Chapter 3 Organizer

Section/Objectives	Standards: National	Standards: State/Local	Lab and Demo Planning
Chapter Opener	See page 14T for a key to the standards.		
Section 3.1 1. **Define** acceleration. 2. **Relate** velocity and acceleration to the motion of objects. 3. **Create** velocity-time graphs.	UCP.2, UCP.3, A.1, A.2, B.4		**Student Lab:** **Launch Lab,** p. 57: spark timer, timer tape, constant-velocity vehicle, dynamics cart, masking tape, graph paper **Mini Lab,** p. 58: U-channel, book, meterstick, two steel balls
Section 3.2 4. **Interpret** position-time graphs for motion with constant acceleration. 5. **Determine** mathematical relationships among position, velocity, acceleration, and time. 6. **Apply** graphical and mathematical relationships to solve constant-acceleration problems.	UCP.2, UCP.3, B.4		**Teacher Demonstration:** **Quick Demo,** p. 66: one constant-velocity vehicle, 100-cm U-channel incline, ball **Quick Demo,** p. 69: U-channel, steel ball
Section 3.3 7. **Define** acceleration due to gravity. 8. **Solve** problems involving objects in free fall.	UCP.1, UCP.3, A.1, A.2, B.4, G.1, G.3		**Student Lab:** **Additional Mini Lab,** p. 73: meterstick, ball **Internet Physics Lab,** pp. 76–77: spark timer, timer tape, 1-kg mass, C-clamp, stack of newspapers, masking tape

Differentiated Instruction

L1 Level 1 activities should be appropriate for students with learning difficulties.

L2 Level 2 activities should be within the ability range of all students.

L3 Level 3 activities are designed for above-average students.

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FAST FILE Chapters 1–5 Resources, Chapter 3 Transparency 3-3 Master, p. 99 Study Guide, pp. 81–86 Section 3-2 Quiz, p. 88 **Teaching Transparency 3-3** **Connecting Math to Physics**	**Interactive Chalkboard CD-ROM:** Section 3.2 Presentation **TeacherWorks™ CD-ROM**
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Assessment Resources

FAST FILE Chapters 1-5 Resources, Chapter 3
Chapter Assessment, pp. 103–108

Additional Challenge Problems, p. 3
Physics Test Prep, pp. 5–6
Pre-AP Critical Thinking, pp. 5–6
Supplemental Problems, pp. 5–6

Technology
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Chapter 3

Accelerated Motion

Chapter Overview

The chapter introduces the concept of acceleration as the rate of change of velocity. Velocity-time graphs and position-time graphs are used to develop motion equations and an understanding of the concept of motion with constant acceleration. Students use these equations to solve problems involving motion with constant acceleration. The chapter ends with a discussion of free fall as an example of motion with constant acceleration.

Think About This

As the car speeds up, the distance it has traveled down the track becomes greater and the distance traveled each second becomes greater.

▶ Key Terms

velocity-time graph, p. 58
acceleration, p. 59
average acceleration, p. 59
instantaneous acceleration, p. 59
free fall, p. 72
acceleration due to gravity, p. 72

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
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Rob Tringali/SportsChrome

LAUNCH Lab

Purpose This activity helps students recognize and differentiate between uniform motion and accelerated motion.

Materials spark timer, timer tape, vehicle 1 (bulldozer/constant-velocity vehicle), vehicle 2 (dynamics cart), masking tape, graph paper

Teaching Strategies

CAUTION: Make sure the lab table remains stable to prevent it from falling over.

- Bulldozers (treaded vehicles) are often sold as constant-velocity vehicles.
- To keep students from developing preconceived ideas about the activity, do not refer to vehicle 1 as a constant-velocity vehicle.
- Vehicles may be shared between groups, since it should take only a few minutes to collect data.

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?

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

Expected Results The tape of vehicle 1 has uniformly spaced dots, while that of vehicle 2 has dots that are spaced increasingly farther apart.

Analysis Students should recognize that the dots represent the position of each of the vehicles at specific time intervals. Analysis of the spacing of the dots will reveal which vehicle is moving at a constant speed (no acceleration) and which is accelerating. Vehicle 1 moved with constant speed. Vehicle 2 increased speed. The tape for vehicle 1 has dots that are uniformly spaced, while the tape for vehicle 2 has dots that are spaced increasingly farther apart.

Critical Thinking The graph for constant speed is a straight line on a distance-versus-time graph, while accelerated motion is a curve with constantly increasing slope.

1 FOCUS

Bellringer Activity

A New Kind of Motion Show students an example of accelerated motion, such as a windup toy that slows down quickly or a cart rolled onto sandpaper. Avoid using free fall as an example, because the accelerated motion is difficult to observe. Have students describe differences between this type of motion and the uniform motion discussed in the previous chapter. **L1 Visual-Spatial**

Tie to Prior Knowledge

Motion Diagrams and Graphs Sketch a motion diagram and a displacement-time graph of a person moving at a constant velocity, and have students interpret them. Ask students what quantity the slope of the line of the *d*–*t* graph physically represents. velocity (rate of change of position) Point out that they will use slope-analysis technique to describe motion that has a constant rate of change of velocity. **L2 Visual-Spatial**

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2 TEACH

MINI LAB

A Steel Ball Race

See page 75 of **FAST FILE Chapters 1–5 Resources** *for the accompanying Mini Lab Worksheet.*

Purpose to investigate the acceleration of steel balls rolling on an inclined ramp

Materials U-channel, book, meterstick, two steel balls

Expected Results Students who confuse velocity and acceleration will predict that the second steel ball will gain on the first. However, the distance between the steel balls remains the same in Step 4 and increases in Step 5.

Analyze and Conclude

6. In Step 4, the instantaneous velocities of the balls are equal. At each moment in Step 5, the velocity of the second ball is greater than that of the first.

7. The distance between the balls remains the same in Step 4 because at each moment the velocities of both balls are equal and are apparently increasing at the same rate. In step 5, the distance between the two balls increases because at each moment the velocity of the first ball is greater than that of the second, and both velocities are apparently increasing at the same rate. (The distance between the two balls, d_{1-2}, is give by the equation $d_{1-2} = d + \sqrt{2adt}$, where d is the distance between the two balls when the second ball is released (0.40 m), a is the acceleration down the incline, and t is the time that the second ball has been moving.)

8. One can infer from the observations of Step 4 that the balls have the same acceleration.

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.

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.

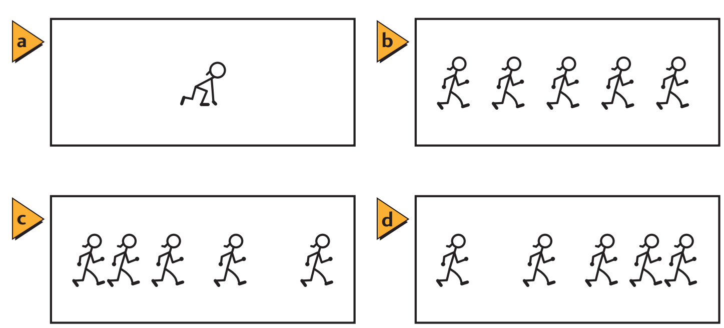
Consider the motion diagrams shown in **Figure 3-1.** How would you describe the motion of the person in each case? In one diagram, the person is motionless. In another, she is moving at a constant speed. In a third, she is speeding up, and in a fourth, she is slowing down. How do you know which one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



■ **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).**

3.1 Resource MANAGER

FAST FILE Chapters 1–5 Resources
- Transparency 3–1 Master, p. 95
- Transparency 3–2 Master, p. 97
- Study Guide, pp. 81–86
- Reinforcement, p. 91
- Section 3–1 Quiz, p. 87
- Mini Lab Worksheet, p. 75

Teaching Transparency 3-1
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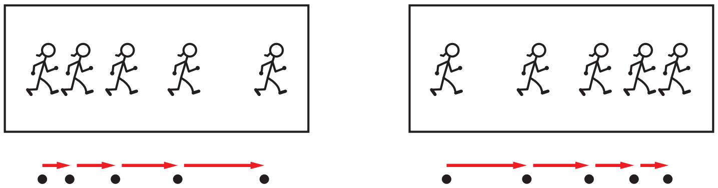


■ **Figure 3-2** The particle-model version of the motion diagram indicates the runner's changing velocity not only by the change in spacing of the position dots, but also by the change in length of the velocity vectors.

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.

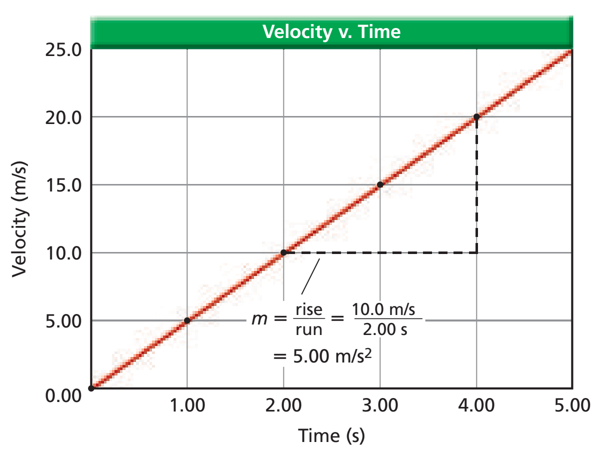
Average and Instantaneous Acceleration

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



Concept Development

Describing Velocity Changes Phrases such as "speed up" and "slow down" describe motion with specific changes in the velocity vector. If an object speeds up, consecutive velocity vectors in its motion diagram increase in length. If an object slows down, consecutive velocity vectors decrease in length.

