Contents

1   Constant Motion

1.1   Position, Distance, and Displacement

Physical objects—like a person, an asteroid, or an electron—move through physical space. To trace and describe their motion, we use physical properties like position, speed, and acceleration. Position (d) is the location of an object on a fixed axis.

Symbol	Quantity	SI Unit	Unit Symbol
d	position	meter	m

Example 1.1. Consider the position axis below. (a) What is the position of the stick figure? (b) What is the position of the house? (c) What is tree's position?
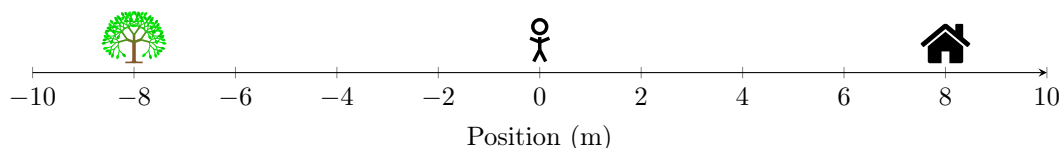

Figure 1.1: A position axis with a person at the origin and a tree and house at different positions.

SOLUTION We read the axis to specify the position of objects. (a) The stick figure's position is zero meters. (b) The house's position is $d = 8$ meters. (c) The tree's position is $d = -8$ m.

END OF SOLUTION

If the person in Example 1.1 moves from the origin to the house, then we can speak of his initial position and final position. Initial position (d_i) is the position of an object at the beginning of its motion, and final position (d_f) is the position at the end of the motion. In this case,

$$d_i = 0\,\text{m} \quad \text{and} \quad d_f = 8\,\text{m}$$

Related to position is distance, a concept all students new to physics are familiar with. Distance is the total length of the path traveled between two positions. For example, if you're walking exactly

one lap around a circular track, your initial and final positions are the same location, but the distance you travel is circumference of the track.

Related to distance and position is displacement. Displacement (Δd) is the straight-line distance and direction from the initial position to the final position. In physics, the Greek letter Δ means "change in," so Δd means "change in position." Displacement on a position axis is calculated by subtracting initial position from final position:

$$\Delta d = d_f - d_i \tag{1.1}$$

Symbol	Quantity	SI Unit	Unit Symbol
Δd	displacement	meter	m
d_f	final position	meter	m
d_i	initial position	meter	m

Example 1.2. Luis takes a trip from the origin to the house. What is his displacement?

SOLUTION We know his initial and final positions: $d_i = 0$ and $d_f = 8\,\text{m}$. By Equation (1.1), his displacement is calculated by

$$\Delta d = d_f - d_i = 8 - 0 = +8\,\text{m}$$

Displacement may also be shown graphically:
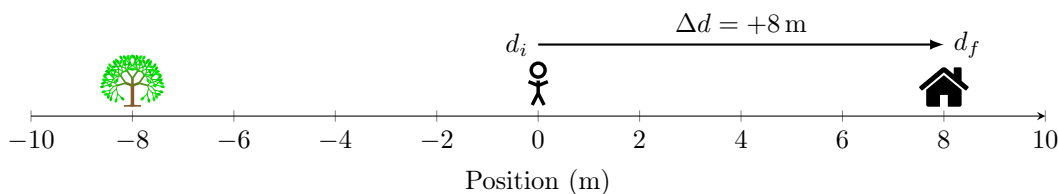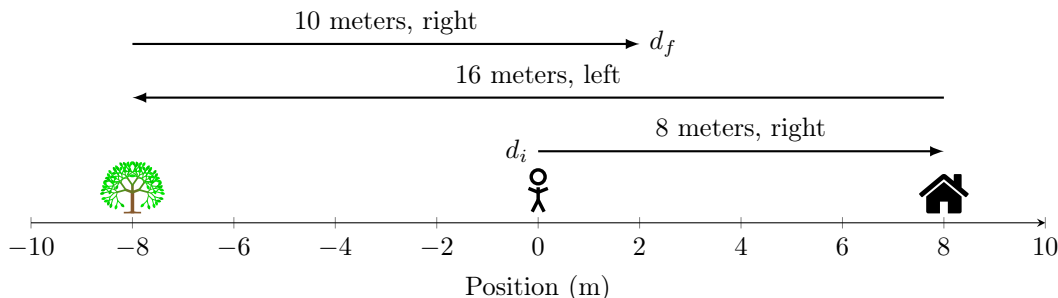

Luis's displacement is positive 8 meters, or 8 meters to the right.

END OF SOLUTION

Example 1.3. Douglas starts at the origin, then moves to the house, then moves to the tree, and finishes 2 meters to **RIGHT** of the origin. (a) What distance does he travel? (b) What is his displacement?

SOLUTION (a) Start by drawing a sketch of his trip and annotating the length of his trips:
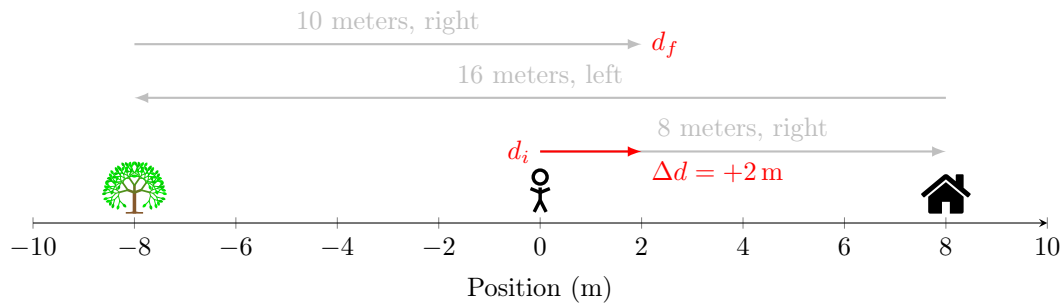
Distance is the length of the path traveled, which is calculated as

$$D = 8 + 16 + 10 = 34\,\text{m}$$

Therefore, Douglas traveled 34 meters.

