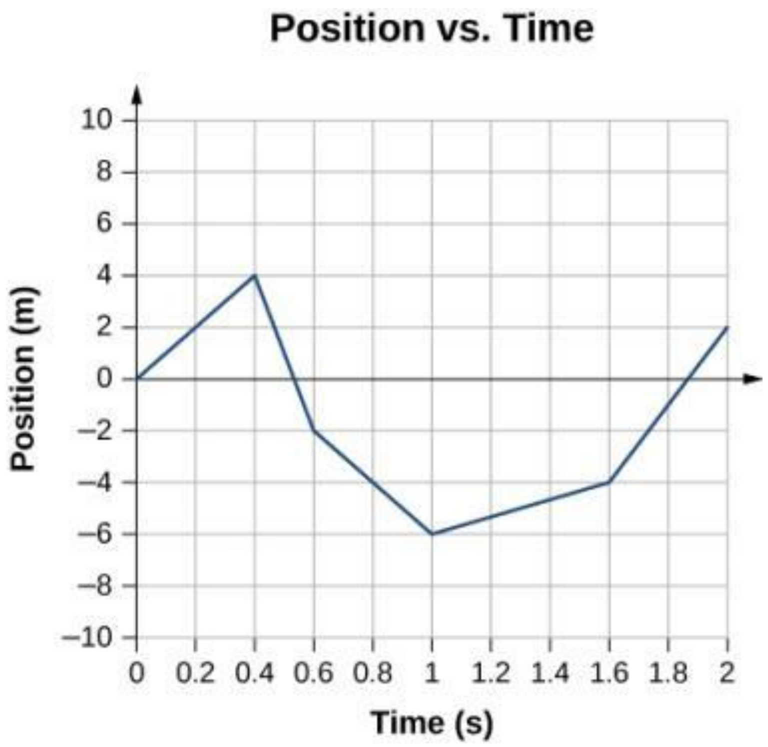
FIGURE 3.30



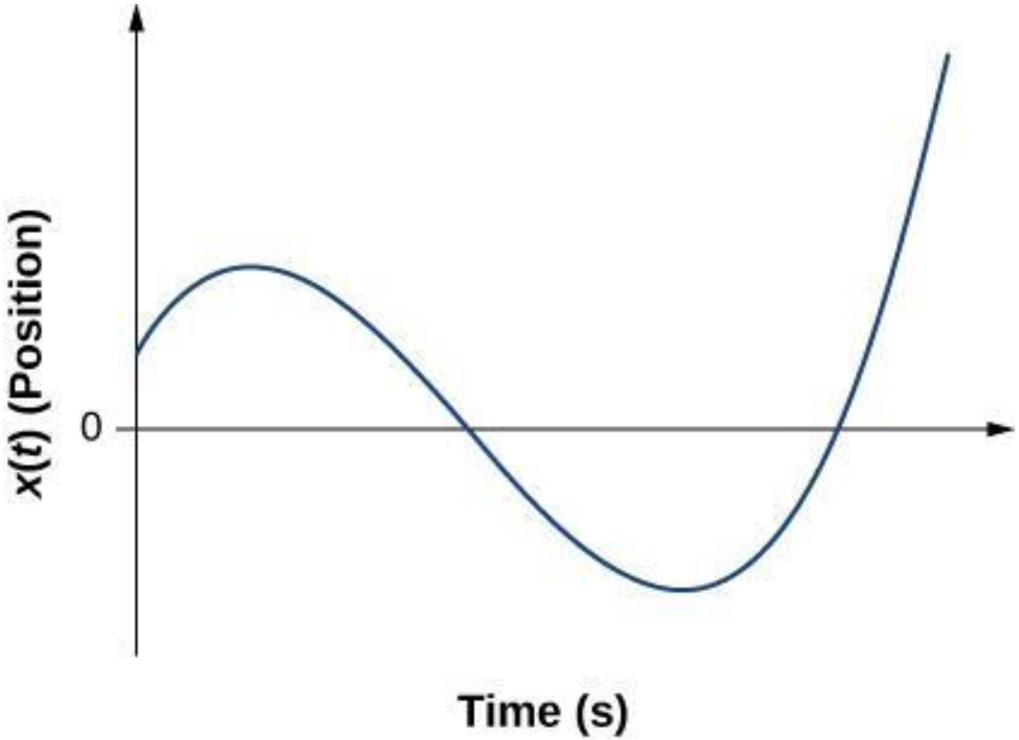
(a) Velocity of the motorboat as a function of time. The motorboat decreases its velocity to zero in 6.3 s. At times greater than this, velocity becomes negative—meaning, the boat is reversing direction.