■ Using Figure 3-2

Have students hold a plane mirror perpendicular to the page and look at Figure 3-2 and its reflection. Ask students why the left motion diagram in the figure and its mirror image both show motion that is speeding up even though the motion is in opposite directions. The velocity vectors are increasing in length. Have students confirm that the right diagram and its mirror image both show motion that is slowing down in opposite directions because the velocity vectors are decreasing in length.
L1 Visual-Spatial

Critical Thinking

Interpreting Graphs Ask students to interpret a horizontal line on a velocity-time graph. The object's motion has a constant velocity. Ask them to interpret a vertical line on the graph. The object simultaneously has many different instantaneous velocities, which is impossible in the same frame of reference. **L2 Visual-Spatial**

Teacher F.Y.I. **CONTENT BACKGROUND**

Acceleration in Common Usage In everyday English, the word *acceleration* is often used to describe a state of increasing speed. However, if an object slows down, there is also acceleration (in everyday language, de-acceleration). And, if an object in motion changes direction, such as a car going around a curve at constant speed, there is acceleration. For many students, their only experience with acceleration comes from car ads. When a commercial shouts "zero to sixty in 6.7 seconds" what it means is that this particular car takes 6.7 s to reach a speed of 60 mph starting from a complete stop. This example illustrates acceleration as it is commonly understood, but, as students will see, acceleration in physics is much more than just increasing speed.

Using Figure 3-4

Have students recall how they determined $\Delta \boldsymbol{d}$ in Chapter 2. Point out that the same technique is used to determine $\Delta \boldsymbol{v}$ in Figure 3-4. The definition of $\Delta \boldsymbol{v}$, $\boldsymbol{v}_f - \boldsymbol{v}_i$ is rewritten as $\boldsymbol{v}_f + (-\boldsymbol{v}_i)$ where $(-\boldsymbol{v}_i)$ is a vector equal in magnitude to $\boldsymbol{v}_i$ but in the opposite direction. The vector sum of $\boldsymbol{v}_f + (-\boldsymbol{v}_i)$—that is, $\Delta \boldsymbol{v}$—is a vector whose base is located at the base of $\boldsymbol{v}_f$ and whose tip is located at the tip of $\boldsymbol{v}_i$. **L2**

IN-CLASS Example

Question Describe a windup car's velocity and average acceleration, as shown in the graph.

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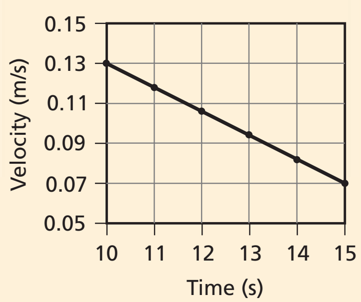
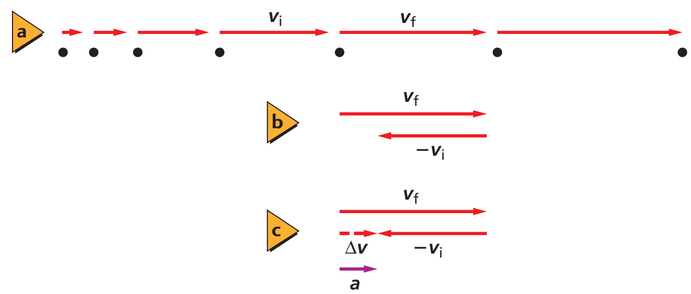


Answer The windup car's velocity decreases uniformly with an average acceleration of $-0.020\ \text{m/s}^2$. The acceleration is negative because it is opposite the direction chosen to be positive for the velocities.

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



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.

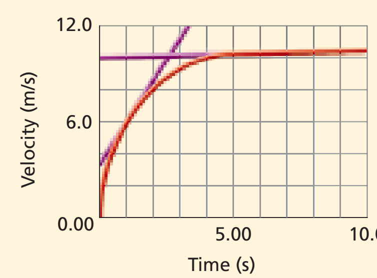
EXAMPLE Problem 1

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:	**Unknown:**
v = varies	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:

$$a = \frac{\text{rise}}{\text{run}}$$ **The slope of the line at 1.0 s is equal to the acceleration at that time.**

$$= \frac{11.0\ \text{m/s} - 2.8\ \text{m/s}}{2.4\ \text{s} - 0.00\ \text{s}}$$

$$= 3.4\ \text{m/s}^2$$

Solve for acceleration at 5.0 s:

$$a = \frac{\text{rise}}{\text{run}}$$ **The slope of the line at 5.0 s is equal to the acceleration at that time.**

$$= \frac{10.3\ \text{m/s} - 10.0\ \text{m/s}}{10.0\ \text{s} - 0.00\ \text{s}}$$

$$= 0.030\ \text{m/s}^2$$

Math Handbook
Slope
page 850

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

3 Evaluate the Answer

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

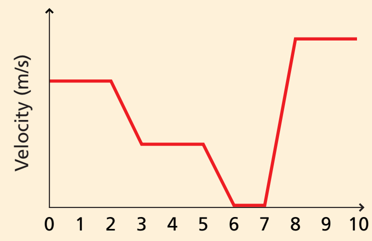
HELPING STRUGGLING STUDENTS Activity

Direction of $\Delta \boldsymbol{v}$ Emphasize that $\Delta \boldsymbol{v}$ is the change in velocity from $\boldsymbol{v}_i$ to $\boldsymbol{v}_f$. For example, in Figure 3-4, have students note that the speed of an object is increasing to the right, the length of the velocity vector stretches from $\boldsymbol{v}_i$ to $\boldsymbol{v}_f$ by an amount equal to the length Δv. Have students note that the direction of the vector $\Delta \boldsymbol{v}$ is in the direction of motion. Have students draw the motion diagram of an object slowing to the right, noting that the velocity vector reduces in length from $\boldsymbol{v}_i$ to $\boldsymbol{v}_f$ by the amount Δv. Because the vector has reduced in length, the direction of the change in the velocity vector, $\Delta \boldsymbol{v}$, is to the left, opposite the direction of motion. **L2** **Visual-Spatial**

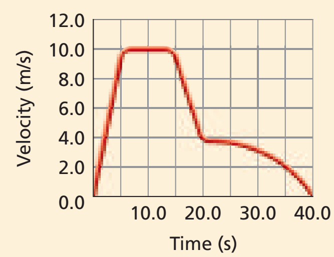
▶ PRACTICE Problems

Additional Problems, Appendix B

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.



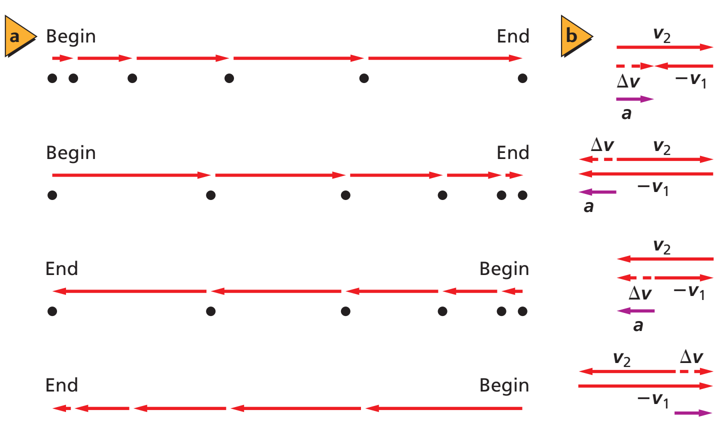
■ **Figure 3-5**



■ **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).**

▶ PRACTICE Problems

1. See Solutions Manual.
2. See Solutions Manual.
3. **a.** 5.0 to 15.0 s
   b. 0.0 to 5.0 s
   c. 15.0 to 20.0 s
4. **a.** 2.0 m/s^2
   b. -1.2 m/s^2
   c. 0.0 m/s^2
5. See Solutions Manual.