(b) Draw another sketch of initial and final positions:

Position (m)

From the Figure in part (a), we know his initial position and final position: $d_i = 0$ and $d_f = 2\,\text{m}$. By definition, displacement is
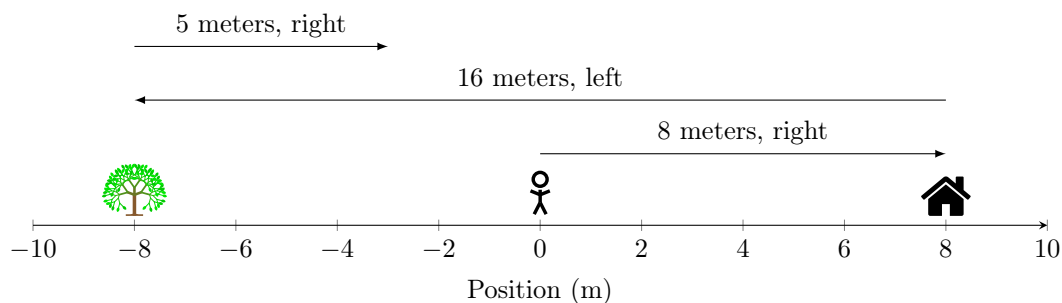
$$\Delta d = d_f - d_i = 2 - 0 = +2\,\text{m}$$

The displacement of Douglas is $+2\,\text{m}$, or 2 meters to the right of the origin.

END OF SOLUTION

Example 1.4. Rodrigo starts at the origin, then moves to the house, then moves to the tree, and finishes 3 meters to **LEFT** of the origin. (a) What distance does he travel? (b) What is his displacement?

SOLUTION (a) First, a sketch of his trip:
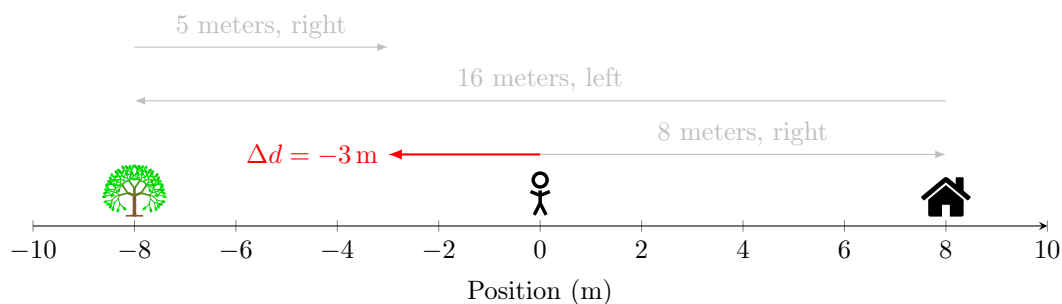

Position (m)

Distance is the length of the path traveled. From the sketch, distance traveled is

$$D = 8 + 16 + 5 = 29\,\text{m}$$

Therefore, Rodrigo travels a distance of 29 meters.

(b) A sketch of initial and final positions:

3

5 meters, right

16 meters, left

8 meters, right

$\Delta d = -3\,\mathrm{m}$

Position (m)

From the Figure in part (a), we know his initial position and final position: $d_i = 0$ and $d_f = -3\,\mathrm{m}$. By definition, displacement is
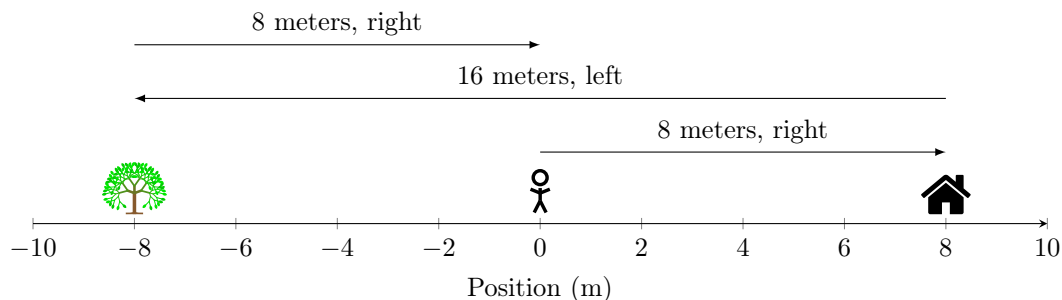
$$\Delta d = d_f - d_i = -3 - 0 = -3\,\mathrm{m}$$

So, Rodrigo's displacement is $-3\,\mathrm{m}$, or 3 meters to the left of the origin.

Example 1.5. Norma starts at the origin, then moves to the house, then moves to the tree, and finishes at the origin. (a) What distance does Norma travel? (b) What is her displacement?

SOLUTION (a) Total distance is $\mathrm{D} = 8 + 16 + 8 = 32\,\mathrm{m}$

8 meters, right

16 meters, left

8 meters, right

Position (m)

(b) From the figure in part (a) Norma's initial and final positions are $d_i = 0$ and $d_f = 0$. Displacement is

$$\Delta d = d_f - d_i = 0$$

Norma's displacement is zero because she finished at the same position at which she started (the origin).

Magnitude means size or amount. A scalar is a quantity with magnitude but no direction, and a vector is a quantity with both magnitude *and* direction. Distance is a scalar, and displacement is a vector. That's why, in previous examples, direction of displacement was always indicated by numerical sign or by left/right direction. In Example 1.3(b) the magnitude of displacement is 2 meters, and in Example 1.4 the magnitude of displacement is 3 meters, since signs are dropped when expressing magnitude only. As a scalar, distance has no direction and, therefore, no sign.

Example 1.6. (*Example 1.3 Revisited.*) Suppose that we could not see the position axis in Example 1.3 but instead only knew about Douglas's three movements: he goes 8 meters to the right, 16 meters to the left, and 10 meters to right. Calculate total displacement given this information.
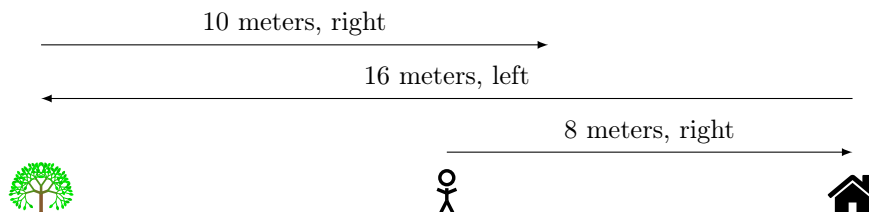
SOLUTION Assume the direction to the right is positive. To calculate displacement from a series of positive (rightward) and negative (leftward) movements, we need to take the "vector sum," which means that we should make rightward movements positive, make leftward movements negative, and sum them up in the following way:

$$\Delta d = +8 - 16 + 10 = +2$$

Without a position axis, we arrive at the same result from Example 1.3: displacement is $+2$ m.

<div align="right">END OF SOLUTION</div>

1.2 Speed and Velocity

Speed is the rate at which object changes position, or how fast or slow an object moves. Speed is a scalar. Average speed is distance divided by time:

$$\text{speed} = \frac{\text{distance}}{\text{time}} \quad \text{or} \quad S = \frac{D}{T} \tag{1.2}$$

Example 1.7. A marble rolls down a ramp a distance of 5.2 meters in a time interval of 1.8 seconds. What is the marble's average speed?