(b) Position of the motorboat as a function of time. At t = 6.3 s, the velocity is zero and the boat has stopped. At times greater than this, the velocity becomes negative—meaning, if the boat continues to move with the same acceleration, it reverses direction and heads back toward where it originated.

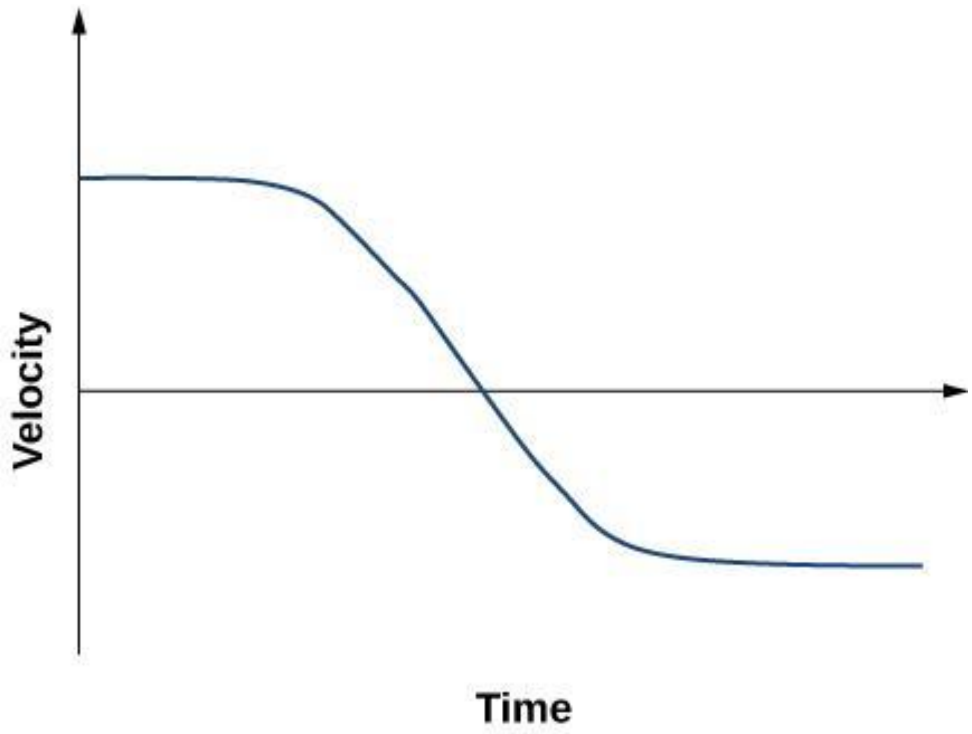
EXERCISE 31


Position vs. Time
10
8
6
4
2
0
−2
−4
−6
−8
−10
Position (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (s)