■ Using Figure 3-7

Have students note that in the first and third motion diagrams, the lengths of the velocity vectors are increasing, indicating that the object is gaining speed. Have them also note that $\boldsymbol{v}_1$, $\boldsymbol{v}_2$, $\Delta \boldsymbol{v}$, and $\boldsymbol{a}$ have the same direction. Point out that one can then predict that an object will speed up if its acceleration is in the same direction as its motion. Have students use analogous arguments to predict under what conditions an object will slow down. **L2**

Identifying Misconceptions

Positive and Negative Acceleration Students often associate positive acceleration solely with speeding up and negative acceleration with slowing down. Ask students what effect a positive acceleration will have on an object moving in the positive direction. The object will speed up. Then, ask them what effect a negative acceleration will have on an object moving in the negative direction. The object will speed up. **L2**

DIFFERENTIATED INSTRUCTION Activity

Visually Impaired To aid students in comprehending Figure 3-7, construct vectors that the visually impaired student can distinguish by tactile experience. For example, from a piece of cardboard, cut two arrows 10 cm and 20 cm in length to represent two different $\boldsymbol{v}_2$ vectors. Glue a piece of sandpaper to the cardboard and cut a 15-cm-long arrow. Glue a scrap piece of felt to another piece of cardboard and cut a 5-cm arrow. Pair a sighted student with the visually impaired student and have the team use the arrows to construct each of the cases in Figure 3-7. In each case, the visually impaired student can manipulate and determine the magnitude and direction $\boldsymbol{v}_1$, $\boldsymbol{v}_2$, and $\Delta \boldsymbol{v}$ by touch. **L1 Kinesthetic**

Discussion

Question A classmate is skateboarding along a level surface into a very strong wind, which slows her and eventually moves her backward. As her motion changes direction, what is her velocity? Is her acceleration as her motion changes positive, negative, or zero?

Answer The instant she changes direction, her instantaneous velocity is zero. If her initial direction of motion is positive, then her acceleration is negative, and vice versa. L2

Using an Analogy

Rate of a Rate Change Units Point out that the acceleration unit, m/s^2, measures the rate at which a rate is changing. Write the unit as (m/s)/s. Make an analogy to more a common rate of a changing rate. Point out that during exercise, one's pulse rate increases. Write the expression, (beats/min)/min, on the chalkboard and state the unit as "beats per minute per minute." Have students interpret what the unit beats/min^2 measures. Rate of change in pulse rate. L2

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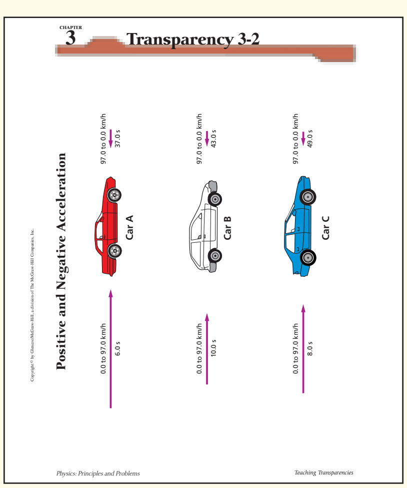
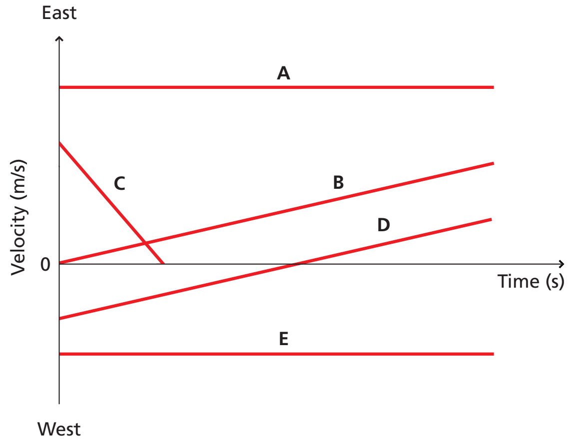
Page 97, FAST FILE Chapters 1–5 Resources





■ **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 equal to the change in velocity, divided by the time it takes to make that change.

Teacher F.Y.I. CONTENT BACKGROUND

Deceleration The text does not use the term *deceleration* because of ambiguity in its interpretation. To some, deceleration implies "slowing down"—that is, reducing speed. To others, deceleration implies "negative acceleration." As this section emphasizes, a negative acceleration could be either a slowing down or a speeding up, depending on how the coordinate system is assigned.

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?

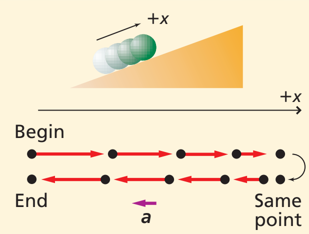
$$\bar{a} \equiv \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

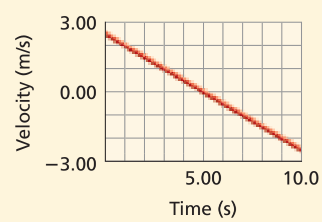
$$= \frac{(-4.0\ \text{m/s}) - (4.0\ \text{m/s})}{10.0\ \text{s}} = \frac{-8.0\ \text{m/s}}{10.0\ \text{s}} = -0.80\ \text{m/s}^2$$

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:
$v_i = +2.5$ m/s
$v_f = 0.00$ m/s at $t = 5.00$ s

Unknown:
$a = ?$

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.

Reinforcement

Direction of Acceleration Have students draw a motion diagram for the following situation, assuming the forward direction is positive. A stopped car (a) backs up, (b) stops, (c) moves forward, and then (d) stops. Ask students to identify which motions have positive accelerations and which have negative accelerations. Motions (a) and (c) have positive accelerations; (b) and (d) have negative accelerations.
L1 Visual-Spatial

IN-CLASS Example

Question A hockey player glides along the ice at a constant speed of 1.25 m/s in the positive direction onto a rough section of ice, which slows him. If he stops in 5.0 s, what is the magnitude and direction of his acceleration?

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Answer

$a = \frac{\Delta v}{\Delta t} = \frac{1.25\ \text{m/s}}{5.0\ \text{s}}$

$= 0.25\ \text{m/s}^2$, negative

PHYSICS PROJECT Activity

Slowest Speeded-Up Motion Challenge teams of students to demonstrate motions that have a very small, constant acceleration (other than zero) in the direction of motion. The motion may include motion of an object on an incline or in free fall. Each team must demonstrate to the class that the motion lasts for at least three seconds and then must support its claim with appropriate data that the acceleration is constant during this time. **L2 Kinesthetic**

PRACTICE Problems

6. 8.0 m/s^2
7. -7.0 m/s^2
8. 3.0 m/s^2
9. a. -8.3 m/s^2
   b. Half as great (-4.2 m/s^2).
10. -0.28 m/s^2
11. -0.5 cm/yr^2

ACTIVITY

Moving Graphs For each student, prepare an index card with a different *v-t* graph sketched on it. Set up a coordinate system in the classroom and have each student demonstrate the motion represented by the graph. Have classmates volunteer to sketch on the chalkboard the graph that they think represents the motion demonstrated by the student. **L1 Kinesthetic**

3 ASSESS

Reteach

Motion and Vectors Draw two consecutive velocity vectors of increasing length and same direction on the chalkboard, labeling them v_1 and v_2, respectively. Explain that the two velocities are positive. Have students explain how they would use the velocity vectors to find the direction of the acceleration vector. Find Δv by subtracting v_1 from v_2. The direction of a is that of Δv. **L2 Visual-Spatial**

Extension

Experiences with Accelerated Motion Ask students to describe experiences that they have had within the past day or so involving accelerated motion. Have students estimate the accelerations or explain how they might measure them. **L2**

PRACTICE Problems

Additional Problems, Appendix B

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.

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3.1 Section Review

12. The velocity at any time, the time at which the object had a particular velocity, the sign of the velocity, and the displacement.
13. a. They would have the same slope, but would rise from the *d*-axis at $+15$ m and -15 m.
    b. Their graphs would be identical.
14. Draw a horizontal line at the specified velocity. Find the point where the graph intersects this line. Drop a line to the *t*-axis. This would be the required time.
15. See Solutions Manual.
16. a. -1 m/s b. -0.8 m/s^2
17. See Solutions Manual. No, they had the same position, not velocity. To have the same velocity, they would have had to have the same relative position for a length of time.

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.

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,

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

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

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

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

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

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.

▶ **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.

PRACTICE Problems

Additional Problems, Appendix B

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?

Section 3.2

1 FOCUS

Bellringer Activity

Incline Motion Construct two U-channel inclines at visibly different angles. Have students observe as you release a steel ball from rest on each incline. Ask students for evidence that the balls had different accelerations. It took different times for the balls to move the same distance from rest.
L1 **Visual-Spatial**

Tie to Prior Knowledge

Slope and Average Acceleration Remind students that in Section 3-1, they determined that the slope of a velocity-time graph is the equation for average acceleration.

2 TEACH

PRACTICE Problems

18. a. 1.0 m/s **b.** −1.0 m/s

c. The ball's velocity decreased in the first case. In the second, the ball slowed to a stop and then began rolling back down the hill. See Solutions Manual.

