Chapter 3

Accelerated Motion

What You'll Learn

- You will develop descriptions of accelerated motion.
- You will use graphs and equations to solve problems involving moving objects.
- You will describe the motion of objects in free fall.

Why It's Important

Objects do not always move at constant velocities. Understanding accelerated motion will help you better decribe the motion of many objects.

Acceleration Cars, planes, subways, elevators, and other common forms of transportation often begin their journeys by speeding up quickly, and end by stopping rapidly.

Think About This ▶

The driver of a dragster on the starting line waits for the green light to signal the start of the race. At the signal, the driver will step on the gas pedal and try to speed up as quickly as possible. As the car speeds up, how will its position change?

Physics Online

physicspp.com

Rob Tringali/SportsChrome

LAUNCH Lab Do all types of motion look the same when graphed?

Question

How does a graph showing constant speed compare to a graph of a vehicle speeding up?

Procedure

1. Clamp a spark timer to the back edge of a lab table.
2. Cut a piece of timer tape approximately 50 cm in length, insert it into the timer, and tape it to vehicle 1.
3. Turn on the timer and release the vehicle. Label the tape with the vehicle number.
4. Raise one end of the lab table 8–10 cm by placing a couple of bricks under the back legs. ***CAUTION: Make sure the lab table remains stable.***
5. Repeat steps 2–4 with vehicle 2, but hold the vehicle in place next to the timer and release it after the timer has been turned on. Catch the vehicle before it falls.
6. **Construct and Organize Data** Mark the first dark dot where the timer began as *zero.* Measure the distance to each dot from the zero dot for 10 intervals and record your data.
7. **Make and Use Graphs** Make a graph of total distance versus interval number. Place data for both vehicles on the same plot and label each graph.

Analysis

Which vehicle moved with constant speed? Which one sped up? Explain how you determined this by looking at the timer tape.

Critical Thinking Describe the shape of each graph. How does the shape of the graph relate to the type of motion observed?

Horizons Companies

3.1 Acceleration

Uniform motion is one of the simplest kinds of motion. You learned in Chapter 2 that an object in uniform motion moves along a straight line with an unchanging velocity. From your own experiences, you know, however, that few objects move in this manner all of the time. In this chapter, you will expand your knowledge of motion by considering a slightly more complicated type of motion. You will be presented with situations in which the velocity of an object changes, while the object's motion is still along a straight line. Examples of objects and situations you will encounter in this chapter include automobiles that are speeding up, drivers applying brakes, falling objects, and objects thrown straight upward. In Chapter 6, you will continue to add to your knowledge of motion by analyzing some common types of motion that are not confined to a straight line. These include motion along a circular path and the motion of thrown objects, such as baseballs.

Objectives

- **Define** acceleration.
- **Relate** velocity and acceleration to the motion of an object.
- **Create** velocity-time graphs.

Vocabulary

velocity-time graph
acceleration
average acceleration
instantaneous acceleration

Changing Velocity

You can feel a difference between uniform and nonuniform motion. Uniform motion feels smooth. You could close your eyes and it would feel as though you were not moving at all. In contrast, when you move along a curve or up and down a roller coaster, you feel pushed or pulled.

Consider the motion diagrams shown in **Figure 3-1.** How would you describe the motion of the person in each case? In one diagram, the person is motionless. In another, she is moving at a constant speed. In a third, she is speeding up, and in a fourth, she is slowing down. How do you know which one is which? What information do the motion diagrams contain that could be used to make these distinctions?

The most important thing to notice in these motion diagrams is the distance between successive positions. You learned in Chapter 2 that motionless objects in the background of motion diagrams do not change positions. Therefore, because there is only one image of the person in **Figure 3-1a,** you can conclude that she is not moving; she is at rest. **Figure 3-1b** is like the constant-velocity motion diagrams in Chapter 2. The distances between images are the same, so the jogger is moving at a constant speed. The distance between successive positions changes in the two remaining diagrams. If the change in position gets larger, the jogger is speeding up, as shown in **Figure 3-1c.** If the change in position gets smaller, as in **Figure 3-1d,** the jogger is slowing down.

What does a particle-model motion diagram look like for an object with changing velocity? **Figure 3-2** shows the particle-model motion diagrams below the motion diagrams of the jogger speeding up and slowing down. There are two major indicators of the change in velocity in this form of the motion diagram. The change in the spacing of the dots and the differences in the lengths of the velocity vectors indicate the changes in velocity. If an object speeds up, each subsequent velocity vector is longer. If the object slows down, each vector is shorter than the previous one. Both types of motion diagrams give an idea of how an object's velocity is changing.

Velocity-Time Graphs

Just as it was useful to graph a changing position versus time, it also is useful to plot an object's velocity versus time, which is called a **velocity-time,** or ***v-t* graph. Table 3-1** on the next page shows the data for a car that starts at rest and speeds up along a straight stretch of road.

MINI LAB

A Steel Ball Race

If two steel balls are released at the same instant, will the steel balls get closer or farther apart as they roll down a ramp?

1. Assemble an inclined ramp from a piece of U-channel or two metersticks taped together.

2. Measure 40 cm from the top of the ramp and place a mark there. Place another mark 80 cm from the top.

3. Predict whether the steel balls will get closer or farther apart as they roll down the ramp.

4. At the same time, release one steel ball from the top of the ramp and the other steel ball from the 40-cm mark.

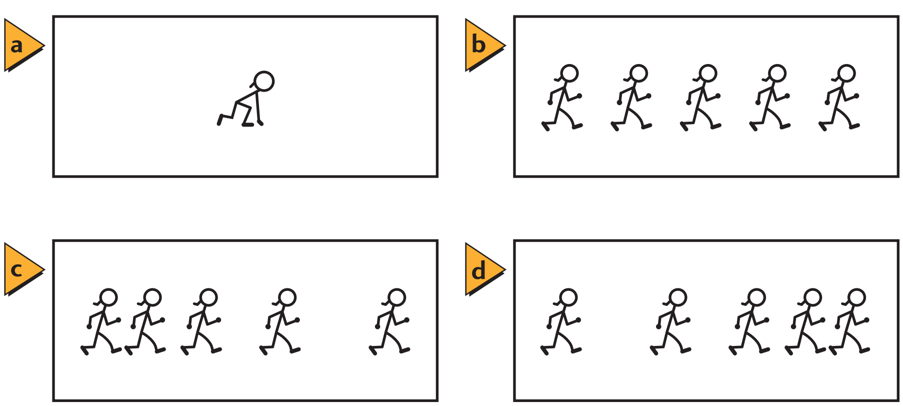
5. Next, release one steel ball from the top of the ramp. As soon as it reaches the 40-cm mark, release the other steel ball from the top of the ramp.

Analyze and Conclude

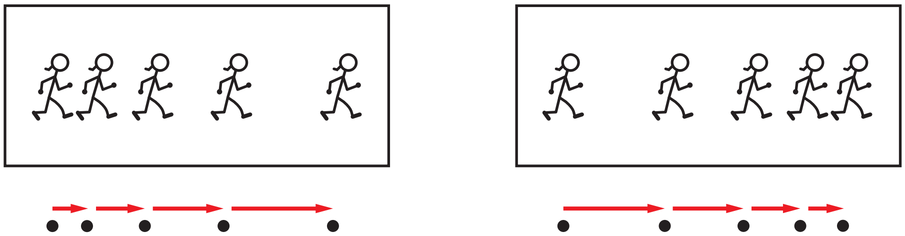
6. Explain your observations in terms of velocities.

7. Do the steel balls have the same velocity as they roll down the ramp? Explain.

8. Do they have the same acceleration? Explain.



■ **Figure 3-1** By noting the distance the jogger moves in equal time intervals, you can determine that the jogger is standing still **(a),** moving at a constant speed **(b),** speeding up **(c),** and slowing down **(d).**



■ **Figure 3-2** The particle-model version of the motion diagram indicates the runner's changing velocity not only by the change in spacing of the position dots, but also by the change in length of the velocity vectors.

Concepts In Motion

Interactive Figure To see an animation on velocity-time graphs, visit physicspp.com.

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The velocity-time graph obtained by plotting these data points is shown in **Figure 3-3.** The positive direction has been chosen to be the same as that of the motion of the car. Notice that this graph is a straight line, which means that the car was speeding up at a constant rate. The rate at which the car's velocity is changing can be found by calculating the slope of the velocity-time graph.

The graph shows that the slope is (10.0 m/s)/(2.00 s), or 5.00 m/s^2. This means that every second, the velocity of the car increased by 5.00 m/s. Consider a pair of data points that are separated by 1 s, such as 4.00 s and 5.00 s. At 4.00 s, the car was moving at a velocity of 20.0 m/s. At 5.00 s, the car was traveling at 25.0 m/s. Thus, the car's velocity increased by 5.00 m/s in 1.00 s. The rate at which an object's velocity changes is called the **acceleration** of the object. When the velocity of an object changes at a constant rate, it has a constant acceleration.

Average and Instantaneous Acceleration

The **average acceleration** of an object is the change in velocity during some measurable time interval divided by that time interval. Average acceleration is measured in m/s^2. The change in velocity at an instant of time is called **instantaneous acceleration.** The instantaneous acceleration of an object can be found by drawing a tangent line on the velocity-time graph at the point of time in which you are interested. The slope of this line is equal to the instantaneous acceleration. Most of the situations considered in this textbook involve motion with acceleration in which the average and instantaneous accelerations are equal.

■ **Figure 3-3** The slope of a velocity-time graph is the acceleration of the object represented.

Table 3-1

Velocity v. Time

Time (s)	Velocity (m/s)
0.00	0.00
1.00	5.00
2.00	10.0
3.00	15.0
4.00	20.0
5.00	25.0

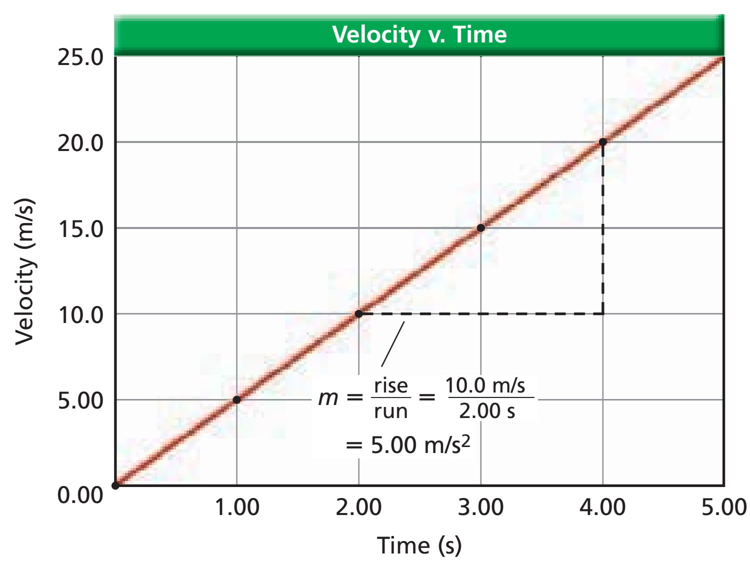
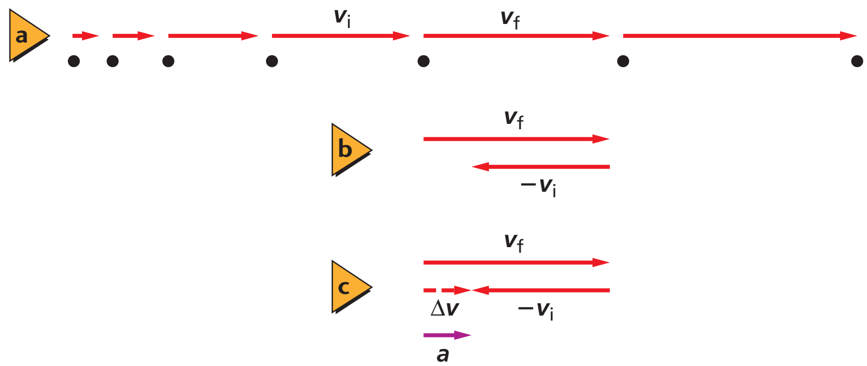


Figure 3-4 Looking at two consecutive velocity vectors and finding the difference between them yields the average acceleration vector for that time interval.