SOLUTION We are given distance and time $D = 5.2\,\text{m}$ and $T = 1.8\,\text{s}$ The marble's average speed is

$$S = \frac{D}{T} = \frac{5.2\,\text{m}}{1.8\,\text{s}} = 2.9\,\text{m/s}$$

<div align="right">END OF SOLUTION</div>

Example 1.8. Milo the cat walks at a speed of $3.2\,\text{m/s}$ for $40\,\text{s}$. How far did he travel?

SOLUTION We are given speed and time: $S = 3.2\,\text{m/s}$ and $T = 40\,\text{s}$. The unknown we are looking for is distance: $D = ?$

The given and unknown quantities are related by Equation (1.2):

$$S = \frac{D}{T}$$

Substituting the given values leads to

$$3.2 = \frac{D}{40}$$

We must solve this equation for distance, D. This goal is accomplished through the following algebraic steps:

Write D on left	$\frac{D}{40} = 3.2$
Multiply by 40	$\frac{D}{\cancel{40}} \times \cancel{40} = 3.2 \times 40$
Simplify	$D = 3.2 \times 40$
Simplify	$D = 128$

Therefore, Milo walked a distance of 128 meters.

<div align="right">END OF SOLUTION</div>

Elapsed time is a change in time, or a time interval. It's calculated as final time minus initial time:

$$\Delta t = t_f - t_i \tag{1.3}$$

Symbol	Quantity	Base SI Unit	Unit Symbol
Δt	elapsed time	second	s
t_f	final time	second	s
t_i	initial time	second	s

Velocity is the speed *and* direction of an object at an instant in time. Because it specifies direction, velocity is a vector and can be numerically negative.

Motion occurs not at an instant in time but over a time interval. Velocity is related to time by the quantity known as average velocity. Average velocity is displacement divided by an elapsed time:

$$\bar{v} = \frac{\text{displacement}}{\text{time}} = \frac{\Delta d}{\Delta t} \tag{1.4}$$

Symbol	Quantity	SI Base Unit	Unit Symbol
$\bar{v}$	average velocity	meter per second	m/s
Δd	displacement	meter	m
Δt	elapsed time	second	s

Example 1.9. Otto travels north, then south, as shown below. Assume that north is the positive direction. If his trip takes a total of 180 seconds, what is Otto's average velocity?
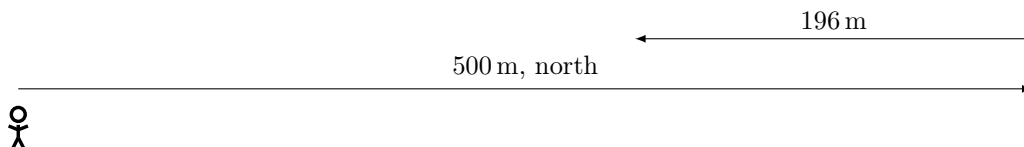
196 m

500 m, north

SOLUTION In Example 1.6, we used the "vector sum" method to find total displacement from smaller displacements. Using the same method, Otto's total displacement is

$$\Delta d = +500 - 196 = +304$$

or 304 meters north. We are also given elapsed time: $\Delta t = 180\,\text{s}$. The unknown is average velocity: $\bar{v} = ?$ The given and unknown quantities are related by Equation (1.4) as

$$\bar{v} = \frac{\Delta d}{\Delta t}$$

Substituting known values leads to

$$\bar{v} = \frac{304}{180} = 1.69$$

Therefore, Otto's average velocity is 1.69 meters north, or $+1.69\,\text{m}$.

END OF SOLUTION

Example 1.10. How long will it take Phillip to get to school if he walks 428 meters west in a straight line with an average velocity of $1.7\,\text{m/s}$ west?

SOLUTION We are given displacement and average velocity: $\Delta d = 428\,\text{m}$ west and $v = 1.7\,\text{m/s}$ west. We are solving for elapsed time, Δt. These quantities are related by average velocity:

$$v = \frac{\Delta d}{\Delta t}$$

Substituting the given values leads to

$$1.7 = \frac{428}{\Delta t}$$

We can solve this equation for elapsed time, Δt, as follows:

$$\textbf{Multiply by } \Delta t \qquad 1.7 \times \Delta t = \frac{428}{\Delta t} \times \Delta t$$

$$\textbf{Simplify} \qquad 1.7\,\Delta t = 428$$

$$\textbf{Divide by 1.7} \qquad \frac{1.7\,\Delta t}{1.7} = \frac{428}{1.7}$$

$$\textbf{Simplify} \qquad \Delta t = \frac{428}{1.7}$$

$$\textbf{Simplify} \qquad \Delta t = 252$$

Therefore, Phillip's elapsed time to school is $252\,\text{s}$ (about 4 minutes).

END OF SOLUTION

1.3 Position vs. Time Graphs

In algebra the vertical axis is called the "y-axis," and the horizontal axis is called the "x-axis." Thus, a position vs. time graph in physics is a graph with position plotted on the y-axis and time on the x-axis. In position vs. time graphs, initial and final positions and times can be read at a variety of instances.

Example 1.11. The position vs. time graph below represents the constant motion of Woody, the dog, walking down the street. Use the coordinates to find (a) Woody's initial position and (b) his final position throughout the time interval.
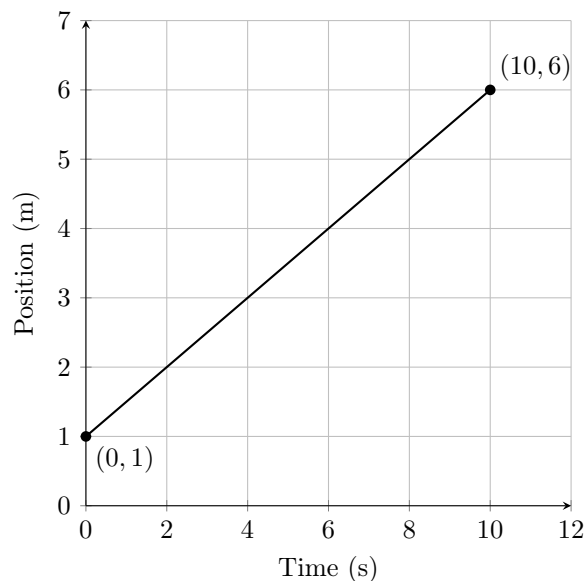

Figure 1.3: A position vs. time graph representing constant motion (that is, constant speed).