19. 120 km/h

20. 5.1 s

21. 9.0 s

3.2 Resource MANAGER

FAST FILE Chapters 1–5 Resources
- Transparency 3–3 Master, p. 99
- Study Guide, pp. 81–86
- Section 3–2 Quiz, p. 88

Teaching Transparency 3-3
Connecting Math to Physics

Technology
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Exam*View*® Pro Testmaker CD-ROM
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QUICK DEMO

Average and Final Velocity

Estimated Time 15 minutes

Materials one constant-velocity vehicle, 100-cm U-channel incline, ball

Procedure Incline the U-channel so that the ball and vehicle travel 100 cm in the same time. Point out that the vehicle and the ball will both move 100 cm in the same time. Release the ball from rest at the top of the incline just as the vehicle begins its 100-cm trip. Have students observe that both reach the end of the ramp at the same time. Be sure to have a student stop the ball before it moves off the ramp. Have students agree that the magnitude of the average velocity of each vehicle was the same. Point out that the final velocity of the ball can be related to its average velocity. Repeat the demonstration but let the ball roll off the ramp. Stop the ball and the vehicle simultaneously and show that the ball has moved twice as far from the end of the ramp as the vehicle. Ask how fast the ball was moving compared to the vehicle. twice as fast because it went twice as far from the end of the ramp Explain that the final velocity of an object moving with constant acceleration from rest is twice its average velocity during the time interval.

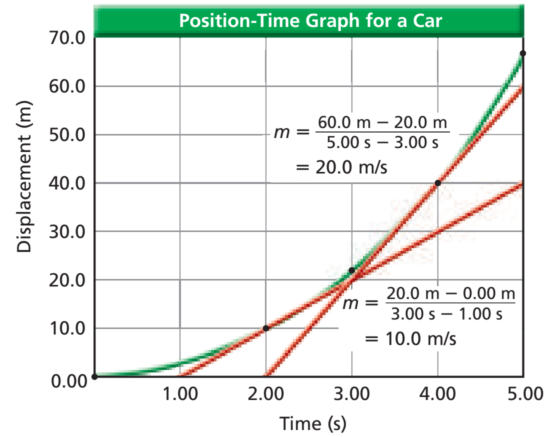
Discussion

Question Return to the Bellringer Activity. Ask students the ways in which both balls could reach the bottom at the same time. Categorize their conclusions according to changes in inclination, v_1, or d, and then test their conclusions.

Answer Answers should include changing the inclination of one of the channels so they are equal, changing the initial speed, or changing the starting point of one of the balls. L2

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



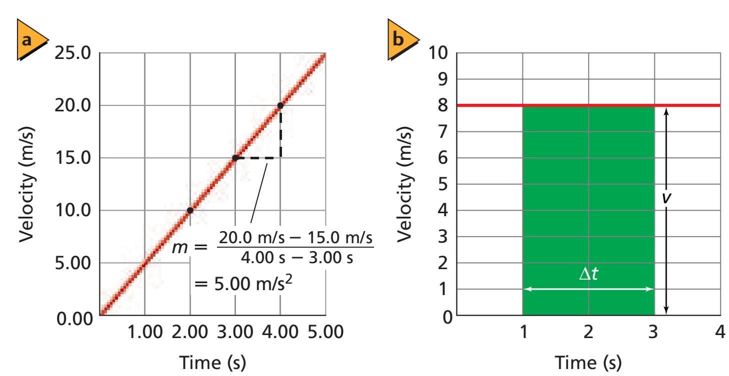
■ **Figure 3-9** The slope of a position-time graph of a car moving with a constant acceleration gets steeper as time goes on.

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).**

CHALLENGE Activity

Deriving $d_f = \left(\frac{1}{2}\right)at_f^2$ Have students use the result of the Quick Demo (the final velocity of an object moving with constant acceleration from rest equals twice its average velocity during that time interval) and the definition of $\bar{a}$ to show that $d_f = \frac{1}{2}at^2$ for an object initially at rest. If $v_i = 0$, $t_i = 0$, and $d_i = 0$, then $v_f = at_f = 2v_{ave} = 2\frac{d_f}{t_f}$ or $at_f = 2\frac{d_f}{t_f}$. Solving for d_f yields $d_f = \frac{a(t_f)^2}{2} = \frac{1}{2}at_f^2$.

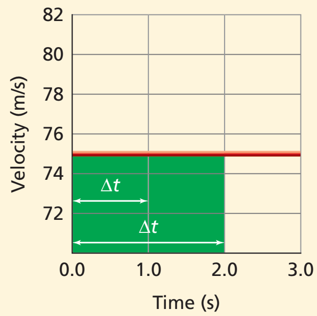
L3 **Logical-Mathematical**

▶ 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.

$\Delta d = v\Delta t$

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

$= +75$ m

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

$\Delta d = v\Delta t$

$= (+75 \text{ m/s})(2.0 \text{ s})$ — **Substitute $v = +75$ m/s, $\Delta t = 2.0$ s**

$= +150$ 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

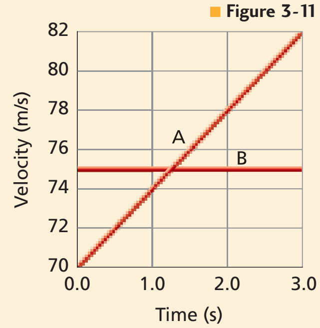
22. Use **Figure 3-11** to determine the velocity of an airplane that is speeding up at each of the following times.
a. 1.0 s **b.** 2.0 s **c.** 2.5 s

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

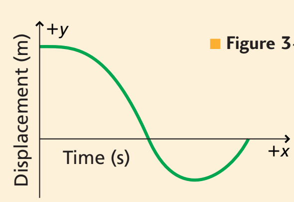
24. A position-time graph for a pony running in a field is shown in **Figure 3-12.** Draw the corresponding velocity-time graph using the same time scale.

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

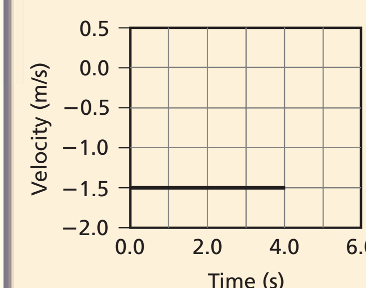


■ Using Figure 3-10a

Have students use the data in Table 3-2 to construct a d–t graph. Then allow them to determine the slope at various times, such as $t = 1.0$ s and 3.0 s and then check their calculations against the values plotted in Figure 3-10a. **L2**

▶ IN-CLASS Example

Question The v-t graph below represents the motion of a car backing out of a driveway. What is the car's displacement at $t = 4.0$ s?



Answer

$d = vt = (-1.5 \text{ m/s})(4.0 \text{ s})$

$= -6.0$ m

Identifying Misconceptions

Area Under a v-t Graph In Example Problem 3, students may consider the height of the area to be 75 m/s − 70 m/s. Remind students that v is the height of the plotted line above the t-axis, which is understood to intersect the v-axis at $v = 0$.

HELPING STRUGGLING STUDENTS Activity

Area of a v-t graph Most students have calculated the surface area of a block by multiplying two perpendicular length measurements. Point out that any area has a dimension that is the product of the dimension displayed along the x-axis and the dimension displayed along the y-axis. In a v-t graph, the x-axis displays time and the y-axis displays a rate (velocity). The dimension of this area is (m/s)s = m, which is a physical quantity. Thus, the area represents a physical quantity. Have students consider another rate-time graph—one in which pay rate ($/h) is plotted on the y-axis and daily hours worked in a week (h) on the x-axis. Ask students what the area of this graph represents and what is its dimension. weekly pay, dollars **L1 Visual-Spatial**

▶ PRACTICE Problems

22. a. 74 m/s **b.** 78 m/s
c. 80 m/s

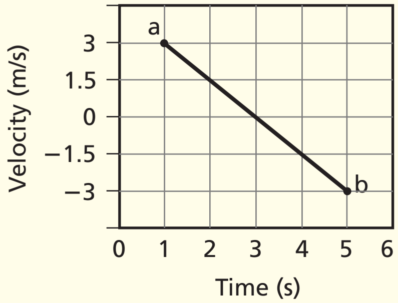
23. 2.7×10^2 km/h

24. See Solutions Manual.

25. a. See Solutions Manual.
distance: 1.8 km
time: 25 min
b. See Solutions Manual.

Critical Thinking

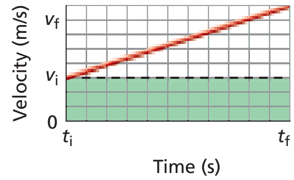
Positive and Negative Areas of a *v-t* Graph On the chalkboard, sketch the graph below.



Have students explain what the displacement is for the time interval t_a–t_b. The displacement is 0 m. The areas bounded by v and the t-axis during the first half and second half of the time interval are equal, which indicates equal distances traveled. However, the first displacement is positive, while the second is negative. The total displacement for the interval is the sum of two equal-sized displacements in opposite directions, which is 0 m. **L3 Visual-Spatial**

APPLYING PHYSICS

▶ Explain to students that when a race car is trying to achieve maximum acceleration, the weight distribution and traction of the vehicle is affected. Draw a graph that shows as acceleration increases, the weight on the front wheels decreases, while the weight on the rear wheels increases. The weight that must be placed on the front wheels in order for the tires to grip, called the traction limit, also increases during acceleration. Thus, as the force increases during acceleration, the reaction force and traction decrease in the front of the car and increase in the rear. The limit to acceleration is the point at which the traction is reached, or when the front wheels lift off the ground and there is a loss of directional control. ◀



■ **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 $\Delta d_{\text{rectangle}} = v_i\Delta t$, and the area of the triangle can be found by $\Delta d_{\text{triangle}} = \frac{1}{2}\Delta v\Delta t$. 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 $\Delta d_{\text{triangle}} = \frac{1}{2}(\bar{a}\Delta t)\Delta t$, or $\frac{1}{2}\bar{a}(\Delta t)^2$. Solving for the total area under the graph results in the following:

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

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

An object's position at a time after the initial time is equal to the sum of its initial position, the product of the initial velocity and the time, and half the product of the acceleration and the square of the 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). ◀

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

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

Teacher F.Y.I.