CLICK HERE

Color Convention

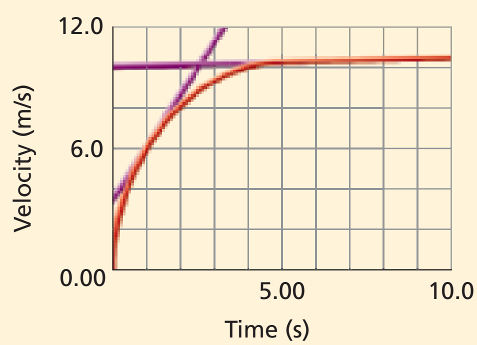
- Acceleration vectors are **violet.**
- Velocity vectors are **red.**
- Displacement vectors are **green.**

Displaying Acceleration on a Motion Diagram

For a motion diagram to give a full picture of an object's movement, it also should contain information about acceleration. This can be done by including average acceleration vectors. These vectors will indicate how the velocity is changing. To determine the length and direction of an average acceleration vector, subtract two consecutive velocity vectors, as shown in **Figures 3-4a** and **b.** That is, $\Delta \boldsymbol{v} = \boldsymbol{v}_f - \boldsymbol{v}_i = \boldsymbol{v}_f + (-\boldsymbol{v}_i)$. Then divide by the time interval, Δt. In Figures 3-4a and b, the time interval, Δt, is 1 s. This vector, $(\boldsymbol{v}_f - \boldsymbol{v}_i)/1$ s, shown in violet in **Figure 3-4c,** is the average acceleration during that time interval. The velocities $\boldsymbol{v}_i$ and $\boldsymbol{v}_f$ refer to the velocities at the beginning and end of a chosen time interval.

EXAMPLE Problem 1

Velocity and Acceleration How would you describe the sprinter's velocity and acceleration as shown on the graph?



1 Analyze and Sketch the Problem

- From the graph, note that the sprinter's velocity starts at zero, increases rapidly for the first few seconds, and then, after reaching about 10.0 m/s, remains almost constant.

Known: v = varies

Unknown: a = ?

2 Solve for the Unknown

Draw a tangent to the curve at $t = 1.0$ s and $t = 5.0$ s.

Solve for acceleration at 1.0 s:

$$a = \frac{\text{rise}}{\text{run}} = \frac{11.0\text{ m/s} - 2.8\text{ m/s}}{2.4\text{ s} - 0.00\text{ s}} = 3.4\text{ m/s}^2$$

The slope of the line at 1.0 s is equal to the acceleration at that time.

Solve for acceleration at 5.0 s:

$$a = \frac{\text{rise}}{\text{run}} = \frac{10.3\text{ m/s} - 10.0\text{ m/s}}{10.0\text{ s} - 0.00\text{ s}} = 0.030\text{ m/s}^2$$

The slope of the line at 5.0 s is equal to the acceleration at that time.

The acceleration is not constant because it changes from 3.4 m/s^2 to 0.03 m/s^2 at 5.0 s.
The acceleration is in the direction chosen to be positive because both values are positive.

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Slope
page 850

3 Evaluate the Answer

- **Are the units correct?** Acceleration is measured in m/s^2.

PRACTICE Problems

- Additional Problems, Appendix B
- Solutions to Selected Problems, Appendix C

1. A dog runs into a room and sees a cat at the other end of the room. The dog instantly stops running but slides along the wood floor until he stops, by slowing down with a constant acceleration. Sketch a motion diagram for this situation, and use the velocity vectors to find the acceleration vector.

2. **Figure 3-5** is a *v-t* graph for Steven as he walks along the midway at the state fair. Sketch the corresponding motion diagram, complete with velocity vectors.

3. Refer to the *v-t* graph of the toy train in **Figure 3-6** to answer the following questions.

a. When is the train's speed constant?

b. During which time interval is the train's acceleration positive?

c. When is the train's acceleration most negative?

4. Refer to Figure 3-6 to find the average acceleration of the train during the following time intervals.

a. 0.0 s to 5.0 s **b.** 15.0 s to 20.0 s **c.** 0.0 s to 40.0 s

5. Plot a *v-t* graph representing the following motion. An elevator starts at rest from the ground floor of a three-story shopping mall. It accelerates upward for 2.0 s at a rate of 0.5 m/s^2, continues up at a constant velocity of 1.0 m/s for 12.0 s, and then experiences a constant downward acceleration of 0.25 m/s^2 for 4.0 s as it reaches the third floor.

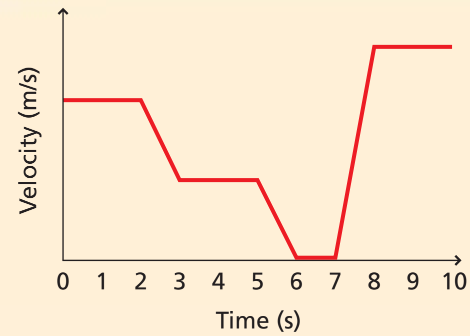


Figure 3-5

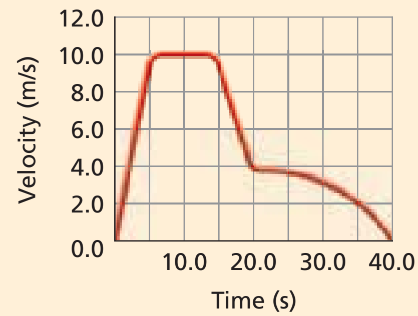


Figure 3-6

Positive and Negative Acceleration

Consider the four situations shown in **Figure 3-7a.** The first motion diagram shows an object moving in the positive direction and speeding up. The second motion diagram shows the object moving in the positive direction and slowing down. The third shows the object speeding up in the negative direction, and the fourth shows the object slowing down as it moves in the negative direction. **Figure 3-7b** shows the velocity vectors for the second time interval of each diagram, along with the corresponding acceleration vectors. Note Δt is equal to 1 s.

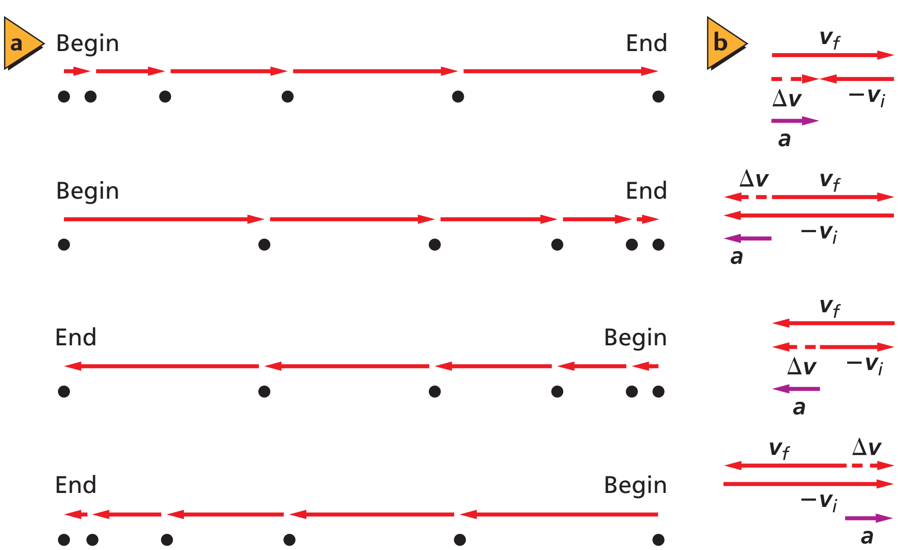
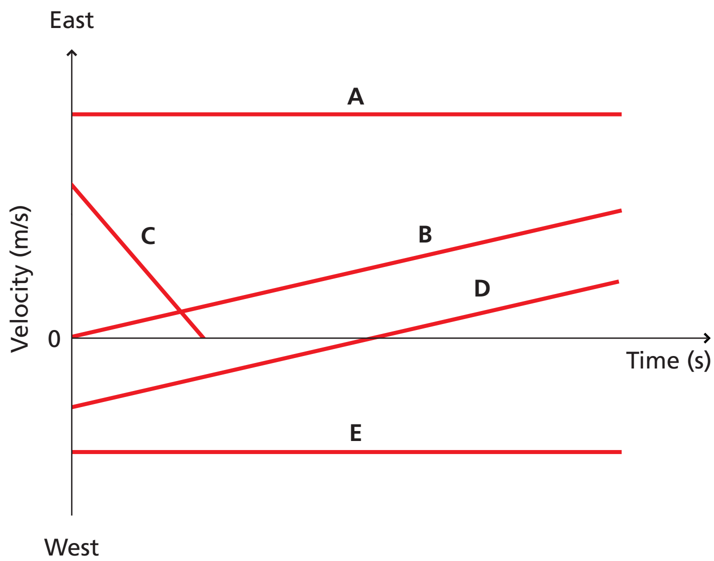


Figure 3-7 These four motion diagrams represent the four different possible ways to move along a straight line with constant acceleration **(a).** When the velocity vectors of the motion diagram and acceleration vectors point in the same direction, an object's speed increases. When they point in opposite directions, the object slows down **(b).**



■ **Figure 3-8** Graphs A and E show motion with constant velocity in opposite directions. Graph B shows both positive velocity and positive acceleration. Graph C shows positive velocity and negative acceleration. Graph D shows motion with constant positive acceleration that slows down while velocity is negative and speeds up when velocity is positive.

In the first and third situations when the object is speeding up, the velocity and acceleration vectors point in the same direction in each case, as shown in Figure 3-7b. In the other two situations in which the acceleration vector is in the opposite direction from the velocity vectors, the object is slowing down. In other words, when the object's acceleration is in the same direction as its velocity, the object's speed increases. When they are in opposite directions, the speed decreases. Both the direction of an object's velocity and its direction of acceleration are needed to determine whether it is speeding up or slowing down. An object has a positive acceleration when the acceleration vector points in the positive direction and a negative acceleration, when the acceleration vector points in the negative direction. The sign of acceleration does not indicate whether the object is speeding up or slowing down.

Determining Acceleration from a *v-t* Graph

Velocity and acceleration information also is contained in velocity-time graphs. Graphs A, B, C, D, and E, shown in **Figure 3-8,** represent the motions of five different runners. Assume that the positive direction has been chosen to be east. The slopes of Graphs A and E are zero. Thus, the accelerations are zero. Both Graphs A and E show motion at a constant velocity—Graph A to the east and Graph E to the west. Graph B shows motion with a positive velocity. The slope of this graph indicates a constant, positive acceleration. You also can infer from Graph B that the speed increased because it shows positive velocity and acceleration. Graph C has a negative slope. Graph C shows motion that begins with a positive velocity, slows down, and then stops. This means that the acceleration and velocity are in opposite directions. The point at which Graphs C and B cross shows that the runners' velocities are equal at that point. It does not, however, give any information about the runners' positions.

Graph D indicates movement that starts out toward the west, slows down, and for an instant gets to zero velocity, and then moves east with increasing speed. The slope of Graph D is positive. Because the velocity and acceleration are in opposite directions, the speed decreases and equals zero at the time the graph crosses the axis. After that time, the velocity and acceleration are in the same direction and the speed increases.

Calculating acceleration How can you describe acceleration mathematically? The following equation expresses average acceleration as the slope of the velocity-time graph.

Average Acceleration $\bar{a} \equiv \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$

Average acceleration is defined as the change in velocity, divided by the time it takes to make that change.

Suppose you run wind sprints back and forth across the gym. You first run at 4.0 m/s toward the wall. Then, 10.0 s later, you run at 4.0 m/s away from the wall. What is your average acceleration if the positive direction is toward the wall?

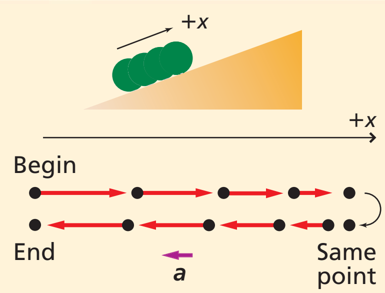
$$\bar{a} \equiv \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

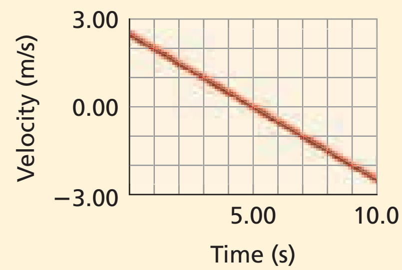
$$= \frac{(-4.0\ \text{m/s}) - (4.0\ \text{m/s})}{10.0\ \text{s}} = \frac{-8.0\ \text{m/s}}{10.0\ \text{s}} = -0.80\ \text{m/s}^2$$

The negative sign indicates that the direction of acceleration is away from the wall. The velocity changes when the direction of motion changes, because velocity includes the direction of motion. A change in velocity results in acceleration. Thus, acceleration also is associated with a change in the direction of motion.