SOLUTION (a) The first given coordinate is $(0,1)$. Since time is on the x-axis and position is on the y-axis, the coordinate $(0,1)$ means that at a time of 0 seconds, Woody's (initial) position is at 1 meter. Therefore, his initial position is

$$d_i = 1\,\text{m}$$

(b) Likewise, the second coordinate $(10,6)$ indicates that at a time of 10 seconds, his position changed to 6 meters, so his final position is

$$d_f = 6\,\text{m}$$

The straight line between these 2 coordinates on a position vs. times graph signify that Woody traveled with *constant* motion—that is, with a constant speed or velocity.

END OF SOLUTION

Example 1.12. Calculate the displacement of Woody, from Example 1.11.

SOLUTION In Example 1.11, we interpreted the position vs. time graph (Figure 1.3) as indicating that Woody's initial and final positions are

$$d_i = 1\,\text{m} \quad \text{and} \quad d_f = 6\,\text{m}$$

By Equation (1.1), therefore, his displacement is

$$\Delta d = d_f - d_i = 6 - 1 = 5$$

Therefore, Woody's displacement across the 10-second time interval, is 5 meters.

END OF SOLUTION

Example 1.13. Calculate the average velocity of Woody, from Example 1.11.

SOLUTION As noted in Example 1.11, the straight line between the end points indicates that Woody travels with constant motion, or constant velocity. Thus, even though the graph is labeled "position vs. time," it is nevertheless possible to calculate speed and velocity information. In Example 1.12, we calculated that Woody's displacement is 5 meters:

$$\Delta d = 5\,\text{m}$$

Furthermore, from Figure 1.3, the time interval during the displacement is 10 seconds:
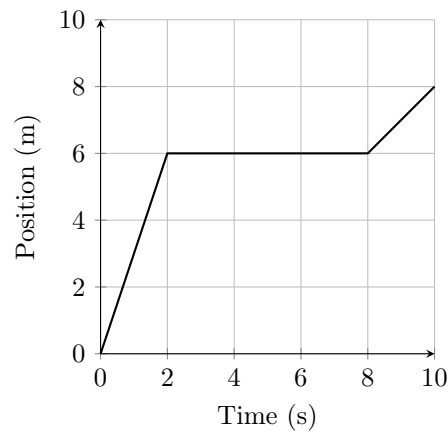
$$\Delta t = 10\,\text{s}$$

Therefore, by Equation (1.4), the average velocity is displacement divided by elapsed time:

$$\bar{v} = \frac{\Delta d}{\Delta t} = \frac{5}{10} = 0.5$$

Woody's average velocity is 0.5 meters per second.

END OF SOLUTION

Example 1.14. Consider the position vs. time graph below, which describes the motion of a pedestrian over time. What is the pedestrian's displacement across the entire time interval?

We are given the pedestrian's initial position, final position, and elapsed time: $d_i = 0\,\mathrm{m}$, $d_f = 8\,\mathrm{m}$, and $\Delta t = 10\,\mathrm{s}$. The unknown is displacement. By Eq. (1.1), displacement is

$$\Delta d = d_f - d_i = 8 - 0 = 8\,\mathrm{m}$$

The pedestrian's displacement is 8 meters from the origin.

Example 1.15. For the graph in Example 1.14, calculate the pedestrian's average velocity in the last 2 seconds of motion.

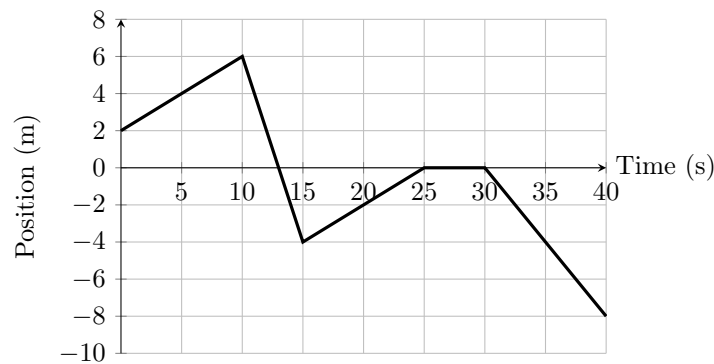We are given initial and final positions and initial and final times for the last 2 seconds of motion: $d_i = 6\,\mathrm{m}$, $d_f = 8\,\mathrm{m}$, $t_i = 8\,\mathrm{s}$, and $t_f = 10\,\mathrm{s}$. The unknown is average velocity during this time interval: $\bar{v} = ?$ By Eq. (1.4), average velocity is

$$\bar{v} = \frac{d_f - d_i}{t_f - t_i} = \frac{8 - 6}{10 - 8} = 1\,\mathrm{m/s}$$

The pedestrian's average velocity is 1 meter per second.

Example 1.16. Calculate average velocity in the graph below for time elapsed from 10 seconds to 40 seconds.

From the graph, which seems complicated, we simply see that we are given initial and final positions and initial and final times from 10 to 40 seconds:

$$d_i = 6\,\mathrm{m}\ , \quad d_f = -8\,\mathrm{m}\ , \quad t_i = 10\,\mathrm{s}\ , \quad t_f = 40\,\mathrm{s}$$

The unknown is average velocity across this time interval: $\bar{v} = ?$ The given and unknown quantities are related by Equation (1.4),

$$\bar{v} = \frac{\Delta d}{\Delta t} = \frac{d_f - d_i}{t_f - t_i}$$

Substituting given values leads to

$$\bar{v} = \frac{-8 - 6}{40 - 10}$$

This simplifies to

$$\bar{v} = \frac{-14}{30} = -0.47 \, \text{m/s}$$

The average velocity is -0.47 meters per second, or 0.47 meters per second to the left.

1.4   Velocity vs. Time Graphs

A velocity vs. time graph is like a position vs. times graph but with velocity on the y-axis. These v vs. t graphs show when objects speed up, slow down, or move at a constant speed. This entire unit has involved objects traveling at constant or zero velocity. In the next unit, we will explore objects that change velocity over time. But first, let's revisit the average velocity equation.

Example 1.17. Solve the average velocity equation (1.4) algebraically for displacement.