REAL-LIFE CAREERS

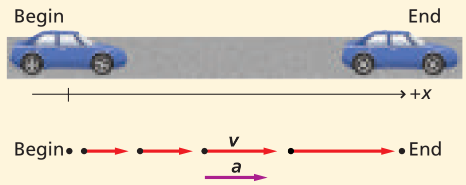
Motion Control Engineering Many manufacturing companies make use of robotics to automatically fabricate and package their products along advanced conveyor systems. Motion control engineers are responsible for designing robotic automation systems, integrating the operation of a variety of mechanical, optical, and electronic devices. To make sure products are manufactured properly, motion control engineers address such questions as how fast and how far an object must move on a conveyor, when the object should be moving, and where it must be at any given time. The precise determination of acceleration, velocity, and position of an object at any given time during system operation is an essential aspect to this work.

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

Math Handbook
Order of Operations
page 843

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

$$= 89\text{ m}$$

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

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?

IN-CLASS Example

INTERACTIVE CHALKBOARD with Image Bank PowerPoint® Presentations

Question Joni jogs at a velocity of 2.50 m/s. If she then accelerates at a constant -0.10 m/s^2, how fast will she be jogging when she has moved 10.0 m?

Answer

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

$v_f^2 = 2(0.10\text{ m/s})^2(10.0\text{ m} - 0\text{ m})$

$= 2.1$ m/s

PRACTICE Problems

26. 8.8 s

27. 1.2×10^2 m

28. 25 s

29. 0.94 m/s

QUICK DEMO

Relating Vectors *a* and *v*

Estimated Time 10 minutes

Materials U-channel, steel ball

Procedure Arrange the U-channel to form a trough with sides of equal slant. Before releasing a steel ball from rest down the left incline (facing the students), have students predict how far the ball will roll up the right incline. Release the ball and have students observe that within experimental limits, the distances are equal. Use the demonstration to review the algebraic sign of the ball's acceleration on each incline if motion to the right is positive. Positive on the first incline and negative on the second. Ask students why they can use the equation $v_f^2 = 2ad + v_i^2$ to show that the magnitude of the ball's acceleration on each incline is the same. The ball's final velocity on the first incline equals its initial velocity on the second incline.

CHALLENGE Activity

Equal but Opposite Accelerations Have students collect displacement data from the Quick Demo above. From the displacement data, have them calculate the magnitudes of the two accelerations. They will discover that the magnitude of the acceleration on the first incline is equal to the magnitude of the acceleration on the second incline. As an alternative method, have them show that the two accelerations are equal in magnitude by considering the time for the ball to traverse the first incline and then the second. **L3 Logical-Mathematical**

Concept Development

Motion with Different Accelerations Remind students that motion problems must be broken into parts whenever the acceleration changes. For example, in Example Problem 5, part 1, a is 0 m/s^2; in part 2, a is 8.5 m/s^2.

Reinforcement

Validity of Equations Refer students to the equations in Table 3-3 on page 68 and ask them under what conditions these equations model motion. The equations model motion that has constant acceleration, including $a = 0$. L2

IN-CLASS Example

Question A cat runs at 2.0 m/s for 3.0 s, then slows to a stop with an acceleration of −0.80 m/s^2. What is the cat's displacement during this motion?

Answer

$d_i = (2.0\text{ m/s})(3.0\text{ s}) = 6.0\text{ m};$

$$d_f = \frac{v_f^2 - v_i^2}{2a} = \frac{(0.0\text{ m/s})^2 - (2.0\text{ m/s})^2}{2(-0.80\text{ m/s}^2)} = 2.5\text{ m};$$

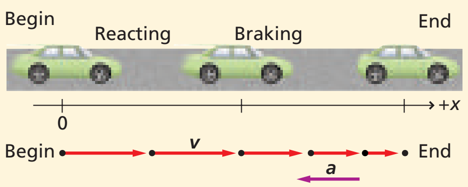
$$d_{total} = d_i + d_f = 6.0\text{ m} + 2.5\text{ m} = +8.5\text{ m}$$

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:	Unknown:
$v_{reacting} = 25$ m/s	$d_{reacting} = ?$
$t_{reacting} = 0.45$ s	$d_{braking} = ?$
$\bar{a} = a_{braking} = -8.5$ m/s^2	$d_{total} = ?$
$v_{i,\,braking} = 25$ m/s	
$v_{f,\,braking} = 0.00$ m/s	

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 $d_{braking}$.

Math Handbook
Isolating a Variable
page 845

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

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

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

$$= 37\text{ m}$$

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.

Teacher F.Y.I. — REAL-LIFE PHYSICS

Real-Life Accelerations To give students a feeling for different magnitudes of acceleration, the following data can be shared. A reasonable braking acceleration for automobiles is about 7 m/s^2 for dry surfaces and 4.0 m/s^2 on wet surfaces. Linearly launched roller coasters have an initial acceleration of 10–20 m/s^2. The space shuttle accelerates vertically at about 30 m/s^2 at takeoff.

PRACTICE Problems

Additional Problems, Appendix B

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.

Physics Online physicspp.com/self_check_quiz

3.2 Section Review

34. -1.3 m/s^2

35. $v_f^2 = v_i^2 + 2ad_f$

36. 34 m

37. 71 m/s

38. 7.0×10^1 m/s

39. a. 1.35×10^3 m

b. 90.0 m/s

40. See Solutions Manual.

41. One person reads a stopwatch and calls out time intervals. Another person reads the speedometer at each time and records it. Plot speed versus time and find the slope.

PRACTICE Problems

30. 4.3×10^3 m

31. See Solutions Manual. 27 m

32. 1.16×10^3 m

33. 0.077 m/s^2

3 ASSESS

Check for Understanding

Motion Equations Write the equation $v_f = v_i + at_f$ on the chalkboard. Ask students to explain if that equation could be used to calculate the answer to the following problem. Calculate the final velocity of a car that has a constant acceleration of 2.0 m/s^2 for 4.0 s. It can't be used because both the direction of the acceleration and the car's initial velocity are unknown. **L1**

Reteach

Motion Equations State the above problem again, and explain that the information can be used only to calculate the size of Δv. Point out that because neither the direction of a nor Δv is known, one cannot determine whether the car is speeding up or slowing down. Now state the following problem. What is the final velocity of a car that travels at a constant acceleration of 2.0 m/s^2 in the direction of motion for 4.0 s, with an initial velocity of 3.0 m/s east? Guide students in drawing motion diagrams and substituting the correct algebraic values in the equation. 11 m/s east

L2 Visual-Spatial

1 FOCUS

Bellringer Activity

Vertical Incline Show students a U-channel inclined at about 30°, and then raise it to about at 60°. Ask them on which incline would a rubber ball have a greater constant acceleration. The steeper one. Hold the U-channel vertically and drop a ball along it. Have the students draw upon the first two examples and ask them if they think that the ball most likely has a constant downward acceleration. **L2** **Visual-Spatial**

Tie to Prior Knowledge

Analyzing and Describing Free Fall All graphical methods of analyzing motion with constant acceleration and the relevant equations developed in Sections 3.1 and 3.2 can be applied to free fall.

2 TEACH

Identifying Misconceptions

Graphs and Paths For those students who were unsure of the correct response to Using Figure 3-15 above, point out that the parabolic shape is that of the *equation* relating displacement and time. To emphasize this point, have students refer to Figure 3-14. Ask them what shape would be produced if each successive image of the egg were moved slightly to the right and a line were drawn to connect them. Half a parabola. Point out that the *d–t* graphs shown in Figure 3-15 represent a series of snapshots separated by time of an object moving in a straight line. **L2**

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.

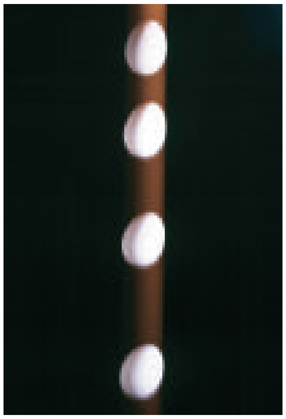
Galileo concluded that, neglecting the effect of the air, all objects in free fall had the same acceleration. It didn't matter what they were made of, how much they weighed, what height they were dropped from, or whether they were dropped or thrown. The acceleration of falling objects, given a special 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.