EXAMPLE Problem 2

Acceleration Describe the motion of a ball as it rolls up a slanted driveway. The ball starts at 2.50 m/s, slows down for 5.00 s, stops for an instant, and then rolls back down at an increasing speed. The positive direction is chosen to be up the driveway, and the origin is at the place where the motion begins. What is the sign of the ball's acceleration as it rolls up the driveway? What is the magnitude of the ball's acceleration as it rolls up the driveway?





1 Analyze and Sketch the Problem

- Sketch the situation.
- Draw the coordinate system based on the motion diagram.

Known:	Unknown:
$v_i = +2.5$ m/s	$a = ?$
$v_f = 0.00$ m/s at $t = 5.00$ s	

2 Solve for the Unknown

Find the magnitude of the acceleration from the slope of the graph.

Solve for the change in velocity and the time taken to make that change.

$\Delta v = v_f - v_i$

$= 0.00\ \text{m/s} - 2.50\ \text{m/s}$ **Substitute $v_f = 0.00$ m/s at $t_f = 5.00$ s, $v_i = 2.50$ m/s at $t_i = 0.00$ s**

$= -2.50$ m/s

$\Delta t = t_f - t_i$

$= 5.00\ \text{s} - 0.00\ \text{s}$ **Substitute $t_f = 5.00$ s, $t_i = 0.00$ s**

$= 5.00$ s

Solve for the acceleration.

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

$= \frac{-2.50\ \text{m/s}}{5.00\ \text{s}}$ **Substitute $\Delta v = -2.50$ m/s, $\Delta t = 5.00$ s**

$= -0.500\ \text{m/s}^2$ or $0.500\ \text{m/s}^2$ down the driveway

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Operations with Significant Digits
pages 835–836

3 Evaluate the Answer

- **Are the units correct?** Acceleration is measured in m/s^2.
- **Do the directions make sense?** In the first 5.00 s, the direction of the acceleration is opposite to that of the velocity, and the ball slows down.

PRACTICE Problems

• Additional Problems, Appendix B
• Solutions to Selected Problems, Appendix C

6. A race car's velocity increases from 4.0 m/s to 36 m/s over a 4.0-s time interval. What is its average acceleration?

7. The race car in the previous problem slows from 36 m/s to 15 m/s over 3.0 s. What is its average acceleration?

8. A car is coasting backwards downhill at a speed of 3.0 m/s when the driver gets the engine started. After 2.5 s, the car is moving uphill at 4.5 m/s. If uphill is chosen as the positive direction, what is the car's average acceleration?

9. A bus is moving at 25 m/s when the driver steps on the brakes and brings the bus to a stop in 3.0 s.

a. What is the average acceleration of the bus while braking?

b. If the bus took twice as long to stop, how would the acceleration compare with what you found in part **a?**

10. Rohith has been jogging to the bus stop for 2.0 min at 3.5 m/s when he looks at his watch and sees that he has plenty of time before the bus arrives. Over the next 10.0 s, he slows his pace to a leisurely 0.75 m/s. What was his average acceleration during this 10.0 s?

11. If the rate of continental drift were to abruptly slow from 1.0 cm/y to 0.5 cm/y over the time interval of a year, what would be the average acceleration?

There are several parallels between acceleration and velocity. Both are rates of change: acceleration is the time rate of change of velocity, and velocity is the time rate of change of position. Both acceleration and velocity have average and instantaneous forms. You will learn later in this chapter that the area under a velocity-time graph is equal to the object's displacement and that the area under an acceleration-time graph is equal to the object's velocity.

3.1 Section Review

12. Velocity-Time Graph What information can you obtain from a velocity-time graph?

13. Position-Time and Velocity-Time Graphs Two joggers run at a constant velocity of 7.5 m/s toward the east. At time $t = 0$, one is 15 m east of the origin and the other is 15 m west.

a. What would be the difference(s) in the position-time graphs of their motion?

b. What would be the difference(s) in their velocity-time graphs?

14. Velocity Explain how you would use a velocity-time graph to find the time at which an object had a specified velocity.

15. Velocity-Time Graph Sketch a velocity-time graph for a car that goes east at 25 m/s for 100 s, then west at 25 m/s for another 100 s.

16. Average Velocity and Average Acceleration A canoeist paddles upstream at 2 m/s and then turns around and floats downstream at 4 m/s. The turnaround time is 8 s.

a. What is the average velocity of the canoe?

b. What is the average acceleration of the canoe?

17. Critical Thinking A police officer clocked a driver going 32 km/h over the speed limit just as the driver passed a slower car. Both drivers were issued speeding tickets. The judge agreed with the officer that both were guilty. The judgement was issued based on the assumption that the cars must have been going the same speed because they were observed next to each other. Are the judge and the police officer correct? Explain with a sketch, a motion diagram, and a position-time graph.

Physics Online physicspp.com/self_check_quiz

3.2 Motion with Constant Acceleration

You have learned that the definition of average velocity can be algebraically rearranged to show the new position after a period of time, given the initial position and the average velocity. The definition of average acceleration can be manipulated similarly to show the new velocity after a period of time, given the initial velocity and the average acceleration.

▶ **Objectives**

- **Interpret** position-time graphs for motion with constant acceleration.
- **Determine** mathematical relationships among position, velocity, acceleration, and time.
- **Apply** graphical and mathematical relationships to solve problems related to constant acceleration.

Velocity with Average Acceleration

If you know an object's average acceleration during a time interval, you can use it to determine how much the velocity changed during that time. The definition of average acceleration,

$\bar{a} \equiv \frac{\Delta v}{\Delta t}$, can be rewritten as follows:

$$\Delta v = \bar{a}\Delta t$$

$$v_f - v_i = \bar{a}\Delta t$$

The equation for final velocity with average acceleration can be written as follows.

Final Velocity with Average Acceleration $\quad v_f = v_i + \bar{a}\Delta t$

The final velocity is equal to the initial velocity plus the product of the average acceleration and time interval.

In cases in which the acceleration is constant, the average acceleration, $\bar{\boldsymbol{a}}$, is the same as the instantaneous acceleration, $\boldsymbol{a}$. This equation can be rearranged to find the time at which an object with constant acceleration has a given velocity. It also can be used to calculate the initial velocity of an object when both the velocity and the time at which it occurred are given.

▶ PRACTICE **Problems**

• Additional Problems, Appendix B
• Solutions to Selected Problems, Appendix C

18. A golf ball rolls up a hill toward a miniature-golf hole. Assume that the direction toward the hole is positive.

a. If the golf ball starts with a speed of 2.0 m/s and slows at a constant rate of 0.50 m/s^2, what is its velocity after 2.0 s?

b. What is the golf ball's velocity if the constant acceleration continues for 6.0 s?

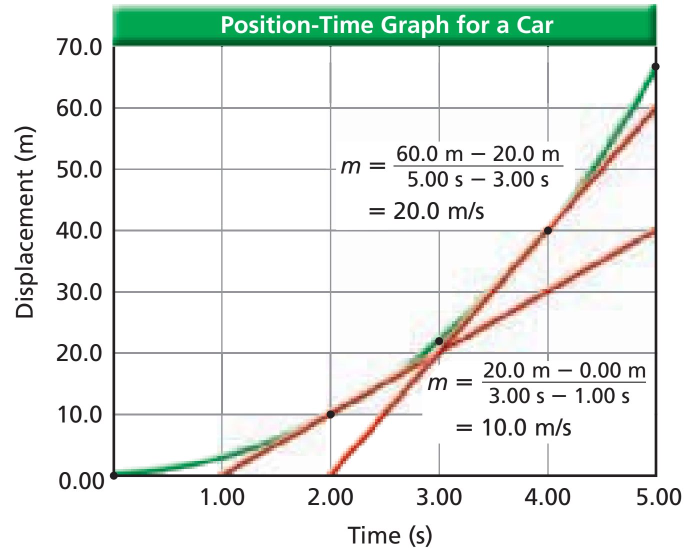
c. Describe the motion of the golf ball in words and with a motion diagram.

19. A bus that is traveling at 30.0 km/h speeds up at a constant rate of 3.5 m/s^2. What velocity does it reach 6.8 s later?

20. If a car accelerates from rest at a constant 5.5 m/s^2, how long will it take for the car to reach a velocity of 28 m/s?

21. A car slows from 22 m/s to 3.0 m/s at a constant rate of 2.1 m/s^2. How many seconds are required before the car is traveling at 3.0 m/s?

Table 3-2	
Position-Time Data for a Car	
Time (s)	**Position (m)**
0.00	0.00
1.00	2.50
2.00	10.0
3.00	22.5
4.00	40.0
5.00	62.5



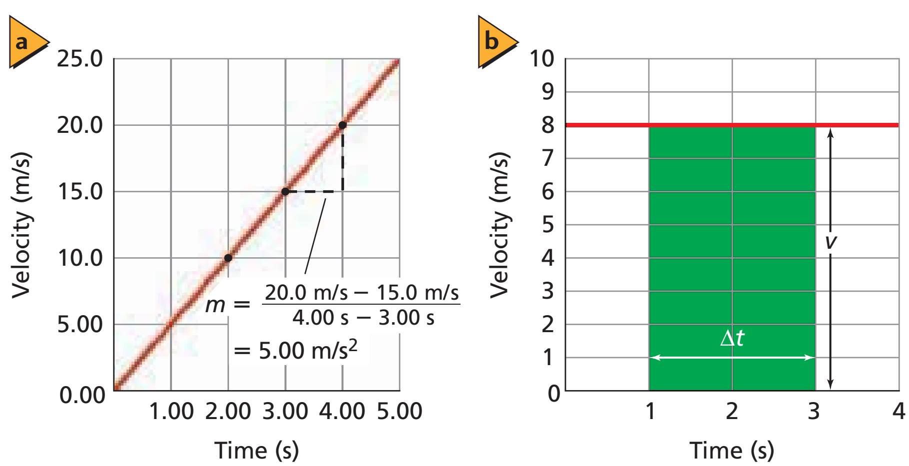
■ **Figure 3-9** The slope of a position-time graph of a car moving with a constant acceleration gets steeper as time goes on.

Position with Constant Acceleration

You have learned that an object experiencing constant acceleration changes its velocity at a constant rate. How does the position of an object with constant acceleration change? The position data at different time intervals for a car with constant acceleration are shown in **Table 3-2.**

The data from Table 3-2 are graphed in **Figure 3-9.** The graph shows that the car's motion is not uniform: the displacements for equal time intervals on the graph get larger and larger. Notice that the slope of the line in Figure 3-9 gets steeper as time goes on. The slopes from the position-time graph can be used to create a velocity-time graph. Note that the slopes shown in Figure 3-9 are the same as the velocities graphed in **Figure 3-10a.**

A unique position-time graph cannot be created using a velocity-time graph because it does not contain any information about the object's position. However, the velocity-time graph does contain information about the object's displacement. Recall that for an object moving at a constant velocity, $v = \bar{v} = \Delta d/\Delta t$, so $\Delta d = v\Delta t$. On the graph in **Figure 3-10b,** v is the height of the plotted line above the t-axis, while Δt is the width of the shaded rectangle. The area of the rectangle, then, is $v\Delta t$, or Δd. Thus, the area under the v-t graph is equal to the object's displacement.



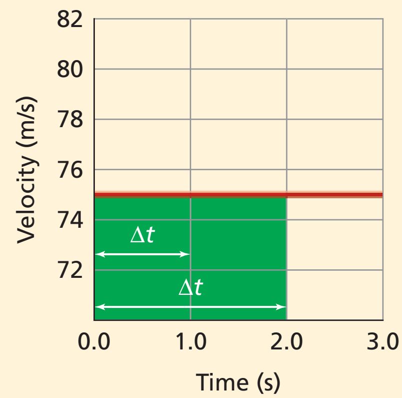
■ **Figure 3-10** The slopes of the p-t graph in Figure 3-9 are the values of the corresponding v-t graph **(a).** For any v-t graph, the displacement during a given time interval is the area under the graph **(b).**

▶ EXAMPLE Problem 3

Finding the Displacement from a *v-t* Graph The *v-t* graph below shows the motion of an airplane. Find the displacement of the airplane at $\Delta t = 1.0$ s and at $\Delta t = 2.0$ s.