SOLUTION Recall that, by Equation (1.4), average velocity is displacement over time:

$$\bar{v} = \frac{\Delta d}{\Delta t}$$

We solve for displacement Δd as follows:

$$\textbf{Write } \Delta d \textbf{ on left} \qquad \frac{\Delta d}{\Delta t} = \bar{v}$$

$$\textbf{Multiply by time} \qquad \frac{\Delta d}{\cancel{\Delta t}} \times \cancel{\Delta t} = \bar{v} \times \Delta t$$

$$\textbf{Simplify} \qquad \Delta d = \bar{v} \, \Delta t$$

Therefore, displacement is average velocity multiplied by time:

$$\Delta d = \bar{v} \, \Delta t \tag{1.5}$$

That is, displacement is the product of average velocity and time. This idea plays an essential role in velocity vs. times graphs and in the next example.

Example 1.18. The velocity vs. time graph below represents the motion of a golf cart traveling at a constant 15 meters per second over a time interval of 6 seconds. What is the cart's displacement throughout the time interval?
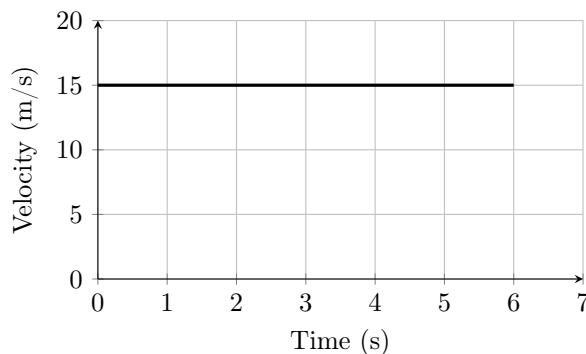

11

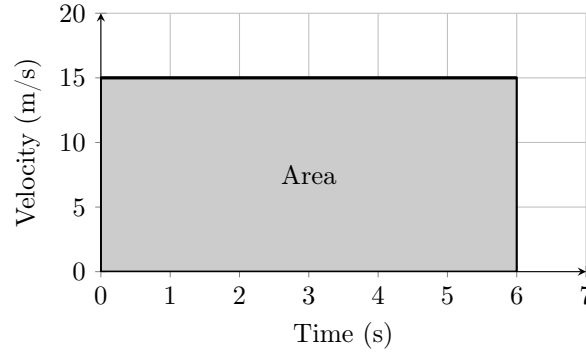SOLUTION Do you see how the line graph bounds a rectangular area, as shown below?

Figure 1.5: The area of a rectangle is bounded by a constant-velocity line graph.

The area of a rectangle is length multiplied by width:

$$A = lw \tag{1.6}$$

Because the "width" of the rectangle in Figure 1.5 is velocity and the "length" is time, the area must be velocity multiplied by time. But according to Equation (1.5), the product of velocity and time is displacement. Therefore, by calculating the area of the rectangle, we are simultaneously calculating the gold cart's displacement. This becomes more apparent when you compare Equations (1.6) and (1.5).

The width is a velocity of $15\,\text{m/s}$, and the length is a time of $6\,\text{s}$. So, the area of the rectangle is
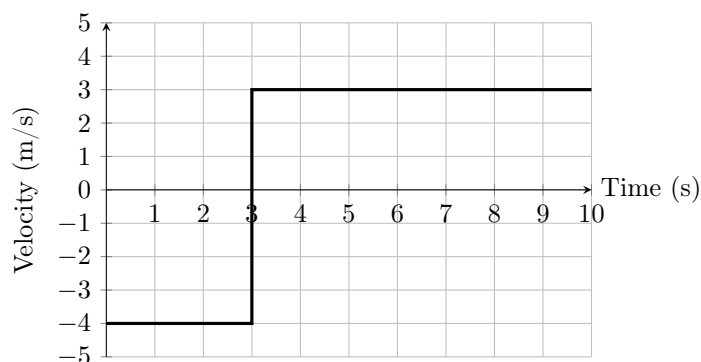
$$A = 6 \times 15 = 90$$

Therefore, the object's displacement is 90 meters to the right of the origin. Although "displacement" does not appear in the title of a "velocity vs. time" graph, it is nevertheless possible to calculate displacement information from these graphs.

END OF SOLUTION

The idea discovered in Example 1.18 that displacement is the area under a velocity vs. times graph is not unique to rectangles: the area bounded by any shape under the graph is displacement.

> **The area bounded by a curve in a velocity vs. time graph is displacement.**

Example 1.19. A golf ball rolls to the left at a constant speed, strikes a wall after 3 seconds, and rolls in the opposite direction at a constant but slower speed. It's motion is described in the graph below. What is the ball's displacement from it's original position across its 10 seconds of motion?

Two rectangles of areas A_1 and A_2 are bounded by the curve:
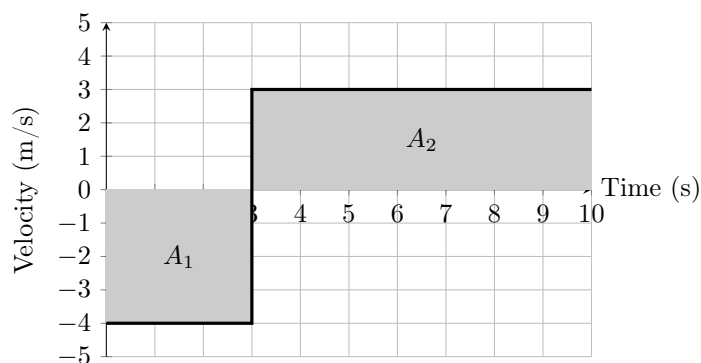
Note that since the first rectangle is below the time axis (x-axis), in the negative velocity region, A_1 is a numerically negative area[1]. This solution develops like Example 1.18.

The length and width of A_1 are 3 and -4, respectively, so by Equation (1.6) the area is

$$A_1 = lw = 3 \times (-4) = -12$$

Thus, area A_1 represents a displacement of -12 meters, which is consistent with the fact that the ball initially moves to the left. The second rectangle has a length of 7, since time elapsed from 3 to 10 seconds, and a width of 3, so the area is

$$A_2 = 7 \times 3 = 21$$

or a displacement of 21 meters to the right. The total displacement is found by summing the two areas as

$$A = A_1 + A_2 = -12 + 21 = 9$$

The golf ball traveled a total distance of 33 meters ($12 + 21$), but since it moved first to the left and then to the right, its overall displacement from the origin is 9 meters to the right.

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[1]Technically, in geometry areas cannot be negative, but we will ignore that fact for now.

1.5   Momentum and Kinetic Energy

So far, we have defined the following physical quantities: position, distance, displacement, time, speed and velocity. Now we will define three more quantities—momentum and kinetic energy, both of which depend on a third quantity, mass. Mass is the quantity of matter in a substance and is measured in kilograms (kg).