3.3 Resource MANAGER

FAST FILE Chapters 1–5 Resources
Transparency 3–4 Master, p. 101
Study Guide, pp. 81–86
Section 3–3 Quiz, p. 89
Physics Lab Worksheet, pp. 77–80
Teaching Transparency 3-4
Connecting Math to Physics

Technology
TeacherWorks™ CD-ROM
Interactive Chalkboard CD-ROM
Exam*View*® Pro Testmaker CD-ROM
physicspp.com
physicspp.com/vocabulary_puzzlemaker

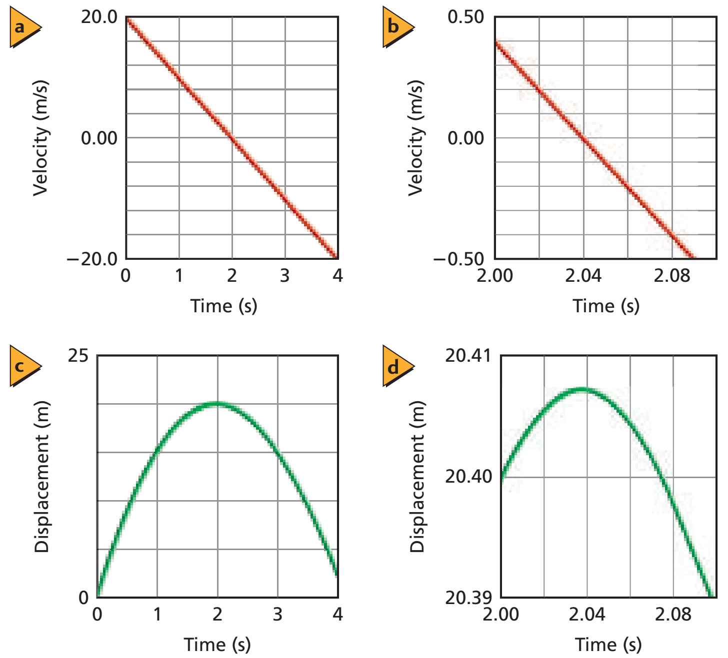


Figure 3-15 In a coordinate system in which the upward direction is positive, the velocity of the thrown ball decreases until it becomes zero at 2.04 s. Then it increases in the negative direction as the ball falls **(a, b).** The *p-t* graphs show the height of the ball at corresponding time intervals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

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 $-9.80\ m/s^2$.

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.

Using Figure 3-15

Ask students if the parabolic line of the displacement-time graph is the path of the moving ball. No, the ball is moving vertically in a straight line. L2

Additional MINI LAB

Free Fall

Estimated Time 10 minutes

Purpose Students will use free fall to estimate acceleration due to gravity.

Materials meterstick, ball

Procedure Have students practice making crude quarter-second measurements by counting "one one-thousand, two one-thousand," and so on. From a height of 1.0 m, drop the ball to the floor. Use the above counting method to time the fall. Then calculate the ball's approximate acceleration

from the equation $d_f = \frac{1}{2} a t_f^2$

for $t_f = 0.5$ s, $a = 8\ m/s^2$

Assessment Have students predict if other objects in free fall will have the same acceleration. They can test their predictions using other objects. Finally, ask them if there would be instances in which an object in free fall would not accelerate at their calculated value for acceleration.

Concept Development

Special Case To emphasize that free fall is just a special case of motion with constant acceleration, always write the general form of the constant-acceleration equation first, before substituting in any values (such as g or $-g$ for a). Encourage students to do the same.

THE MECHANICAL UNIVERSE

HIGH SCHOOL ADAPTATION

Videotape

The Law of Falling Bodies

CHALLENGE Activity

Motion Photographs The photograph of the falling egg on page 72 was made with a camera using light from a stroboscope. The stroboscope is an instrument that provides intermittent illumination of an object to study various aspects of its motion, such as its speed or frequency of vibration. The stroboscope causes the object to appear to slow down or even stop by producing illumination in short bursts of about 1 μs at a selected frequency. Provide the students with several images of objects in free fall, similar to the photograph of the falling egg. Provide them with data regarding position and time interval and have them calculate the velocity and acceleration of the object. L3 **Logical-Mathematical**

Using Models

Vertical Motion Diagrams Have students sketch a motion diagram of an object moving horizontally with a constant acceleration in the direction of motion. Have them rotate their sketches so that the velocity vectors point downward. Point out that they now have a model for motion in free fall—the acceleration is always downward (and on Earth, usually equal to 9.80 m/s^2). **L2 Visual-Spatial**

Reinforcement

$\pm g$ Divide the students into two groups and have one group calculate the time for an object to fall 2.0 m from rest, assuming upward motion is positive. Have the other group do the same calculation assuming downward motion is positive. Have each group explain the calculation, and have the class compare the two answers. **L1 Interpersonal**

Critical Thinking

Acceleration Toss a ball in the air and ask students what the acceleration of the ball is at the very top of its flight. The acceleration of the ball throughout its flight (even at its highest point) is 9.80 m/s^2. If students have difficulty with this concept, ask them to describe the change in speed and acceleration as the ball rises and then falls, including when the ball is at its highest point. At its highest point, the speed of the ball is 0 m/s. Does the acceleration ever change? No—it is always 9.80 m/s^2. **L3**

PRACTICE Problems

42. a. −39 m/s (upward is positive)
b. 78 m
43. a. +39 m/s (downward is positive)
b. 78 m
44. 8.3 m/s
45. a. 25.8 m **b.** 4.60 s
46. a. 2.2 m/s **b.** 0.45 s

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

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?

Teacher F.Y.I. — CONTENT BACKGROUND

Motion with Nonconstant Acceleration Although the acceleration of gravity is assumed constant near Earth, it varies inversely with the square of the distance from the center of Earth. Thus, g cannot be considered constant over long distances. On a much smaller distance scale, the non-uniform motion of a body on a spring, a falling raindrop, or a charged particle are other examples of motion with non-constant acceleration. The equations developed in this chapter cannot be used to model this motion. However, such motion can be modeled by calculus and by the use of specialized computer programs, such as spreadsheets.

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

3.3 Section Review

47. a. three times higher

b. three times as long

48. Velocity is reduced at a constant rate as the ball travels upward. At its highest point, velocity is zero. As the ball begins to drop, the velocity begins to increase in the negative direction until it reaches the height from which it was initially released. At that point, the ball has the same speed it had upon release. The acceleration is constant throughout the ball's flight.

49. 9.2 m/s

50. 15 m/s

51. 11 m

52. The ball is accelerating; its velocity is changing. Take a strobe photo to measure its position. From photos, calculate the ball's velocity.

CHALLENGE PROBLEM

Down is positive. Work this problem in two stages. Stage 1 is falling the distance D to the top of the window. Stage 2 is falling the distance y from the top of the window to the bottom of the window.

Stage 1: the origin is at the top of the fall.

$$v_{f1}^2 = v_{i1}^2 + 2a(d_{f1} - d_{i1})$$
$$= 0 + 2g(D - 0)$$
$$v_{f1} = \sqrt{2gD}$$

Stage 2: the origin is at the top of the window.

$$d_{f2} = d_{i1} + v_{i1}t_{f2} + \frac{1}{2}at_{f2}^2$$
$$y = 0 + v_{f1}t + \frac{1}{2}gt^2$$
$$= 0 + \left(\sqrt{2gD}\right)(t) + \frac{1}{2}gt^2$$
$$\sqrt{2gD} = \frac{y}{t} - \frac{gt}{2}$$

or $D = \frac{1}{2g}\left(\frac{y}{t} - \frac{gt}{2}\right)^2$.

3 ASSESS

Check for Understanding

Free-Fall Motion and Initial Conditions Draw a diagram similar to that shown in Figure 3-14 and tell students that it represents the motion of a ball in free fall. Have students identify two different sets of initial conditions that would produce such a diagram. A ball falling from rest and a ball moving (being thrown) upward L2

Reteach

Free-Fall Motion Using the diagram above, draw velocity vectors for the ball falling from rest. Indicate that upward is chosen as the positive direction. Point out that acceleration due to gravity is downward because the velocity vectors are increasing in length downward, and that its value is -9.80 m/s^2. Guide students as they analyze in a similar way the motion of the ball moving upward in free fall. L2

PHYSICSLAB • Internet

Time Allotment
one laboratory period

Process Skills measure, interpret data, analyze, compare and contrast, communicate

Safety Precautions Caution students not to drop the mass on their feet or toes. They should wear only closed-toed shoes.

Alternative Materials apparatus with electronic timers that measure the time it takes a steel ball to fall a specified distance

Teaching Strategies
- **Encourage students to measure as accurately as possible.**
- **Calibrate the timers before the lab. However, you may wish to demonstrate how to calibrate the timers to your students.**
- **Do not have a stack of papers that is too high to allow for adequate data. Have enough paper to cushion the fall of the mass.**

Sample Data
Timer period (#/s) = 1/60 s

Interval	Distance (cm)	Time (s)	Distance/ Time (cm/s)
1	1.6	1/60	96
2	3.4	2/60	1.0×10^2
3	5.6	3/60	1.1×10^2
4	8.0	4/60	1.2×10^2
5	10.6	5/60	127
6	13.6	6/60	136
7	16.9	7/60	145
8	20.3	8/60	152
9	24.1	9/60	161
10	28.1	10/60	169
11	32.5	11/60	177
12	37.0	12/60	185
13	41.9	13/60	193

PHYSICSLAB • Internet

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

Acceleration Due to Gravity

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 $d_f = v_i t_f + \frac{1}{2}a t_f^2$. Dividing both sides of the equation by t_f yields the following: $d_f/t_f = v_i + \frac{1}{2}a t_f$. 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

Horizons Companies

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.