1 Analyze and Sketch the Problem

- The displacement is the area under the *v-t* graph.
- The time intervals begin at $t = 0.0$.



Known:	**Unknown:**
$v = +75$ m/s	$\Delta d = ?$
$\Delta t = 1.0$ s	
$\Delta t = 2.0$ s	

2 Solve for the Unknown

Solve for displacement during $\Delta t = 1.0$ s.

$$\Delta d = v\Delta t$$
$$= (+75 \text{ m/s})(1.0 \text{ s}) \quad \text{Substitute } v = +75 \text{ m/s}, \Delta t = 1.0 \text{ s}$$
$$= +75 \text{ m}$$

Solve for displacement during $\Delta t = 2.0$ s.

$$\Delta d = v\Delta t$$
$$= (+75 \text{ m/s})(2.0 \text{ s}) \quad \text{Substitute } v = +75 \text{ m/s}, \Delta t = 2.0 \text{ s}$$
$$= +150 \text{ m}$$

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3 Evaluate the Answer

- **Are the units correct?** Displacement is measured in meters.
- **Do the signs make sense?** The positive sign agrees with the graph.
- **Is the magnitude realistic?** Moving a distance equal to about one football field is reasonable for an airplane.

▶ PRACTICE Problems

• Additional Problems, Appendix B
• Solutions to Selected Problems, Appendix C

22. Use **Figure 3-11** to determine the velocity of an airplane that is speeding up at each of the following times.

a. 1.0 s **b.** 2.0 s **c.** 2.5 s

23. Use dimensional analysis to convert an airplane's speed of 75 m/s to km/h.

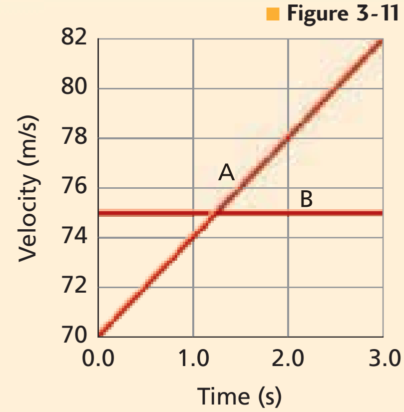
24. A position-time graph for a pony running in a field is shown in **Figure 3-12.** Draw the corresponding velocity-time graph using the same time scale.

25. A car is driven at a constant velocity of 25 m/s for 10.0 min. The car runs out of gas and the driver walks in the same direction at 1.5 m/s for 20.0 min to the nearest gas station. The driver takes 2.0 min to fill a gasoline can, then walks back to the car at 1.2 m/s and eventually drives home at 25 m/s in the direction opposite that of the original trip.

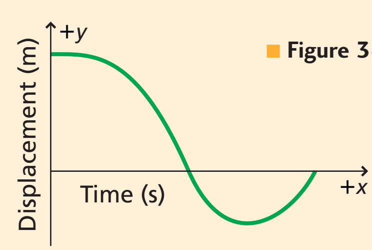
a. Draw a *v-t* graph using seconds as your time unit. Calculate the distance the driver walked to the gas station to find the time it took him to walk back to the car.

b. Draw a position-time graph for the situation using the areas under the velocity-time graph.

■ **Figure 3-11**



■ **Figure 3-12**



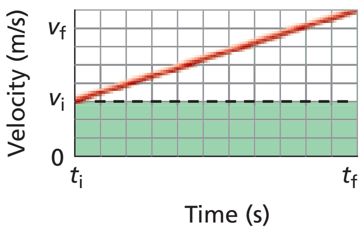


Figure 3-13 The displacement of an object moving with constant acceleration can be found by computing the area under the *v-t* graph.

The area under the *v-t* graph is equal to the object's displacement. Consider the *v-t* graph in **Figure 3-13** for an object moving with constant acceleration that started with an initial velocity of v_i. What is the object's displacement? The area under the graph can be calculated by dividing it into a rectangle and a triangle. The area of the rectangle can be found by $\Delta d_{rectangle} = v_i\Delta t$, and the area of the triangle can be found by $\Delta d_{triangle} = \frac{1}{2}\Delta v\Delta t$. Because average acceleration, $\bar{a}$, is equal to $\Delta v/\Delta t$, Δv can be rewritten as $\bar{a}\Delta t$. Substituting $\Delta v = \bar{a}\Delta t$ into the equation for the triangle's area yields $\Delta d_{triangle} = \frac{1}{2}(\bar{a}\Delta t)\Delta t$, or $\frac{1}{2}\bar{a}(\Delta t)^2$. Solving for the total area under the graph results in the following:

$$\Delta d = \Delta d_{rectangle} + \Delta d_{triangle} = v_i(\Delta t) + \frac{1}{2}\bar{a}(\Delta t)^2$$

When the initial or final position of the object is known, the equation can be written as follows:

$$d_f - d_i = v_i(\Delta t) + \frac{1}{2}\bar{a}(\Delta t)^2 \quad \text{or} \quad d_f = d_i + v_i(\Delta t) + \frac{1}{2}\bar{a}(\Delta t)^2$$

If the initial time is $t_i = 0$, the equation then becomes the following.

Position with Average Acceleration $d_f = d_i + v_i t_f + \frac{1}{2}\bar{a}t_f^2$

An object's final position is equal to the sum of its initial position, the product of the initial velocity and the final time, and half the product of the acceleration and the square of the final time.

An Alternative Expression

Often, it is useful to relate position, velocity, and constant acceleration without including time. Rearrange the equation $v_f = v_i + \bar{a}t_f$ to solve for time: $t_f = \frac{v_f - v_i}{\bar{a}}$.

Rewriting $d_f = d_i + v_i t_f + \frac{1}{2}\bar{a}t_f^2$ by substituting t_f yields the following:

$$d_f = d_i + v_i\frac{v_f - v_i}{\bar{a}} + \frac{1}{2}\bar{a}\left(\frac{v_f - v_i}{\bar{a}}\right)^2$$

This equation can be solved for the velocity, v_f, at any time, t_f.

Velocity with Constant Acceleration $v_f^2 = v_i^2 + 2\bar{a}(d_f - d_i)$

The square of the final velocity equals the sum of the square of the initial velocity and twice the product of the acceleration and the displacement since the initial time.

APPLYING PHYSICS

Drag Racing A dragster driver tries to obtain maximum acceleration over a 402-m (quarter-mile) course. The fastest time on record for the 402-m course is 4.480 s. The highest final speed on record is 147.63 m/s (330.23 mph).

The three equations for motion with constant acceleration are summarized in **Table 3-3.** Note that in a multi-step problem, it is useful to add additional subscripts to identify which step is under consideration.

Connecting Math to Physics

Table 3-3

Equations of Motion for Uniform Acceleration

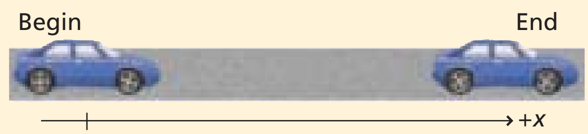
Equation	Variables	Initial Conditions
$v_f = v_i + \bar{a}t_f$	t_f, v_f, $\bar{a}$	v_i
$d_f = d_i + v_i t_f + \frac{1}{2}\bar{a}t_f^2$	t_f, d_f, $\bar{a}$	d_i, v_i
$v_f^2 = v_i^2 + 2\bar{a}(d_f - d_i)$	d_f, v_f, $\bar{a}$	d_i, v_i

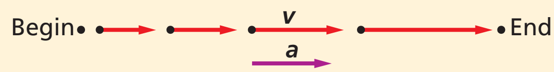
▶ EXAMPLE Problem 4

Displacement An automobile starts at rest and speeds up at 3.5 m/s^2 after the traffic light turns green. How far will it have gone when it is traveling at 25 m/s?

1 Analyze and Sketch the Problem

- Sketch the situation.
- Establish coordinate axes.
- Draw a motion diagram.





Known:	**Unknown:**
$d_i = 0.00$ m	$d_f = ?$
$v_i = 0.00$ m/s	
$v_f = 25$ m/s	
$\bar{a} = a = 3.5$ m/s^2	

2 Solve for the Unknown

Solve for d_f.

$$v_f^2 = v_i^2 + 2a(d_f - d_i)$$

$$d_f = d_i + \frac{v_f^2 - v_i^2}{2a}$$

$$= 0.00\text{ m} + \frac{(25\text{ m/s})^2 - (0.00\text{ m/s})^2}{2(3.5\text{ m/s}^2)}$$

Substitute d_i = 0.00 m, v_f = 25 m/s, v_i = 0.00 m/s

$$= 89\text{ m}$$

Physics Online

Personal Tutor For an online tutorial on displacement, visit physicspp.com.

3 Evaluate the Answer

- **Are the units correct?** Position is measured in meters.
- **Does the sign make sense?** The positive sign agrees with both the pictorial and physical models.
- **Is the magnitude realistic?** The displacement is almost the length of a football field. It seems large, but 25 m/s is fast (about 55 mph); therefore, the result is reasonable.

▶ PRACTICE Problems

- Additional Problems, Appendix B
- Solutions to Selected Problems, Appendix C

26. A skateboarder is moving at a constant velocity of 1.75 m/s when she starts up an incline that causes her to slow down with a constant acceleration of −0.20 m/s^2. How much time passes from when she begins to slow down until she begins to move back down the incline?

27. A race car travels on a racetrack at 44 m/s and slows at a constant rate to a velocity of 22 m/s over 11 s. How far does it move during this time?

28. A car accelerates at a constant rate from 15 m/s to 25 m/s while it travels a distance of 125 m. How long does it take to achieve this speed?

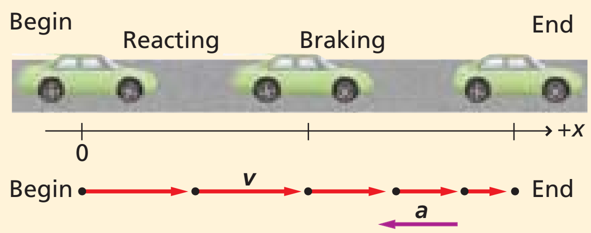
29. A bike rider pedals with constant acceleration to reach a velocity of 7.5 m/s over a time of 4.5 s. During the period of acceleration, the bike's displacement is 19 m. What was the initial velocity of the bike?

▶ EXAMPLE Problem 5

Two-Part Motion You are driving a car, traveling at a constant velocity of 25 m/s, when you see a child suddenly run onto the road. It takes 0.45 s for you to react and apply the brakes. As a result, the car slows with a steady acceleration of 8.5 m/s^2 and comes to a stop. What is the total distance that the car moves before it stops?

1 Analyze and Sketch the Problem

- Sketch the situation.
- Choose a coordinate system with the motion of the car in the positive direction.
- Draw the motion diagram and label v and a.



Known:

$v_{reacting} = 25$ m/s

$t_{reacting} = 0.45$ s

$\bar{a} = a_{braking} = -8.5$ m/s^2

$v_{i,\ braking} = 25$ m/s

$v_{f,\ braking} = 0.00$ m/s

Unknown:

$d_{reacting} = ?$

$d_{braking} = ?$

$d_{total} = ?$

2 Solve for the Unknown

Reacting:

Solve for the distance the car travels at a constant speed.

$$d_{reacting} = v_{reacting}t_{reacting}$$

$$d_{reacting} = (25\ \text{m/s})(0.45\ \text{s})$$

$$= 11\ \text{m}$$

Substitute $v_{reacting}$ = 25 m/s, $t_{reacting}$ = 0.45 s

Braking:

Solve for the distance the car moves while braking.

$$v_{f,\ braking}^2 = v_{reacting}^2 + 2a_{braking}(d_{braking})$$

Solve for $d_{braking}$.

$$d_{braking} = \frac{v_{f,\ braking}^2 - v_{reacting}^2}{2a_{braking}}$$

$$= \frac{(0.00\ \text{m/s})^2 - (25\ \text{m/s})^2}{2(-8.5\ \text{m/s}^2)}$$

$$= 37\ \text{m}$$

Substitute $v_{f,\ braking}$ = 0.00 m/s, $v_{reacting}$ = 25 m/s, $a_{braking}$ = −8.5 m/s^2

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The total distance traveled is the sum of the reaction distance and the braking distance.