Momentum (p) is the product of a system's mass and its velocity:

$$p = mv \tag{1.7}$$

The SI units of momentum are the kilogram-meter per second ($\mathrm{kg\,m/s}$).

Symbol	Quantity	SI Unit	Unit Symbol
p	momentum	kilogram meter per second	$\mathrm{kg\,m/s}$
m	mass	kilogram	kg
v	velocity	meter per second	m/s

Equation (1.7) suggests that momentum is directly proportional to the object's mass (m) and velocity (v). Therefore, the greater an object's mass or the greater its velocity, the greater its momentum. A large, fast-moving object has greater momentum than a smaller, slower object.

Example 1.20. Calculate the momentum of a 110-kg football player running at $8\,\mathrm{m/s}$.

SOLUTION We are given mass and velocity: $m = 110\,\mathrm{kg}$ and $v = 8\,\mathrm{m/s}$. We want to find momentum: $p = ?$ By Eq. (1.7), momentum is mass times velocity:

$$p = mv = (110)(8) = 880\,\mathrm{kg\,m/s}$$

END OF SOLUTION

Kinetic energy is the energy of motion. Like momentum, it depends on an object's mass and velocity but is calculated using the following equation:

$$\mathrm{KE} = \frac{1}{2}mv^2 \tag{1.8}$$

The SI unit of kinetic energy is the joule (J).

Symbol	Quantity	SI Base Unit	Unit Symbol
KE	kinetic energy	joule	J
m	mass	kilogram	kg
v	velocity	meter per second	m/s

Example 1.21. Chris Farley runs to the stage at $4.0\,\mathrm{m/s}$. If his mass is $134\,\mathrm{kg}$, what is his kinetic energy?

SOLUTION We are given Farley's mass and velocity: $m = 134\,\mathrm{kg}$ and $v = 4.0\,\mathrm{m/s}$. The unknown we are finding is kinetic energy: $\mathrm{KE} = ?$. By Eq. (1.8),

$$\mathrm{KE} = \frac{1}{2}mv^2 = \frac{1}{2}\left(134\,\mathrm{kg}\right)\left(4.0\,\mathrm{m/s}\right)^2 = 1072\,\mathrm{J}$$

END OF SOLUTION

Calculator tip: When using a calculator, don't use `1/2`. Instead, use `0.5`.

Example 1.22. The kinetic energy of a 60-kg skater is 5880 J. What is her velocity?

We are given the skater's kinetic energy and mass: KE = 5880 J and $m = 60$ kg. The unknown we are looking for is the skater's velocity: $v = ?$ These three quantities are related by Equation (1.8) as
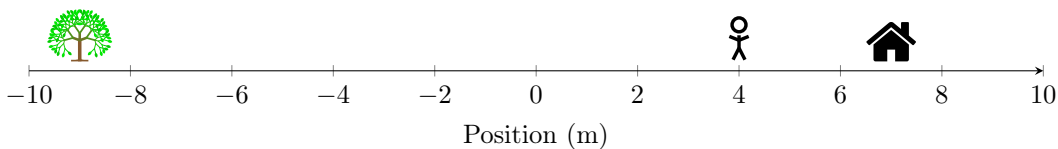
$$\text{KE} = \frac{1}{2}mv^2$$

We can solve this equation for velocity (v) via the following steps:

$$\begin{aligned}
\textbf{Write } v \textbf{ on left} \qquad & \frac{1}{2}mv^2 = \text{KE} \\[1.5ex]
\textbf{Substitute given quantities} \qquad & \frac{1}{2} \cdot 60 \cdot v^2 = 5880 \\[1.5ex]
\textbf{Multiply } \tfrac{1}{2} \textbf{ by 60} \qquad & 30\,v^2 = 5880 \\[1.5ex]
\textbf{Divide by 30} \qquad & \frac{\cancel{30}\,v^2}{\cancel{30}} = \frac{5880}{30} \\[1.5ex]
\textbf{Simplify} \qquad & v^2 = 196 \\[1.5ex]
\textbf{Take square root} \qquad & \sqrt{v^2} = \sqrt{196} \\[1.5ex]
\textbf{Simplify} \qquad & v = 14\,\text{m/s}
\end{aligned}$$

Therefore, the skater's speed is 14 meters per second.

1.6   Exercises

Position (m)

**1.1.** Find the position of (a) the person, (b) the tree, and (c) the house.

1.2. The person walks to the house, then to the tree. What is their total distance traveled?

1.3. The person walks to the house, then to the tree. What is the person's displacement?

1.4. If the figure above shows the person's final position, and if they started at the house, what is their displacement?

1.5–1.6 Emma Walker undergoes the three displacements shown below. Assume right is the positive direction.

$$85\,\text{m}$$

$$60\,\text{m}$$

$$48\,\text{m}$$
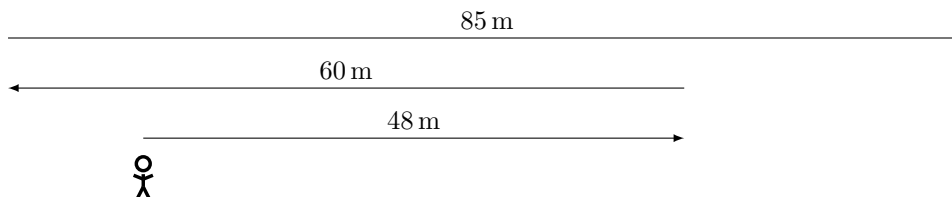
1.5. What is the total distance traveled by Emma?

1.6. What is Emma's total displacement?

1.7. Which of the following does your car's odometer record: distance or displacement?

1.8. Is distance a scalar or a vector?

1.9. Is displacement a scalar or a vector?

1.10. Provide at least 3 differences between distance and displacement.

1.11. Calculate Rodrigo's displacement, from Example 1.4, using the vector sum method that was modeled in Example 1.6.

1.12. Calculate Norma's displacement, from Example 1.5, using the vector sum method that was modeled in Example 1.6.

1.13. A dog walks 14 meters to the east and then 20 meters back to the west. (a) Draw a sketch of the dog's trip. (b) Calculate the distance traveled. (c) Calculate the dog's displacement. (*Hint*: Let east be the positive direction.) (d) What is the magnitude of his displacement?

In a coordinate system in which the direction to the right is positive, Morgan walks 35 meters to the left, 18 meters to the right, and then 26 meters to the left.

1.14. What distance does Morgan travel?

**1.15.** What is Morgan's displacement?

Nimzy the cat moves 16 meters eastward, then 7 meters westward, and finally 3 meters eastward.