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.

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

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?

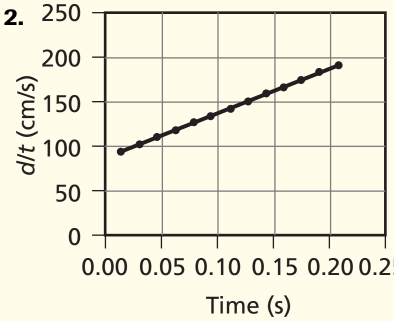
Share Your Data

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**

Analyze

1. See sample data table.
2. 

3. Sample slope
   $$= \frac{192.4\ \text{cm/s} - 112\ \text{cm/s}}{13/60\ \text{s} - 3/60\ \text{s}}$$
   $= 482\ \text{cm/s}^2$
   $= 4.82\ \text{m/s}^2$

Conclude and Apply

1. $g = (2)(4.82\ \text{m/s}^2)$
   $= 9.64\ \text{m/s}^2$
2. % error
   $$= \frac{9.80\ \text{m/s}^2 - 9.64\ \text{m/s}^2}{9.80\ \text{m/s}^2} \times 100$$
   $= 1.63\%$
3. From y-intercept of graph, $v_i = 0.83$ m/s.

Going Further

Answers will vary. Possible answers may include: error was reduced by not having to use the beginning of the timer tape, which may have jerked when it was first dropped; the dots may be very close together at the beginning, making it difficult to accurately count; or there may have been a lag in time from when the dot was made and when the mass was dropped at rest, creating a small error.

Real-World Physics

The curved section gradually reduces the acceleration along the curve. The acceleration along the straight portion of the exit track is negative and causes the rapidly moving cart to slow. Both sections prevent a sudden decrease in velocity of the cart, which might cause injuries to its passengers.

ALTERNATIVE INQUIRY LAB

To Make this Lab an Inquiry Lab: Ask students the following: How can acceleration due to gravity, g, be determined using $d_f - d_i = v_i(t_f - t_i) + \frac{1}{2}a(t_f - t_i)^2$ and a spark timer? Students can explore various methods of using the spark timer before writing procedures. For example, if students begin measuring distance from the moment the mass is dropped, then $v_i = 0$, which simplifies the above relationship. Some students may devise a method similar to the one described in this lab and others may choose to investigate g using $v_i = 0$. Groups could compare and contrast results and techniques.

Background

Time dilation is a consequence of Einstein's theory of relativity, which has been supported by the results of thousands of experiments. Although time dilation occurs in any moving frame of reference, it is only significant at speeds achieved in nuclear particle accelerators. The concept is inherently non-intuitive, even to those who have understood it for years. Note that a frame of reference—say, the rocket—subjected to time dilation or other results of relativity would be unaffected: the astronauts would not feel any different.

Teaching Strategies

- Review with students the concepts of speed, distance, and frames of reference.
- The concept of time dilation is about 100 years old and has been supported by many types of experiments. In one type of experiment, subatomic particles are accelerated to speeds close to c and a decrease in their rate of decay is observed.

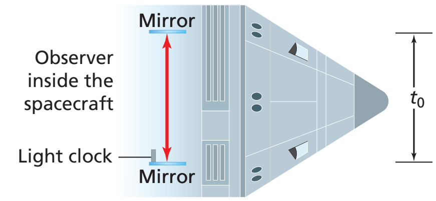
Discussion

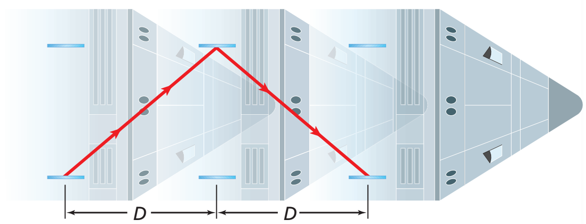
Speed Limitations Can $v = c$? Ask students to explain why it can or cannot. A discussion of whether velocity can equal the speed of light can include the exploration of many complex topics, including black holes and receding galaxies. Some scientists study the distances at which galaxies appear to be receding from us faster than the speed of light. However, the time dilation effect, our position within Earth's gravitational field, and our own relative velocity situated on Earth might prevent us from being able to accurately measure these phenomena.

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?





Observer on Earth

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?

THE MECHANICAL UNIVERSE
HIGH SCHOOL ADAPTATION

Videotape

Special Relativity

Going Further

1. v_{Earth} = 10889 km/s. $t_s = 0.0000181t_o$.
2. Use $v^2t_s^2 + c^2t_o^2 = c^2t_s^2$. Solve for t_s.
3. Time dilation takes place between a moving and stationary frame of reference. Time travel takes place in the same frame of reference.

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.

Physics Online physicspp.com/vocabulary_puzzlemaker

Chapter 3
Study Guide

Key Concepts
Summary statements can be used by students to review the major concepts of the chapter.

Physics Online
Visit physicspp.com
/self_check_quiz
/vocabulary_puzzlemaker
/chapter_test
/standardized_test

VOCABULARY PuzzleMaker

For additional help with vocabulary, have students access the Vocabulary PuzzleMaker online.
physicspp.com/vocabulary_puzzlemaker

Concept Mapping

53. See Solutions Manual.

Mastering Concepts

54. Acceleration is the change in velocity divided by the time interval in which it occurs: it is the rate of change of velocity.

55. a. if forward is the positive direction, a car moving backward at decreasing speed

b. in the same coordinate system, a car moving backward at increasing speed

56. The car starts from rest and increases its speed. As the car's speed increases, the driver shifts gears.

57. instantaneous acceleration

58. Yes, a car's velocity is positive or negative with respect to its direction of motion from some point of reference. An object undergoing positive acceleration is either increasing its velocity in the positive direction or reducing its velocity in the negative direction. A car's velocity can change signs when experiencing constant acceleration. For example, it can be traveling right, while the acceleration is to the left. The car slows down, stops, and then starts accelerating to the left.

59. Yes, the velocity of an object can change when its acceleration is constant. Example: dropping a book. The longer it drops, the faster it goes, but the acceleration is constant at g.

60. When the velocity-time graph is a line parallel to the t-axis, the acceleration is zero.

61. the change in displacement

62. $t_f = \dfrac{(v_f - v_i)}{a}$

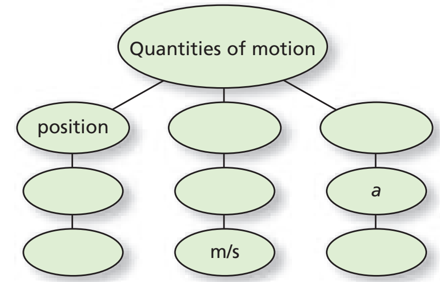
$v_f = v_i + at_f$

$d_f = \dfrac{(v_f - v_i)(t_f)}{2}$

63. All objects accelerate toward the ground at the same rate.

Concept Mapping

53. Complete the following concept map using the following symbols or terms: *d, velocity, m/s², v, m, acceleration.*

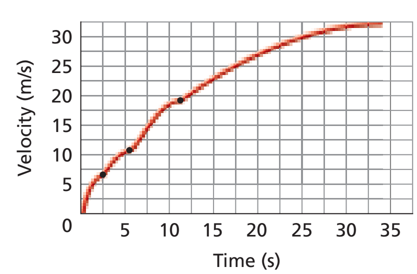


Mastering Concepts

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.

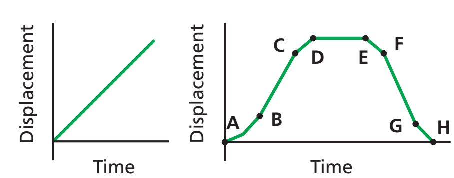
69. If an object has zero velocity at some instant, is its acceleration zero? Give an example.

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**

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

64. Student answers will vary. Some examples are sheets of paper, parachutes, leaves, and feathers.

65. Student answers will vary. Some examples are a steel ball, a rock, and a person falling through small distances.

Applying Concepts

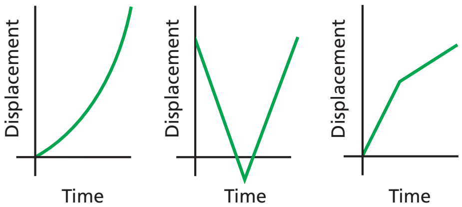
66. No, if the positive axis points in the direction opposite the velocity, the acceleration will be positive.