Solve for d_{total}.

$$d_{total} = d_{reacting} + d_{braking}$$

$$= 11\ \text{m} + 37\ \text{m}$$

$$= 48\ \text{m}$$

Substitute $d_{reacting}$ = 11 m, $d_{braking}$ = 37 m

3 Evaluate the Answer

- **Are the units correct?** Distance is measured in meters.
- **Do the signs make sense?** Both $d_{reacting}$ and $d_{braking}$ are positive, as they should be.
- **Is the magnitude realistic?** The braking distance is small because the magnitude of the acceleration is large.

PRACTICE Problems

• Additional Problems, Appendix B
• Solutions to Selected Problems, Appendix C

30. A man runs at a velocity of 4.5 m/s for 15.0 min. When going up an increasingly steep hill, he slows down at a constant rate of 0.05 m/s^2 for 90.0 s and comes to a stop. How far did he run?

31. Sekazi is learning to ride a bike without training wheels. His father pushes him with a constant acceleration of 0.50 m/s^2 for 6.0 s, and then Sekazi continues at 3.0 m/s for another 6.0 s before falling. What is Sekazi's displacement? Solve this problem by constructing a velocity-time graph for Sekazi's motion and computing the area underneath the graphed line.

32. You start your bicycle ride at the top of a hill. You coast down the hill at a constant acceleration of 2.00 m/s^2. When you get to the bottom of the hill, you are moving at 18.0 m/s, and you pedal to maintain that speed. If you continue at this speed for 1.00 min, how far will you have gone from the time you left the hilltop?

33. Sunee is training for an upcoming 5.0-km race. She starts out her training run by moving at a constant pace of 4.3 m/s for 19 min. Then she accelerates at a constant rate until she crosses the finish line, 19.4 s later. What is her acceleration during the last portion of the training run?

You have learned several different tools that you can apply when solving problems dealing with motion in one dimension: motion diagrams, graphs, and equations. As you gain more experience, it will become easier to decide which tools are most appropriate in solving a given problem. In the following section, you will practice using these tools to investigate the motion of falling objects.

3.2 Section Review

34. Acceleration A woman driving at a speed of 23 m/s sees a deer on the road ahead and applies the brakes when she is 210 m from the deer. If the deer does not move and the car stops right before it hits the deer, what is the acceleration provided by the car's brakes?

35. Displacement If you were given initial and final velocities and the constant acceleration of an object, and you were asked to find the displacement, what equation would you use?

36. Distance An in-line skater first accelerates from 0.0 m/s to 5.0 m/s in 4.5 s, then continues at this constant speed for another 4.5 s. What is the total distance traveled by the in-line skater?

37. Final Velocity A plane travels a distance of 5.0×10^2 m while being accelerated uniformly from rest at the rate of 5.0 m/s^2. What final velocity does it attain?

38. Final Velocity An airplane accelerated uniformly from rest at the rate of 5.0 m/s^2 for 14 s. What final velocity did it attain?

39. Distance An airplane starts from rest and accelerates at a constant 3.00 m/s^2 for 30.0 s before leaving the ground.

a. How far did it move?

b. How fast was the airplane going when it took off?

40. Graphs A sprinter walks up to the starting blocks at a constant speed and positions herself for the start of the race. She waits until she hears the starting pistol go off, and then accelerates rapidly until she attains a constant velocity. She maintains this velocity until she crosses the finish line, and then she slows down to a walk, taking more time to slow down than she did to speed up at the beginning of the race. Sketch a velocity-time and a position-time graph to represent her motion. Draw them one above the other on the same time scale. Indicate on your *p*-*t* graph where the starting blocks and finish line are.

41. Critical Thinking Describe how you could calculate the acceleration of an automobile. Specify the measuring instruments and the procedures that you would use.

3.3 Free Fall

▶ **Objectives**

- **Define** acceleration due to gravity.
- **Solve** problems involving objects in free fall.

▶ **Vocabulary**

free fall
acceleration due to gravity

Drop a sheet of paper. Crumple it, and then drop it again. Drop a rock or a pebble. How do the three motions compare with each other? Do heavier objects fall faster than lighter ones? A light, spread-out object, such as a smooth sheet of paper or a feather, does not fall in the same manner as something more compact, such as a pebble. Why? As an object falls, it bumps into particles in the air. For an object such as a feather, these little collisions have a greater effect than they do on pebbles or rocks. To understand the behavior of falling objects, first consider the simplest case: an object such as a rock, for which the air does not have an appreciable effect on its motion. The term used to describe the motion of such objects is **free fall,** which is the motion of a body when air resistance is negligible and the action can be considered due to gravity alone.

Acceleration Due to Gravity

About 400 years ago, Galileo Galilei recognized that to make progress in the study of the motion of falling objects, the effects of the substance through which the object falls have to be ignored. At that time, Galileo had no means of taking position or velocity data for falling objects, so he rolled balls down inclined planes. By "diluting" gravity in this way, he could make careful measurements even with simple instruments.

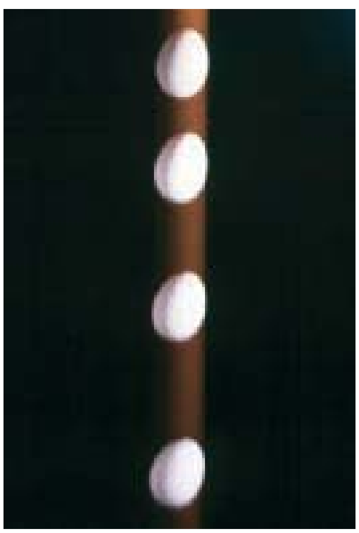
Galileo concluded that, neglecting the effect of the air, all objects in free fall had the same acceleration. It didn't matter what they were made of, how much they weighed, what height they were dropped from, or whether they were dropped or thrown. The acceleration of falling objects, given a special symbol, g, is equal to 9.80 m/s^2. It is now known that there are small variations in g at different places on Earth, and that 9.80 m/s^2 is the average value.

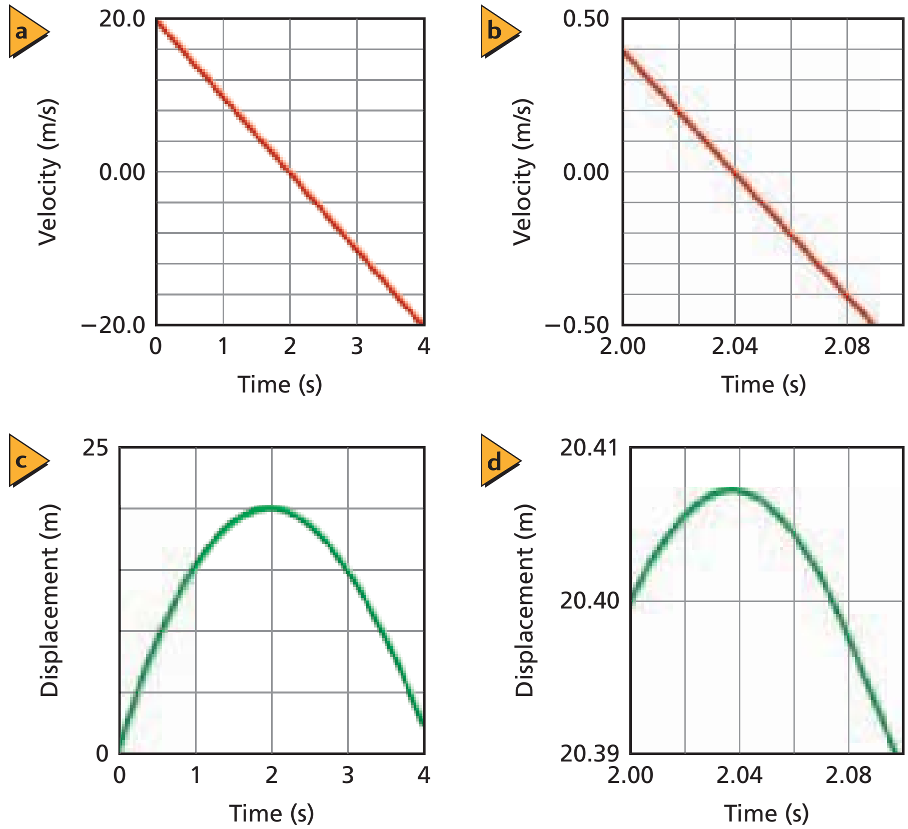
The **acceleration due to gravity** is the acceleration of an object in free fall that results from the influence of Earth's gravity. Suppose you drop a rock. After 1 s, its velocity is 9.80 m/s downward, and 1 s after that, its velocity is 19.60 m/s downward. For each second that the rock is falling, its downward velocity increases by 9.80 m/s. Note that g is a positive number. When analyzing free fall, whether you treat the acceleration as positive or negative depends upon the coordinate system that you use. If your coordinate system defines upward to be the positive direction, then the acceleration due to gravity is equal to $-g$; if you decide that downward is the positive direction, then the acceleration due to gravity is $+g$.

A strobe photo of a dropped egg is shown in **Figure 3-14.** The time interval between the images is 0.06 s. The displacement between each pair of images increases, so the speed is increasing. If the upward direction is chosen as positive, then the velocity is becoming more and more negative.

Ball thrown upward Instead of a dropped egg, could this photo also illustrate a ball thrown upward? If upward is chosen to be the positive direction, then the ball leaves the hand with a positive velocity of, for example, 20.0 m/s. The acceleration is downward, so a is negative. That is, $a = -g = -9.80$ m/s^2. Because the velocity and acceleration are in opposite directions, the speed of the ball decreases, which is in agreement with the strobe photo.

Figure 3-14 An egg accelerates at 9.80 m/s^2 in free fall. If the upward direction is chosen as positive, then both the velocity and the acceleration of this egg in free fall are negative.





■ **Figure 3-15** In a coordinate system in which the upward direction is positive, the velocity of the thrown ball decreases until it becomes zero at 2.04 s. Then it increases in the negative direction as the ball falls **(a, b).** The *p-t* graphs show the height of the ball at corresponding time intervals **(c, d).**

Concepts In Motion

Interactive Figure To see an animation on acceleration due to gravity, physicspp.com.

After 1 s, the ball's velocity is reduced by 9.80 m/s, so it now is traveling at 10.2 m/s. After 2 s, the velocity is 0.4 m/s, and the ball still is moving upward. What happens during the next second? The ball's velocity is reduced by another 9.80 m/s, and is equal to −9.4 m/s. The ball now is moving downward. After 4 s, the velocity is −19.2 m/s, meaning that the ball is falling even faster. **Figure 3-15a** shows the velocity-time graph for the ball as it goes up and comes back down. At around 2 s, the velocity changes smoothly from positive to negative. **Figure 3-15b** shows a closer view of the *v-t* graph around that point. At an instant of time, near 2.04 s, the ball's velocity is zero. Look at the position-time graphs in **Figure 3-15c** and **d,** which show how the ball's height changes. How are the ball's position and velocity related? The ball reaches its maximum height at the instant of time when its velocity is zero.

At 2.04 s, the ball reaches its maximum height and its velocity is zero. What is the ball's acceleration at that point? The slope of the line in the *v-t* graphs in Figure 3-15a and 3-15b is constant at $-9.80\ \text{m/s}^2$.

Often, when people are asked about the acceleration of an object at the top of its flight, they do not take the time to fully analyze the situation, and respond that the acceleration at this point is zero. However, this is not the case. At the top of the flight, the ball's velocity is 0 m/s. What would happen if its acceleration were also zero? Then the ball's velocity would not be changing and would remain at 0 m/s. If this were the case, the ball would not gain any downward velocity and would simply hover in the air at the top of its flight. Because this is not the way objects tossed in the air behave on Earth, you know that the acceleration of an object at the top of its flight must not be zero. Further, because you know that the object will fall from that height, you know that the acceleration must be downward.