1.16. What total distance does Nimzy travel?

1.17. What is the magnitude of the Nimzy's displacement?

1.18. What is the direction of Nimzy's displacement?

1.19–1.20 Suppose you walk halfway around a circular track of radius 63.67 m, as shown in the figure below.
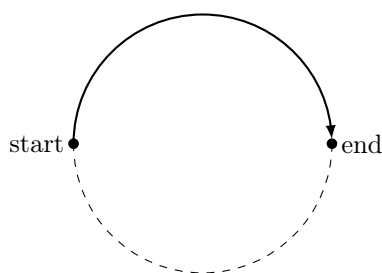
1.19. What total distance do you travel?

1.20. Calculate your displacement.

1.21–**1.25** Quinn jogs back and forth in one dimension, undergoing several displacements in the following sequence: 40 meters east, 24 meters west, 36 m east, 49 m west, 14 m east, and finally 45 m west. The total elapsed time of her trip is 33 seconds. Assume east is the positive direction.

1.21. Draw a diagram for Quinn's trip like Figure 1.2. Include labels and arrows showing the displacements.

1.22. What total distance does Quinn travel?

1.23. What is Quinn's average speed?

1.24. Calculate Quinn's displacement.

1.25. Find Quinn's average velocity.

1.26. Is it possible to determine a car's instantaneous velocity from just the speedometer reading? Explain.

1.27. A pitcher throws a baseball from the pitcher's mound to home plate in 0.46 s. The distance between the mound and home plate is 18.4 m. What is the average speed of the baseball?

1.28. A soccer ball travels with an average speed of 16 m/s for 3.0 s. How far did the ball travel?

1.29. Eduardo jogs with an average velocity of 6.1 meters per second east. What is his displacement after 75 seconds?

1.30. If displacement is 428 m west and average velocity is 1.70 m/s west, what is the elapsed time?
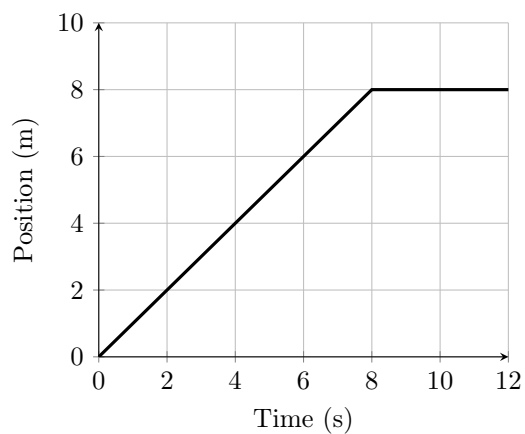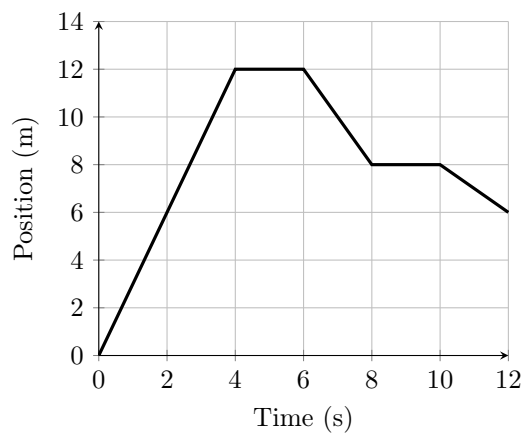
1.31. Find the initial position, final position, and displacement across the entire time interval.

1.32. Calculate displacement in the time interval from 4 to 12 seconds.

1.33. What is the average velocity in the last 6 seconds of motion?
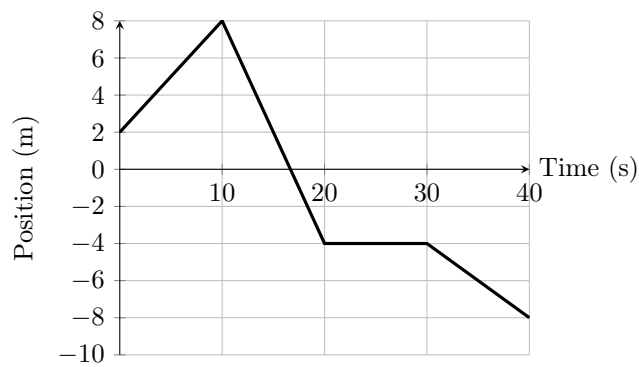

Consider the graph below.

1.34. What is the runner's net displacement over the entire time interval?

1.35. What is the runner's average velocity over the entire time interval?

**1.36.** What is the average velocity in the first 4 seconds?

Consider the graph below.

1.37. What is the displacement over the entire time interval?

1.38. What is the displacement over the first 10 seconds?

1.39. What is the average velocity for the whole time period shown in the graph?

1.40. What is the velocity between 10 and 20 seconds?

1.41. Calculate the displacement of the object whose motion is represented by the graph.
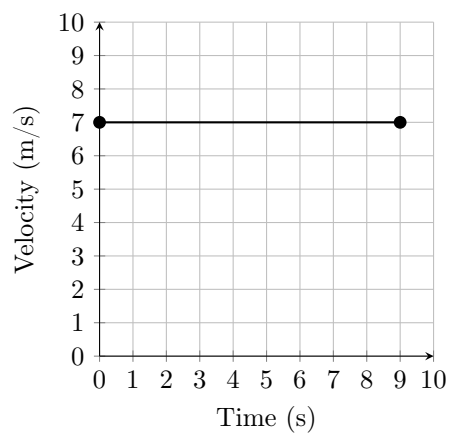
1.42. Calculate the total displacement of the object who's motion is represented by the graph below.
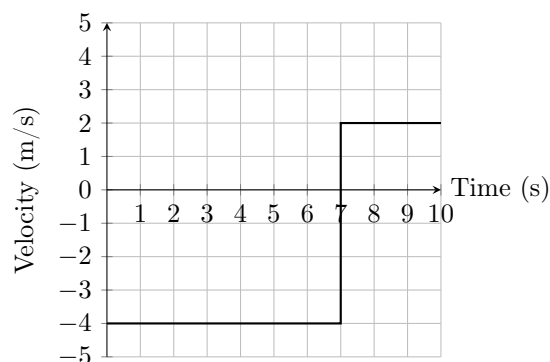
1.43. Calculate the average velocity of object whose motion is represented by the position vs. time graph below. Then create a velocity vs. time graph similar to the one in Figure 1.4.
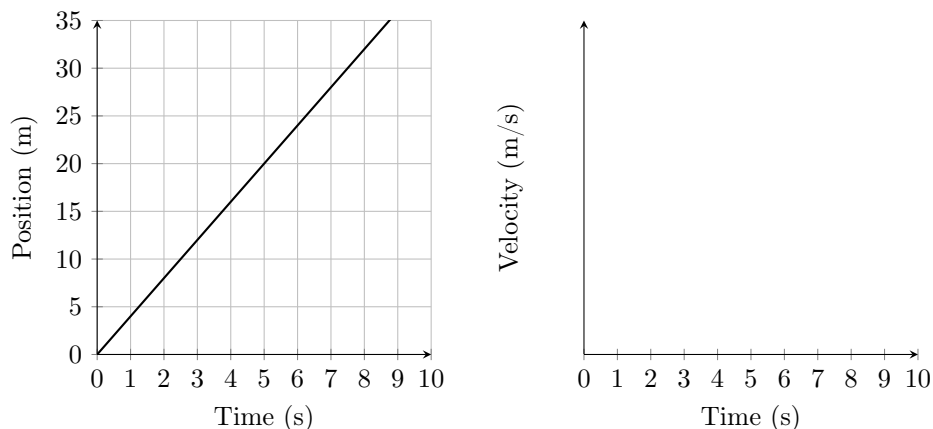
1.44. Can a lighter object have more momentum than a heavier one? How?