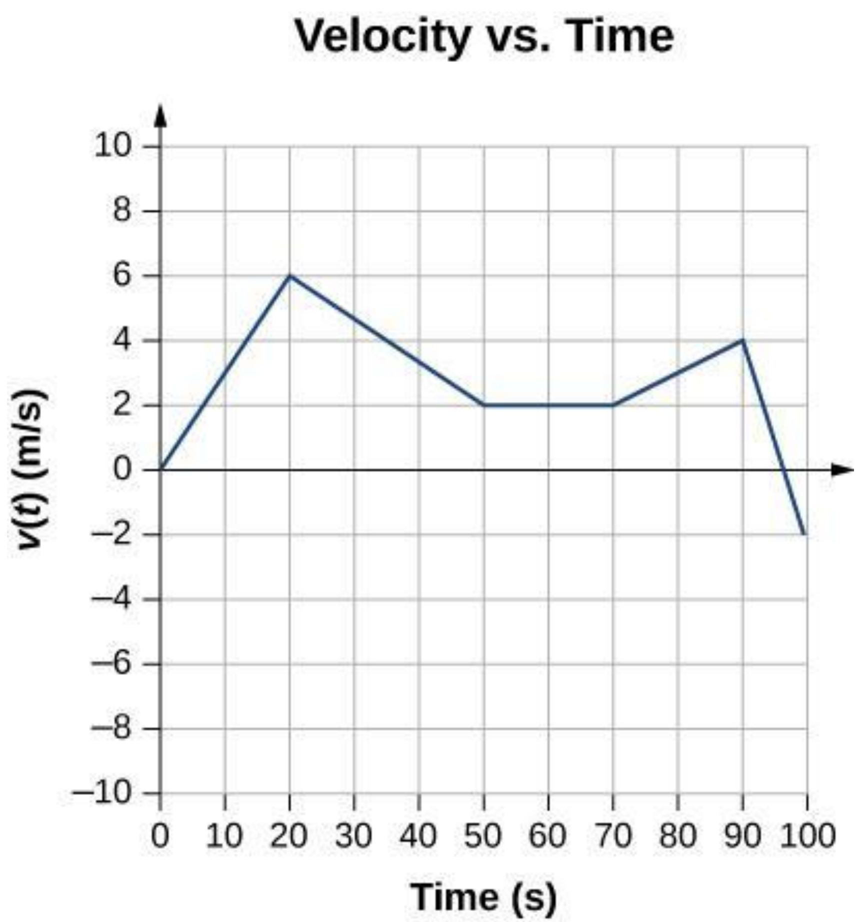
EXERCISE 32



EXERCISE 33

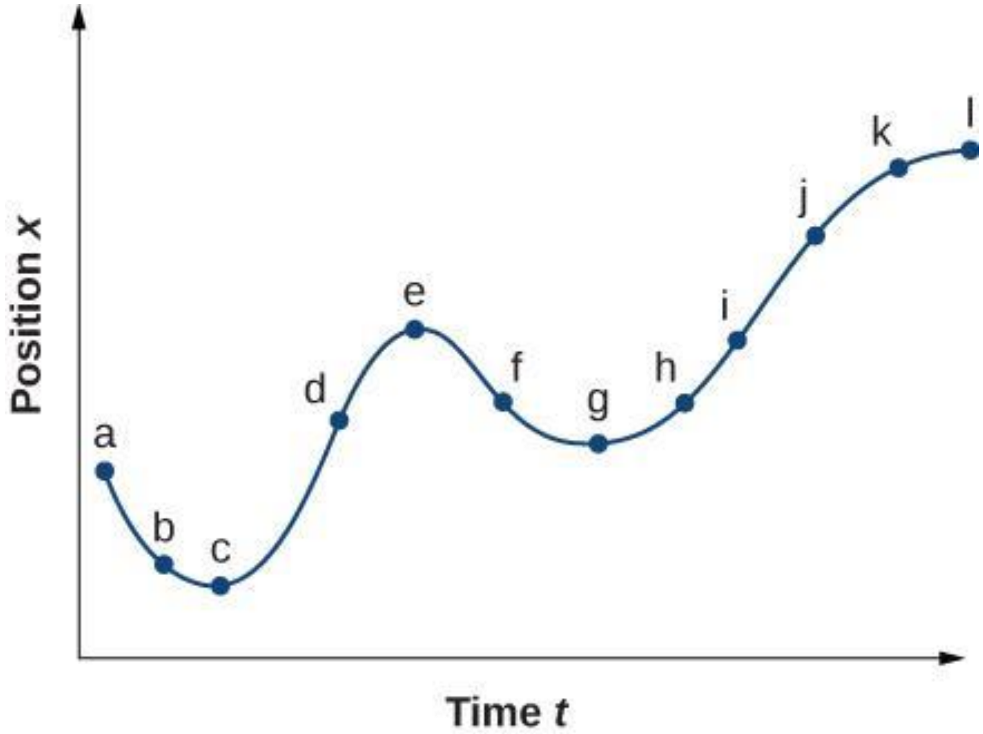


EXERCISE 39

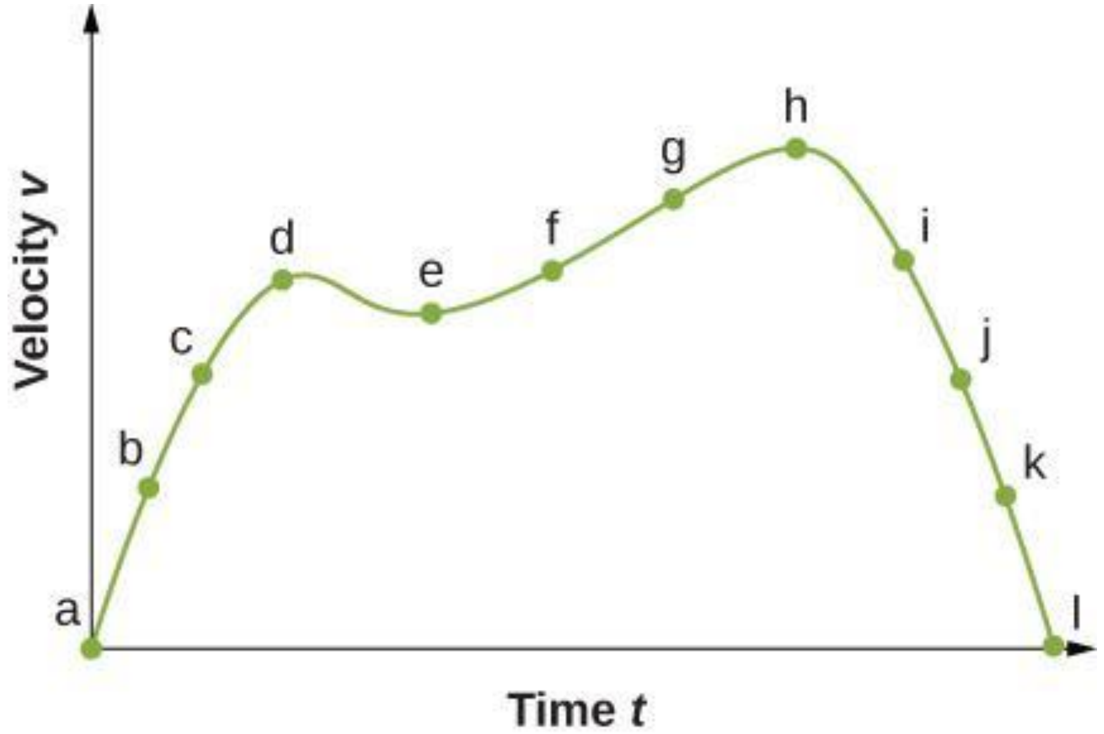


Velocity vs. Time