Free-fall rides Amusement parks use the concept of free fall to design rides that give the riders the sensation of free fall. These types of rides usually consist of three parts: the ride to the top, momentary suspension, and the plunge downward. Motors provide the force needed to move the cars to the top of the ride. When the cars are in free fall, the most massive rider and the least massive rider will have the same acceleration. Suppose the free-fall ride at an amusement park starts at rest and is in free fall for 1.5 s. What would be its velocity at the end of 1.5 s? Choose a coordinate system with a positive axis upward and the origin at the initial position of the car. Because the car starts at rest, v_i would be equal to 0.00 m/s. To calculate the final velocity, use the equation for velocity with constant acceleration.

$$
\begin{aligned}
v_f &= v_i + \bar{a}t_f \\
&= 0.00\ \text{m/s} + (-9.80\ \text{m/s}^2)(1.5\ \text{s}) \\
&= -15\ \text{m/s}
\end{aligned}
$$

How far does the car fall? Use the equation for displacement when time and constant acceleration are known.

$$
\begin{aligned}
d_f &= d_i + v_i t_f + \tfrac{1}{2}\bar{a}t_f^2 \\
&= 0.00\ \text{m} + (0.00\ \text{m/s})(1.5\ \text{s}) + \tfrac{1}{2}(-9.80\ \text{m/s}^2)(1.5\ \text{s})^2 \\
&= -11\ \text{m}
\end{aligned}
$$

PRACTICE Problems

• Additional Problems, Appendix B
• Solutions to Selected Problems, Appendix C

42. A construction worker accidentally drops a brick from a high scaffold.

a. What is the velocity of the brick after 4.0 s?

b. How far does the brick fall during this time?

43. Suppose for the previous problem you choose your coordinate system so that the opposite direction is positive.

a. What is the brick's velocity after 4.0 s?

b. How far does the brick fall during this time?

44. A student drops a ball from a window 3.5 m above the sidewalk. How fast is it moving when it hits the sidewalk?

45. A tennis ball is thrown straight up with an initial speed of 22.5 m/s. It is caught at the same distance above the ground.

a. How high does the ball rise?

b. How long does the ball remain in the air? *Hint: The time it takes the ball to rise equals the time it takes to fall.*

46. You decide to flip a coin to determine whether to do your physics or English homework first. The coin is flipped straight up.

a. If the coin reaches a high point of 0.25 m above where you released it, what was its initial speed?

b. If you catch it at the same height as you released it, how much time did it spend in the air?

CHALLENGE PROBLEM

You notice a water balloon fall past your classroom window. You estimate that it took the balloon about t seconds to fall the length of the window and that the window is about y meters high. Suppose the balloon started from rest. Approximately how high above the top of the window was it released? Your answer should be in terms of t, y, g, and numerical constants.

Remember to define the positive direction when establishing your coordinate system. As motion problems increase in complexity, it becomes increasingly important to keep all the signs consistent. This means that any displacement, velocity, or acceleration that is in the same direction as the one chosen to be positive will be positive. Thus, any displacement, velocity, or acceleration that is in the direction opposite to the one chosen to be positive should be indicated with a negative sign. Sometimes it might be appropriate to choose upward as positive. At other times, it might be easier to choose downward as positive. You can choose either direction you want, as long as you stay consistent with that convention throughout the solution of that particular problem. Suppose you solve one of the practice problems on the preceding page again, choosing the direction opposite to the one you previously designated as the positive direction for the coordinate system. You should arrive at the same answer, provided that you assigned signs to each of the quantities that were consistent with the coordinate system. It is important to be consistent with the coordinate system to avoid getting the signs mixed up.

3.3 Section Review

47. Maximum Height and Flight Time Acceleration due to gravity on Mars is about one-third that on Earth. Suppose you throw a ball upward with the same velocity on Mars as on Earth.

a. How would the ball's maximum height compare to that on Earth?

b. How would its flight time compare?

48. Velocity and Acceleration Suppose you throw a ball straight up into the air. Describe the changes in the velocity of the ball. Describe the changes in the acceleration of the ball.

49. Final Velocity Your sister drops your house keys down to you from the second floor window. If you catch them 4.3 m from where your sister dropped them, what is the velocity of the keys when you catch them?

50. Initial Velocity A student trying out for the football team kicks the football straight up in the air. The ball hits him on the way back down. If it took 3.0 s from the time when the student punted the ball until he gets hit by the ball, what was the football's initial velocity?

51. Maximum Height When the student in the previous problem kicked the football, approximately how high did the football travel?

52. Critical Thinking When a ball is thrown vertically upward, it continues upward until it reaches a certain position, and then it falls downward. At that highest point, its velocity is instantaneously zero. Is the ball accelerating at the highest point? Devise an experiment to prove or disprove your answer.

Physics Online physicspp.com/self_check_quiz

PHYSICS LAB • Internet

Acceleration Due to Gravity

Alternate CBL instructions can be found on the Web site.
physicspp.com

Small variations in the acceleration due to gravity, g, occur at different places on Earth. This is because g varies with distance from the center of Earth and is influenced by the subsurface geology. In addition, g varies with latitude due to Earth's rotation.

For motion with constant acceleration, the displacement is $d_f - d_i = v_i(t_f - t_i) + \frac{1}{2}a(t_f - t_i)^2$. If $d_i = 0$ and $t_i = 0$, then the displacement is $d_f = v_i t_f + \frac{1}{2}at_f^2$. Dividing both sides of the equation by t_f yields the following: $d_f/t_f = v_i + \frac{1}{2}at_f$. The slope of a graph of d_f/t_f versus t_f, is equal to $\frac{1}{2}a$. The initial velocity, v_i, is determined by the y-intercept. In this activity, you will be using a spark timer to collect free-fall data and use it to determine the acceleration due to gravity, g.

QUESTION

How does the value of *g* vary from place to place?

Objectives

- **Measure** free-fall data.
- **Make and use graphs** of velocity versus time.
- **Compare and contrast** values of *g* for different locations.

Safety Precautions

- **Keep clear of falling masses.**

Materials

spark timer
timer tape
1-kg mass
C-clamp
stack of newspapers
masking tape

Procedure

1. Attach the spark timer to the edge of the lab table with the C-clamp.
2. If the timer needs to be calibrated, follow your teacher's instructions or those provided with the timer. Determine the period of the timer and record it in your data table.
3. Place the stack of newspapers on the floor, directly below the timer so that the mass, when released, will not damage the floor.
4. Cut a piece of timer tape approximately 70 cm in length and slide it into the spark timer.
5. Attach the timer tape to the 1-kg mass with a small piece of masking tape. Hold the mass next to the spark timer, over the edge of the table so that it is above the newspaper stack.
6. Turn on the spark timer and release the mass.
7. Inspect the timer tape to make sure that there are dots marked on it and that there are no gaps in the dot sequence. If your timer tape is defective, repeat steps 4–6 with another piece of timer tape.
8. Have each member of your group perform the experiment and collect his or her own data.
9. Choose a dot near the beginning of the timer tape, a few centimeters from the point where the timer began to record dots, and label it *0*. Label the dots after that *1, 2, 3, 4, 5,* etc. until you get near the end where the mass is no longer in free fall. If the dots stop, or the distance between them begins to get smaller, the mass is no longer in free fall.

Horizons Companies

Data Table

Time period (#/s)	

Interval	Distance (cm)	Time (s)	Speed (cm/s)
1			
2			
3			
4			
5			
6			
7			
8			

10. Measure the total distance to each numbered dot from the zero dot, to the nearest millimeter and record it in your data table. Using the timer period, record the total time associated with each distance measurement and record it in your data table.

Analyze

1. **Use Numbers** Calculate the values for speed and record them in the data table.
2. **Make and Use Graphs** Draw a graph of speed versus time. Draw the best-fit straight line for your data.
3. Calculate the slope of the line. Convert your result to m/s^2.

Conclude and Apply

1. Recall that the slope is equal to $\frac{1}{2}a$. What is the acceleration due to gravity?
2. Find the relative error for your experimental value of g by comparing it to the accepted value.

   Relative error =

   $$\frac{\text{Accepted value} - \text{Experimental value}}{\text{Accepted value}} \times 100$$

3. What was the mass's velocity, v_i, when you began measuring distance and time?

Going Further

What is the advantage of measuring several centimeters away from the beginning of the timer tape rather than from the very first dot?

Real-World Physics

Why do designers of free-fall amusement-park rides design exit tracks that gradually curve toward the ground? Why is there a stretch of straight track?

Share Your Data

Communicate the average value of g to others. Go to physicspp.com/internet_lab and post the name of your school, city, state, elevation above sea level, and average value of g for your class. Obtain a map for your state and a map of the United States. Using the data posted on the Web site by other students, mark the values for g at the appropriate locations on the maps. Do you notice any variation in the acceleration due to gravity for different locations, regions and elevations?

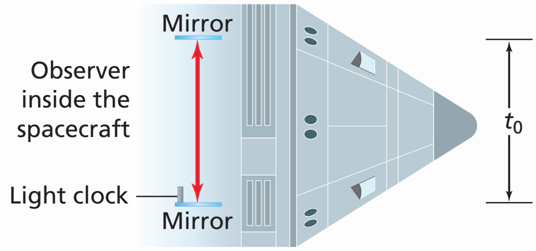
Physics Online

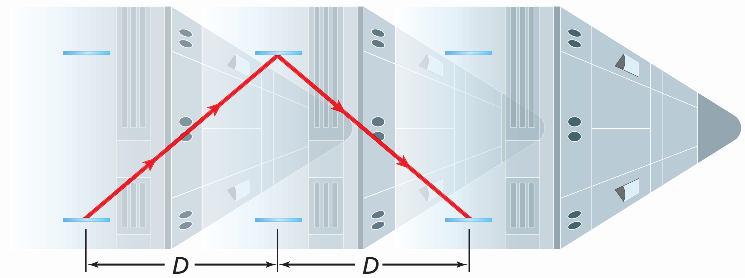
To find out more about accelerated motion, visit the Web site: physicspp.com

eXtreme physics

Time Dilation at High Velocities

Can time pass differently in two reference frames? How can one of a pair of twins age more than the other?





Light Clock Consider the following thought experiment using a light clock. A light clock is a vertical tube with a mirror at each end. A short pulse of light is introduced at one end and allowed to bounce back and forth within the tube. Time is measured by counting the number of bounces made by the pulse of light. The clock will be accurate because the speed of a pulse of light is always c, which is 3×10^8 m/s, regardless of the velocity of the light source or the observer.

Suppose this light clock is placed in a very fast spacecraft. When the spacecraft goes at slow speeds, the light beam bounces vertically in the tube. If the spacecraft is moving fast, the light beam still bounces vertically—at least as seen by the observer in the spacecraft.

A stationary observer on Earth, however, sees the pulse of light move diagonally because of the movement of the spacecraft. Thus, to the stationary observer, the light beam moves a greater distance. Distance = velocity × time, so if the distance traveled by the light beam increases, the product (velocity × time) also must increase.

Because the speed of the light pulse, c, is the same for any observer, time must be increasing for the stationary observer. That is, the stationary observer sees the moving clock ticking slower than the same clock on Earth.

Suppose the time per tick seen by the stationary observer on Earth is t_s, the time seen by the observer on the spacecraft is t_o, the length of the light clock is ct_o, the velocity of the spacecraft is v, and the speed of light is c. For every tick, the spacecraft moves vt_s and the light pulse moves ct_o. This leads to the following equation:

$$t_s = \frac{t_o}{\sqrt{1-\left(\frac{v^2}{c^2}\right)}}$$

To the stationary observer, the closer v is to c, the slower the clock ticks. To the observer on the spacecraft, however, the clock keeps perfect time.

Time Dilation This phenomenon is called time dilation and it applies to every process associated with time aboard the spacecraft. For example, biological aging will proceed more slowly in the spacecraft than on Earth. So if the observer on the spacecraft is one of a pair of twins, he or she would age more slowly than the other twin on Earth. This is called the twin paradox. Time dilation has resulted in a lot of speculation about space travel. If spacecraft were able to travel at speeds close to the speed of light, trips to distant stars would take only a few years for the astronaut.

Going Further

1. **Calculate** Find the time dilation t_s/t_o for Earth's orbit about the Sun if v_{Earth} = 10,889 km/s.
2. **Calculate** Derive the equation for t_s above.
3. **Discuss** How is time dilation similar to or different from time travel?

Chapter 3

Study Guide

3.1 Acceleration

Vocabulary

- velocity-time graph (p. 58)
- acceleration (p.59)
- average acceleration (p. 59)
- instantaneous acceleration (p. 59)

Key Concepts

- A velocity-time graph can be used to find the velocity and acceleration of an object.
- The average acceleration of an object is the slope of its velocity-time graph.

$$\bar{a} \equiv \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

- Average acceleration vectors on a motion diagram indicate the size and direction of the average acceleration during a time interval.
- When the acceleration and velocity are in the same direction, the object speeds up; when they are in opposite directions, the object slows down.
- Velocity-time graphs and motion diagrams can be used to determine the sign of an object's acceleration.