1.45. Calculate the momentum of a 0.410-kg football thrown hard at a speed of 25 m/s. Compare this momentum to the football player's momentum from Example 1.20 by calculating the ratio of the player's momentum to the ball's momentum, $p_{\text{player}}/p_{\text{ball}}$.

1.46. A 5 kg bowling ball is rolled with a velocity of 10 m/s. What is its momentum?

1.47. If an asteroid's mass and velocity are 10 kg and 11 m/s, kinetic energy?

1.48. Calculate the kinetic energy of the bowling ball from Exercise 1.46.

1.49. The kinetic energy of a a 5-kilogram object is 1200 joules. What is its speed?

Glossary

average velocity displacement divided by time over which displacement occurs. 6

average speed distance traveled divided by time during which motion occurs. 5

displacement the net change in position between initial and final positions; the straight-line distance from the initial to the final position; asking "What is the object's displacement?" is like asking "Where is the object relative to its original position?". 2

distance the total length of the path traveled between two positions. 1

elapsed time the difference between the ending time and beginning time; also known as the change in time or the time interval. 6

final position the position of an object at the end of its motion. 1

initial position the position of an object at the beginning of its motion. 1

magnitude size or amount; e.g. *magnitude* of displacement. 4

mass the quantity of matter in a substance; measured in kilograms. 14

momentum the product of a system's mass and velocity. 14

position the location of an object on a fixed axis; the SI unit is the meter. 1

position vs. time graph a graph where position is plotted on the y-axis and time is plotted on the x-axis. 8

scalar a physical quantity that has a magnitude but no direction; e.g., distance is a scalar. 4

speed rate at which an object changes its location. 5

vector a quantity that has both magnitude and direction; an arrow used to represent quantities with both magnitude and direction. 4

velocity the speed and direction of an object. 6

velocity vs. time graph a graph where velocity is plotted on the y-axis and time is plotted on the x-axis. 11

1.7 References & Additional Resources

Videos from the *YouTube* channel `Khan Academy`:

1. "Distance and displacement introduction" (https://youtu.be/vQCkYm3v3aA)
2. "Distance and displacement in one dimension" (https://youtu.be/w2mbvtpQKrM)
3. "Intro to vectors & scalars" (https://youtu.be/ihNZlp7iUHE)
4. "Position-time graphs" (https://youtu.be/9XxzIoUQd78)
5. "Worked example: distance and displacement from position-time graphs" (https://youtu.be/az6i2qvI1E0)
6. "Average velocity and speed worked example" (https://youtu.be/Dzw2nLd7DFw)
7. "Instantaneous speed and velocity" (https://youtu.be/pfTTHx9kCHk)
8. "Why distance is area under velocity-time line" (click here)
9. Practice: Slope from graph (click here)
10. Practice: Slope from two points (click here)

Other resources:

1. *OpenStax Simulations*: "Moving Man" (click here)
2. *YouTube*: "Introduction to Displacement and the Difference between Displacement and Distance" by `Flipping Physics` (click here)
3. *YouTube*: "Maths Bitesize – The DST Triangle" (https://youtu.be/8glfUANjBbY)
4. *PhET Simulation*: "Graphing Lines" (click here)
5. *Math Whiteboard* (https://www.mathwhiteboard.com/whiteboard/)

1.8   Answers to Select Exercises

1.1. (a) 4 meters   (b) $7\,\mathrm{m}$ (c) $-9\,\mathrm{m}$

1.2. $19\,\mathrm{m}$

1.3. $-13\,\mathrm{m}$

1.13. (b) $34\,\mathrm{m}$ (c) $-6\,\mathrm{m}$ or $6\,\mathrm{m}$ west   (d) $6\,\mathrm{m}$

1.14. 79 meters

1.15. $-43\,\mathrm{m}$

1.16. 26 meters

1.17. $12\,\mathrm{m}$

1.18. East

1.22. 208 meters

1.23. $6.3\,\mathrm{m/s}$

1.24. $-28\,\mathrm{m}$

1.25. $-0.85\,\mathrm{m/s}$

1.26. No, since a speedometer doesn't specify direction.

1.27. $40.0\,\mathrm{m/s}$

1.28. $48\,\mathrm{m}$

1.29. $458\,\mathrm{m}$ east

1.30. $252\,\mathrm{m}$

1.31. $d_i = 0\,\mathrm{m/s}$, $d_f = 8\,\mathrm{m}$, $\Delta d = +8\,\mathrm{m}$

1.32. $4\,\mathrm{m}$

1.33. $\frac{1}{3}\,\mathrm{m/s}$

1.34. $6\,\mathrm{m}$

1.35. $0.5\,\mathrm{m/s}$

1.36. $3\,\mathrm{m/s}$

1.37. $-10\,\mathrm{m}$

1.38. $+6\,\mathrm{m}$

1.39. $-0.25\,\mathrm{m/s}$

1.40. $-1.2\,\mathrm{m/s}$

1.41. $63\,\mathrm{m/s}$

1.42. $-22\,\mathrm{m}$

1.45. (a) $10.25\,\mathrm{kg\,m/s}$ (b) 85.9

1.46. $50\,\mathrm{kg\,m/s}$

1.47. $605\,\mathrm{J}$

1.48. $250\,\mathrm{J}$

1.49. $21.9\,\mathrm{m/s}$