10
8
6
4
2
0
–2
–4
–6
–8
–10
v(t) (m/s)
0 10 20 30 40 50 60 70 80 90 100
Time (s)

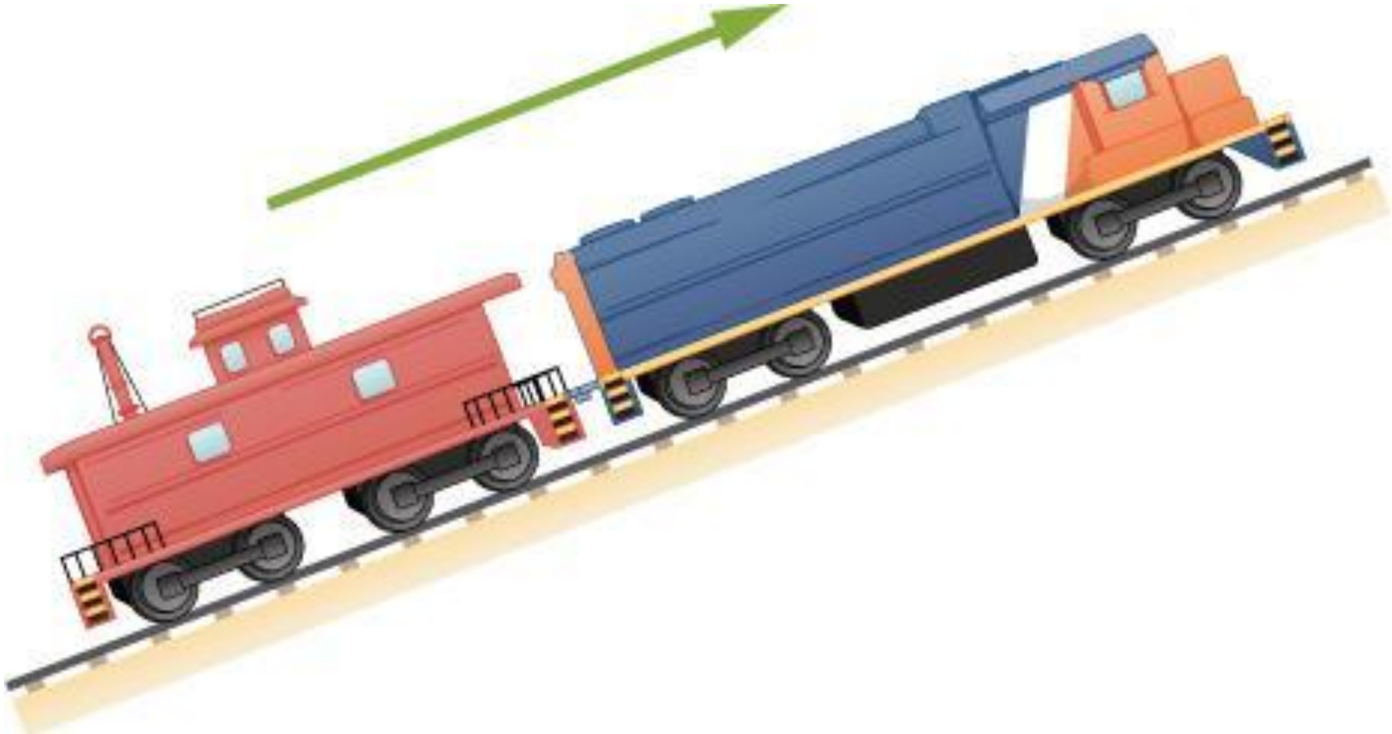
EXERCISE 46



EXERCISE 47



EXERCISE 88



EXERCISE 94