3.2 Motion with Constant Acceleration

Key Concepts

- If an object's average acceleration during a time interval is known, the change in velocity during that time can be found.

$$v_f = v_i + \bar{a}\Delta t$$

- The area under an object's velocity-time graph is its displacement.
- In motion with constant acceleration, there are relationships among the position, velocity, acceleration, and time.

$$d_f = d_i + v_i t_f + \frac{1}{2}\bar{a}t_f^2$$

- The velocity of an object with constant acceleration can be found using the following equation.

$$v_f^2 = v_i^2 + 2\bar{a}(d_f - d_i)$$

3.3 Free Fall

Vocabulary

- free fall (p. 72)
- acceleration due to gravity (p. 72)

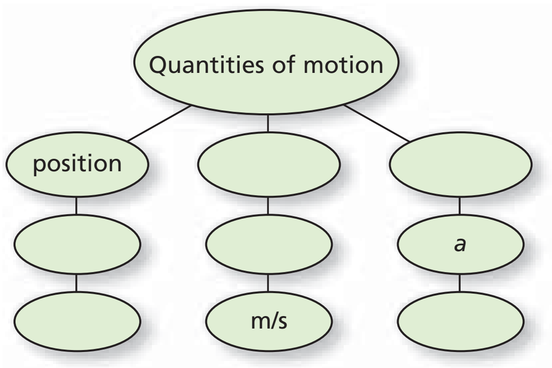
Key Concepts

- The acceleration due to gravity on Earth, g, is 9.80 m/s^2 downward. The sign associated with g in equations depends upon the choice of the coordinate system.
- Equations for motion with constant acceleration can be used to solve problems involving objects in free fall.

Chapter 3 Assessment

Concept Mapping

53. Complete the following concept map using the following symbols or terms: *d*, *velocity*, *m/s*^{2}, *v*, *m*, *acceleration*.



Mastering Concepts

54. How are velocity and acceleration related? (3.1)

55. Give an example of each of the following. (3.1)

a. an object that is slowing down, but has a positive acceleration

b. an object that is speeding up, but has a negative acceleration

56. **Figure 3-16** shows the velocity-time graph for an automobile on a test track. Describe how the velocity changes with time. (3.1)

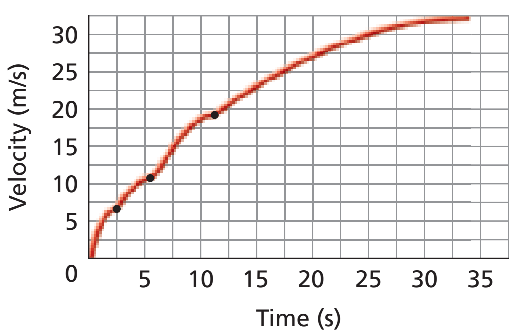


Figure 3-16

57. What does the slope of the tangent to the curve on a velocity-time graph measure? (3.1)

58. Can a car traveling on an interstate highway have a negative velocity and a positive acceleration at the same time? Explain. Can the car's velocity change signs while it is traveling with constant acceleration? Explain. (3.1)

59. Can the velocity of an object change when its acceleration is constant? If so, give an example. If not, explain. (3.1)

60. If an object's velocity-time graph is a straight line parallel to the *t*-axis, what can you conclude about the object's acceleration? (3.1)

61. What quantity is represented by the area under a velocity-time graph? (3.2)

62. Write a summary of the equations for position, velocity, and time for an object experiencing motion with uniform acceleration. (3.2)

63. Explain why an aluminum ball and a steel ball of similar size and shape, dropped from the same height, reach the ground at the same time. (3.3)

64. Give some examples of falling objects for which air resistance cannot be ignored. (3.3)

65. Give some examples of falling objects for which air resistance can be ignored. (3.3)

Applying Concepts

66. Does a car that is slowing down always have a negative acceleration? Explain.

67. **Croquet** A croquet ball, after being hit by a mallet, slows down and stops. Do the velocity and acceleration of the ball have the same signs?

68. If an object has zero acceleration, does it mean its velocity is zero? Give an example.

69. If an object has zero velocity at some instant, is its acceleration zero? Give an example.

70. If you were given a table of velocities of an object at various times, how would you find out whether the acceleration was constant?

71. The three notches in the graph in Figure 3-16 occur where the driver changed gears. Describe the changes in velocity and acceleration of the car while in first gear. Is the acceleration just before a gear change larger or smaller than the acceleration just after the change? Explain your answer.

72. Use the graph in Figure 3-16 and determine the time interval during which the acceleration is largest and the time interval during which the acceleration is smallest.

73. Explain how you would walk to produce each of the position-time graphs in **Figure 3-17.**

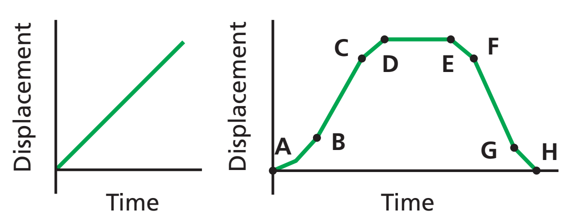
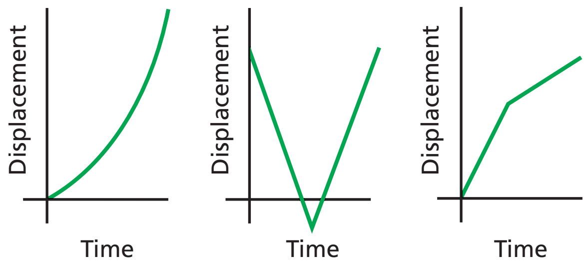


Figure 3-17

74. Draw a velocity-time graph for each of the graphs in **Figure 3-18.**



■ **Figure 3-18**

75. An object shot straight up rises for 7.0 s before it reaches its maximum height. A second object falling from rest takes 7.0 s to reach the ground. Compare the displacements of the two objects during this time interval.

76. The Moon The value of g on the Moon is one-sixth of its value on Earth.
a. Would a ball that is dropped by an astronaut hit the surface of the Moon with a greater, equal, or lesser speed than that of a ball dropped from the same height to Earth?
b. Would it take the ball more, less, or equal time to fall?

77. Jupiter The planet Jupiter has about three times the gravitational acceleration of Earth. Suppose a ball is thrown vertically upward with the same initial velocity on Earth and on Jupiter. Neglect the effects of Jupiter's atmospheric resistance and assume that gravity is the only force on the ball.
a. How does the maximum height reached by the ball on Jupiter compare to the maximum height reached on Earth?
b. If the ball on Jupiter were thrown with an initial velocity that is three times greater, how would this affect your answer to part **a?**

78. Rock A is dropped from a cliff and rock B is thrown upward from the same position.
a. When they reach the ground at the bottom of the cliff, which rock has a greater velocity?
b. Which has a greater acceleration?
c. Which arrives first?

Mastering Problems

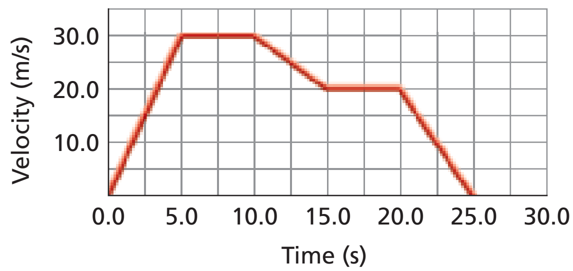
3.1 Acceleration

79. A car is driven for 2.0 h at 40.0 km/h, then for another 2.0 h at 60.0 km/h in the same direction.
a. What is the car's average velocity?
b. What is the car's average velocity if it is driven 1.0×10^2 km at each of the two speeds?

80. Find the uniform acceleration that causes a car's velocity to change from 32 m/s to 96 m/s in an 8.0-s period.

81. A car with a velocity of 22 m/s is accelerated uniformly at the rate of 1.6 m/s^2 for 6.8 s. What is its final velocity?

82. Refer to **Figure 3-19** to find the acceleration of the moving object at each of the following times.
a. during the first 5.0 s of travel
b. between 5.0 s and 10.0 s
c. between 10.0 s and 15.0 s
d. between 20.0 s and 25.0 s



■ **Figure 3-19**

83. Plot a velocity-time graph using the information in **Table 3-4,** and answer the following questions.
a. During what time interval is the object speeding up? Slowing down?
b. At what time does the object reverse direction?
c. How does the average acceleration of the object in the interval between 0.0 s and 2.0 s differ from the average acceleration in the interval between 7.0 s and 12.0 s?

Table 3-4
Velocity v. Time

Time (s)	Velocity (m/s)
0.00	4.00
1.00	8.00
2.00	12.0
3.00	14.0
4.00	16.0
5.00	16.0
6.00	14.0
7.00	12.0
8.00	8.00
9.00	4.00
10.0	0.00
11.0	−4.00
12.0	−8.00

84. Determine the final velocity of a proton that has an initial velocity of 2.35×10^5 m/s and then is accelerated uniformly in an electric field at the rate of -1.10×10^{12} m/s^2 for 1.50×10^{-7} s.

85. Sports Cars Marco is looking for a used sports car. He wants to buy the one with the greatest acceleration. Car A can go from 0 m/s to 17.9 m/s in 4.0 s; car B can accelerate from 0 m/s to 22.4 m/s in 3.5 s; and car C can go from 0 to 26.8 m/s in 6.0 s. Rank the three cars from greatest acceleration to least, specifically indicating any ties.

86. Supersonic Jet A supersonic jet flying at 145 m/s experiences uniform acceleration at the rate of 23.1 m/s^2 for 20.0 s.
- **a.** What is its final velocity?
- **b.** The speed of sound in air is 331 m/s. What is the plane's speed in terms of the speed of sound?

3.2 Motion with Constant Acceleration

87. Refer to Figure 3-19 to find the distance traveled during the following time intervals.
- **a.** $t = 0.0$ s and $t = 5.0$ s
- **b.** $t = 5.0$ s and $t = 10.0$ s
- **c.** $t = 10.0$ s and $t = 15.0$ s
- **d.** $t = 0.0$ s and $t = 25.0$ s

88. A dragster starting from rest accelerates at 49 m/s^2. How fast is it going when it has traveled 325 m?

89. A car moves at 12 m/s and coasts up a hill with a uniform acceleration of -1.6 m/s^2.
- **a.** What is its displacement after 6.0 s?
- **b.** What is its displacement after 9.0 s?

90. Race Car A race car can be slowed with a constant acceleration of -11 m/s^2.
- **a.** If the car is going 55 m/s, how many meters will it travel before it stops?
- **b.** How many meters will it take to stop a car going twice as fast?

91. A car is traveling 20.0 m/s when the driver sees a child standing on the road. She takes 0.80 s to react, then steps on the brakes and slows at 7.0 m/s^2. How far does the car go before it stops?

92. Airplane Determine the displacement of a plane that experiences uniform acceleration from 66 m/s to 88 m/s in 12 s.

93. How far does a plane fly in 15 s while its velocity is changing from 145 m/s to 75 m/s at a uniform rate of acceleration?

94. Police Car A speeding car is traveling at a constant speed of 30.0 m/s when it passes a stopped police car. The police car accelerates at 7.0 m/s^2. How fast will it be going when it catches up with the speeding car?

95. Road Barrier The driver of a car going 90.0 km/h suddenly sees the lights of a barrier 40.0 m ahead. It takes the driver 0.75 s to apply the brakes, and the average acceleration during braking is -10.0 m/s^2.
- **a.** Determine whether the car hits the barrier.
- **b.** What is the maximum speed at which the car could be moving and not hit the barrier 40.0 m ahead? Assume that the acceleration doesn't change.

3.3 Free Fall

96. A student drops a penny from the top of a tower and decides that she will establish a coordinate system in which the direction of the penny's motion is positive. What is the sign of the acceleration of the penny?

97. Suppose an astronaut drops a feather from 1.2 m above the surface of the Moon. If the acceleration due to gravity on the Moon is 1.62 m/s^2 downward, how long does it take the feather to hit the Moon's surface?

98. A stone that starts at rest is in free fall for 8.0 s.
- **a.** Calculate the stone's velocity after 8.0 s.
- **b.** What is the stone's displacement during this time?

99. A bag is dropped from a hovering helicopter. The bag has fallen for 2.0 s. What is the bag's velocity? How far has the bag fallen?

100. You throw a ball downward from a window at a speed of 2.0 m/s. How fast will it be moving when it hits the sidewalk 2.5 m below?

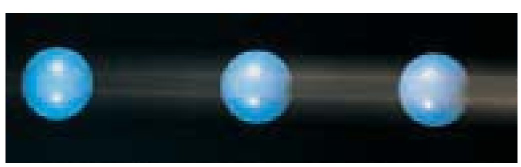
101. If you throw the ball in the previous problem up instead of down, how fast will it be moving when it hits the sidewalk?

102. Beanbag You throw a beanbag in the air and catch it 2.2 s later.
- **a.** How high did it go?
- **b.** What was its initial velocity?

Mixed Review

103. A spaceship far from any star or planet experiences uniform acceleration from 65.0 m/s to 162.0 m/s in 10.0 s. How far does it move?

104. Figure 3-20 is a strobe photo of a horizontally moving ball. What information about the photo would you need and what measurements would you make to estimate the acceleration?



■ **Figure 3-20**

 For more problems, go to Additional Problems, Appendix B.

105. **Bicycle** A bicycle accelerates from 0.0 m/s to 4.0 m/s in 4.0 s. What distance does it travel?

106. A weather balloon is floating at a constant height above Earth when it releases a pack of instruments.
a. If the pack hits the ground with a velocity of −73.5 m/s, how far did the pack fall?
b. How long did it take for the pack to fall?

107. **Baseball** A baseball pitcher throws a fastball at a speed of 44 m/s. The acceleration occurs as the pitcher holds the ball in his hand and moves it through an almost straight-line distance of 3.5 m. Calculate the acceleration, assuming that it is constant and uniform. Compare this acceleration to the acceleration due to gravity.

108. The total distance a steel ball rolls down an incline at various times is given in **Table 3-5.**
a. Draw a position-time graph of the motion of the ball. When setting up the axes, use five divisions for each 10 m of travel on the *d*-axis. Use five divisions for 1 s of time on the *t*-axis.
b. Calculate the distance the ball has rolled at the end of 2.2 s.

Table 3-5
Distance v. Time

Time (s)	Distance (m)
0.0	0.0
1.0	2.0
2.0	8.0
3.0	18.0
4.0	32.0
5.0	50.0

109. Engineers are developing new types of guns that might someday be used to launch satellites as if they were bullets. One such gun can give a small object a velocity of 3.5 km/s while moving it through a distance of only 2.0 cm.
a. What acceleration does the gun give this object?
b. Over what time interval does the acceleration take place?

110. **Sleds** Rocket-powered sleds are used to test the responses of humans to acceleration. Starting from rest, one sled can reach a speed of 444 m/s in 1.80 s and can be brought to a stop again in 2.15 s.
a. Calculate the acceleration of the sled when starting, and compare it to the magnitude of the acceleration due to gravity, 9.80 m/s^2.
b. Find the acceleration of the sled as it is braking and compare it to the magnitude of the acceleration due to gravity.

111. The velocity of a car changes over an 8.0-s time period, as shown in **Table 3-6.**
a. Plot the velocity-time graph of the motion.
b. Determine the displacement of the car during the first 2.0 s.
c. What displacement does the car have during the first 4.0 s?
d. What is the displacement of the car during the entire 8.0 s?
e. Find the slope of the line between t = 0.0 s and t = 4.0 s. What does this slope represent?
f. Find the slope of the line between t = 5.0 s and t = 7.0 s. What does this slope indicate?

Table 3-6
Velocity v. Time

Time (s)	Velocity (m/s)
0.0	0.0
1.0	4.0
2.0	8.0
3.0	12.0
4.0	16.0
5.0	20.0
6.0	20.0
7.0	20.0
8.0	20.0

112. A truck is stopped at a stoplight. When the light turns green, the truck accelerates at 2.5 m/s^2. At the same instant, a car passes the truck going 15 m/s. Where and when does the truck catch up with the car?

113. **Safety Barriers** Highway safety engineers build soft barriers, such as the one shown in **Figure 3-21,** so that cars hitting them will slow down at a safe rate. A person wearing a safety belt can withstand an acceleration of -3.0×10^2 m/s^2. How thick should barriers be to safely stop a car that hits a barrier at 110 km/h?

Figure 3-21

114. Karate The position-time and velocity-time graphs of George's fist breaking a wooden board during karate practice are shown in **Figure 3-22.**

a. Use the velocity-time graph to describe the motion of George's fist during the first 10 ms.

b. Estimate the slope of the velocity-time graph to determine the acceleration of his fist when it suddenly stops.

c. Express the acceleration as a multiple of the gravitational acceleration, $g = 9.80\ m/s^2$.

d. Determine the area under the velocity-time curve to find the displacement of the fist in the first 6 ms. Compare this with the position-time graph.

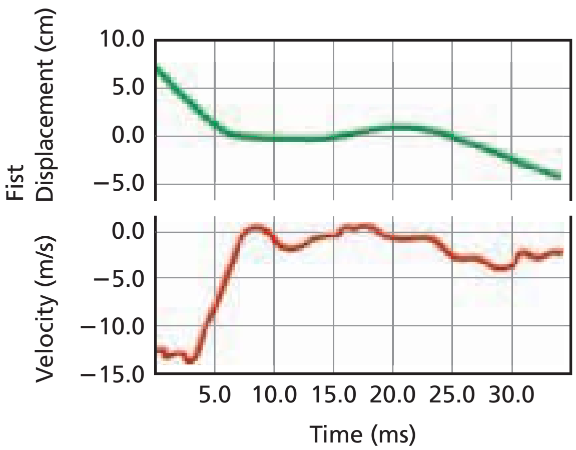


Figure 3-22

115. Cargo A helicopter is rising at 5.0 m/s when a bag of its cargo is dropped. The bag falls for 2.0 s.

a. What is the bag's velocity?

b. How far has the bag fallen?

c. How far below the helicopter is the bag?

Thinking Critically

116. Apply CBLs Design a lab to measure the distance an accelerated object moves over time. Use equal time intervals so that you can plot velocity over time as well as distance. A pulley at the edge of a table with a mass attached is a good way to achieve uniform acceleration. Suggested materials include a motion detector, CBL, lab cart, string, pulley, C-clamp, and masses. Generate distance-time and velocity-time graphs using different masses on the pulley. How does the change in mass affect your graphs?

117. Analyze and Conclude Which has the greater acceleration: a car that increases its speed from 50 km/h to 60 km/h, or a bike that goes from 0 km/h to 10 km/h in the same time? Explain.

118. Analyze and Conclude An express train, traveling at 36.0 m/s, is accidentally sidetracked onto a local train track. The express engineer spots a local train exactly 1.00×10^2 m ahead on the same track and traveling in the same direction. The local engineer is unaware of the situation. The express engineer jams on the brakes and slows the express train at a constant rate of $3.00\ m/s^2$. If the speed of the local train is 11.0 m/s, will the express train be able to stop in time, or will there be a collision? To solve this problem, take the position of the express train when the engineer first sights the local train as a point of origin. Next, keeping in mind that the local train has exactly a 1.00×10^2 m lead, calculate how far each train is from the origin at the end of the 12.0 s it would take the express train to stop (accelerate at $-3.00\ m/s^2$ from 36 m/s to 0 m/s).

a. On the basis of your calculations, would you conclude that a collision will occur?

b. The calculations that you made do not allow for the possibility that a collision might take place before the end of the 12 s required for the express train to come to a halt. To check this, take the position of the express train when the engineer first sights the local train as the point of origin and calculate the position of each train at the end of each second after the sighting. Make a table showing the distance of each train from the origin at the end of each second. Plot these positions on the same graph and draw two lines. Use your graph to check your answer to part **a.**

Writing in Physics

119. Research and describe Galileo's contributions to physics.

120. Research the maximum acceleration a human body can withstand without blacking out. Discuss how this impacts the design of three common entertainment or transportation devices.

Cumulative Review

121. Solve the following problems. Express your answers in scientific notation. (Chapter 1)

a. $6.2\times10^{-4}\ m + 5.7\times10^{-3}\ m$

b. $8.7\times10^{8}\ km - 3.4\times10^{7}\ m$

c. $(9.21\times10^{-5}\ cm)(1.83\times10^{8}\ cm)$

d. $(2.63\times10^{-6}\ m)/(4.08\times10^{6}\ s)$

122. The equation below describes the motion of an object. Create the corresponding position-time graph and motion diagram. Then write a physics problem that could be solved using that equation. Be creative. $d = (35.0\ m/s)\ t - 5.0\ m$ (Chapter 2)

Standardized Test Practice

Multiple Choice

Use the following information to answer the first two questions.

A ball rolls down a hill with a constant acceleration of 2.0 m/s^2. The ball starts at rest and travels for 4.0 s before it stops.

1. How far did the ball travel before it stopped?

Ⓐ 8.0 m Ⓒ 16 m
Ⓑ 12 m Ⓓ 20 m

2. What was the ball's velocity just before it stopped?

Ⓐ 2.0 m/s Ⓒ 12 m/s
Ⓑ 8.0 m/s Ⓓ 16 m/s

3. A driver of a car enters a new 110-km/h speed zone on the highway. The driver begins to accelerate immediately and reaches 110 km/h after driving 500 m. If the original speed was 80 km/h, what was the driver's rate of acceleration?

Ⓐ 0.44 m/s^2 Ⓒ 8.4 m/s^2
Ⓑ 0.60 m/s^2 Ⓓ 9.80 m/s^2

4. A flowerpot falls off the balcony of a penthouse suite 85 m above the street. How long does it take to hit the ground?

Ⓐ 4.2 s Ⓒ 8.7 s
Ⓑ 8.3 s Ⓓ 17 s

5. A rock climber's shoe loosens a rock, and her climbing buddy at the bottom of the cliff notices that the rock takes 3.20 s to fall to the ground. How high up the cliff is the rock climber?

Ⓐ 15.0 m Ⓒ 50.0 m
Ⓑ 31.0 m Ⓓ 1.00×10^2 m

6. A car traveling at 91.0 km/h approaches the turnoff for a restaurant 30.0 m ahead. If the driver slams on the brakes with an acceleration of −6.40 m/s^2, what will be her stopping distance?

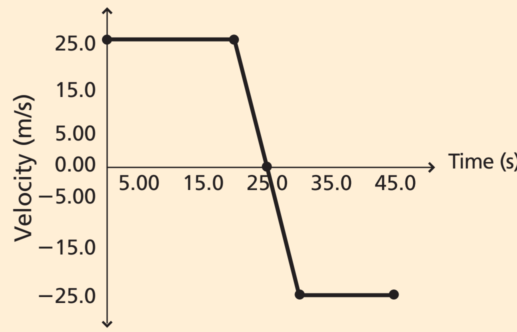
Ⓐ 14.0 m Ⓒ 50.0 m
Ⓑ 29.0 m Ⓓ 100.0 m

7. What is the correct formula manipulation to find acceleration when using the equation $v_f^2 = v_i^2 + 2ad$?

Ⓐ $(v_f^2 - v_i^2)/d$ Ⓒ $(v_f + v_i)^2/2d$
Ⓑ $(v_f^2 + v_i^2)/2d$ Ⓓ $(v_f^2 - v_i^2)/2d$

8. The graph shows the motion of a farmer's truck. What is the truck's total displacement? Assume that north is the positive direction.

Ⓐ 150 m south Ⓒ 300 m north
Ⓑ 125 m north Ⓓ 600 m south



9. How can the instantaneous acceleration of an object with varying acceleration be calculated?

Ⓐ by calculating the slope of the tangent on a distance-time graph
Ⓑ by calculating the area under the graph on a distance-time graph
Ⓒ by calculating the area under the graph on a velocity-time graph
Ⓓ by calculating the slope of the tangent on a velocity-time graph

Extended Answer

10. Graph the following data, and then show calculations for acceleration and displacement after 12.0 s on the graph.

Time (s)	Velocity (m/s)
0.00	8.10
6.00	36.9
9.00	51.3
12.00	65.7

✓ Test-Taking TIP

Tables

If a test question involves a table, skim the table before reading the question. Read the title, column heads, and row heads. Then read the question and interpret the information in the table.