67. No, they have opposite signs.

68. No, $a = 0$ when velocity is constant.

69. No, a ball rolling uphill has zero velocity at the instant it changes direction, but its acceleration is nonzero.

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

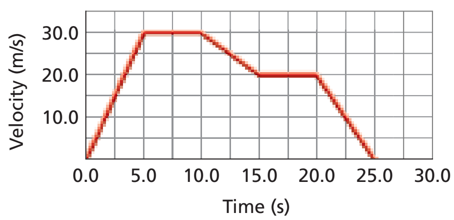
3.1 Acceleration

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

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Chapter 3 Assessment

70. Draw a velocity-time graph and see whether the graph is a straight line, or calculate accelerations using $a = \frac{\Delta v}{\Delta t}$ and compare the answers to see if they are the same.

71. Velocity increases rapidly at first, then more slowly. Acceleration is greatest at the beginning but is reduced as velocity increases. Eventually, it is necessary for the driver to shift into second gear. The acceleration is smaller just before the gear change because the slope is less at that point on the graph. Once the driver shifts and the gears engage, acceleration and the slope of the curve increase.

72. The acceleration is largest during an interval starting at $t = 0$ and lasting about $\frac{1}{2}$ s. It is smallest beyond 33 s.

73. Walk in the positive direction at a constant speed. Walk in the positive direction at an increasing speed for a short time; keep walking at a moderate speed for twice that amount of time; slow down over a short time and stop; remain stopped; and turn around and repeat the procedure until the original position is reached.

74. See Solutions Manual.

75. Both objects traveled the same distance. The object that is shot straight upward rises to the same height from which the other object fell.

76. a. The ball will hit the Moon with a lesser speed because the acceleration due to gravity is less on the Moon.
b. The ball will take more time to fall.

77. a. The relationship between d and g is inverse: $d_f = \frac{(v_f^2 - v_i^2)}{2g}$. If g increases by three times, or $d_f = \frac{(v_f^2 - v_i^2)}{2(3g)}$, d_f changes by one-third. Therefore, a ball on Jupiter would rise to a height of one-third that on Earth.
b. With $v_f = 0$, the value d_f is directly proportional to the square of initial velocity, v_i. That is, $d_f = \frac{v_f^2 - (3v_i)^2}{2g}$. On Earth, an initial velocity that is three times greater results in a ball rising nine times higher. On Jupiter, however, the height would be reduced to only three times higher because of d_f's inverse relationship to a g that is three times greater.

78. a. Rock B hits the ground with a greater velocity.
b. They have the same acceleration—the acceleration due to gravity.
c. rock A

Mastering Problems

3.1 Acceleration

Level 1

79. a. 5.0×10^{1} km/h
b. 48 km/h

80. 8.0 m/s^2

81. 33 m/s

82. a. 6.0 m/s^2
b. 0.0 m/s^2
c. -2.0 m/s^2
d. -4.0 m/s^2

Level 2

83. a. speeding up from 0.0 s to 4.0 s; and 10.0 s to 12.0 s; slowing down from 5.0 s to 10.0 s
b. at 10.0 s
c. between 0.0 s and 2.0 s: 4.0 m/s^2; between 7.0 s and 12.0 s: -4.0 m/s^2

84. 7.0×10^{4} m/s

Level 3

85. Car B has the greatest acceleration of 6.4 m/s^2. Using significant digits, car A and car C tied at 4.5 m/s^2.

86. a. 607 m/s
b. 1.83 times the speed of sound

3.2 Motion with Constant Acceleration

Level 1

87. a. 75 m
b. 150 m
c. 125 m
d. 5.0×10^{2}

Level 2

88. 180 m/s

89. a. 43 m
b. 43 m

90. a. 1.4×10^{2} m
b. 550 m, which is about four times longer than when going half the speed.

91. 45 m

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?

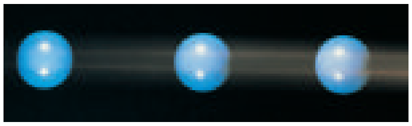

Figure 3-20

 For more problems, go to Additional Problems, Appendix B.
Skip Peticolas/Fundamental Photographs

Level 3

92. 9.2×10^{2} m

93. 1.6×10^{3} m

94. 6.0×10^{1} m/s

95. a. 5.0×10^{1} m, yes, it hits the barrier.
b. 22 m/s

3.3 Free Fall

Level 1

96. The direction of the velocity is positive, and velocity is increasing. Therefore, the acceleration is also positive.

97. 1.2 s

98. a. -78 m/s (downward)
b. -3.1×10^{2} m

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**

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Chapter 3 Assessment

99. -2.0×10^1 m/s; -2.0×10^1 m

Level 2

100. 7.3 m/s

101. 7.3 m/s

Level 3

102. a. 6.2 m
b. 11 m/s

Mixed Review

Level 1

103. 1.14×10^3 m

104. You need to know the time between flashes and the distance between the first two images and the distance between the last two. From these, you get two velocities. Between these two velocities, a time interval of t seconds occurred. Divide the difference between the two velocities by t.

105. 8.0 m

106. a. −276 m
b. 7.50 s

Level 2

107. 2.8×10^2 m/s^2; 29 times g

108. a. See Solutions Manual.
b. approximately 10 m

109. a. 3.1×10^8 m/s^2
b. 11 microseconds

110. a. 247 m/s^2, or 25 times g
b. 207 m/s^2, or 21 times g

111. a. See Solutions Manual.
b. 8.0 m
c. 32 m
d. 110 m
e. 4.0 m/s^2, acceleration
f. 0.0 m/s^2, constant velocity

Level 3

112. 180 m

113. 1.6 m thick

114. a. The fist moves downward at about −13 m/s for about 4 ms. It then suddenly comes to a halt (accelerates).
b. 3.7×10^3 m/s^2
c. 3.8×10^2, The acceleration is about 380 g.
d. −8 cm

115. a. −15 m/s
b. 1.0×10^1 m
c. 2.0×10^1 m below the helicopter

Thinking Critically

116. Students' labs will vary. Students should find that a change in the mass over the edge of the table will not change the distance the cart moves, because the acceleration is always the same: *g*.

117. The change in velocity is the same.

118. a. Express: 216 m; Local: 232 m; On this basis, no collision will occur.

b. See Solutions Manual.

Writing in Physics

119. Student answers will vary. Answers should include Galileo's experiments demonstrating how objects accelerate as they fall. Answers might include his use of a telescope to discover the moons of Jupiter and the rings of Saturn, and his reliance on experimental results rather than authority.

120. Answers will vary. Because humans can experience negative effects, like blackouts, the designers of roller coasters need to structure the downward slopes in such a way that the coasters do not reach accelerations that cause blackouts. Likewise, engineers working on bullet trains need to design the system in such a way that allows the train to rapidly accelerate to high speeds, without causing the passengers to black out.

Cumulative Review

121. a. 6.3×10^{-3} m

b. 8.4×10^{8} km

c. 1.69×10^{4} cm^2

d. 6.45×10^{-13} m/s

122. Graph and motion diagram indicate constant velocity motion with a velocity of 35.0 m/s and an initial position of −5.0 m. See Solutions Manual. Answers will vary for the create-a-problem part.

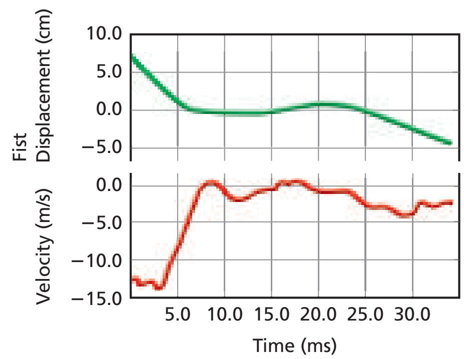
114. Karate The position-time and velocity-time graphs of George's fist breaking a wooden board during karate practice are shown in **Figure 3-22.**

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. 6.2×10^{-4} m + 5.7×10^{-3} m

b. 8.7×10^{8} km − 3.4×10^{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. $d = (35.0\text{ m/s})\,t - 5.0\text{ m}$ (Chapter 2)

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

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?

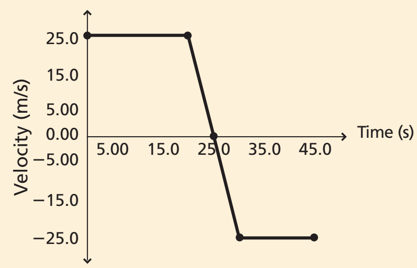
Ⓐ 14.0 m Ⓒ 50.0 m
Ⓑ 29.0 m Ⓓ 100.0 m

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.

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Standardized Test Practice

Rubric

The following rubric is a sample scoring device for extended response questions.

Extended Response

Points	Description
4	The student demonstrates a thorough understanding of the physics involved. The response may contain minor flaws that do not detract from the demonstration of a thorough understanding.
3	The student demonstrates an understanding of the physics involved. The response is essentially correct and demonstrates an essential but less than thorough understanding of the physics.
2	The student demonstrates only a partial understanding of the physics involved. Although the student may have used the correct approach to a solution or may have provided a correct solution, the work lacks an essential understanding of the underlying physical concepts.
1	The student demonstrates a very limited understanding of the physics involved. The response is incomplete and exhibits many flaws.
0	The student provides a completely incorrect solution or no response at all.

Multiple Choice

1. C
2. B
3. A
4. A
5. C
6. C
7. D
8. B
9. D

Extended Answer

10. $\text{Slope} = \dfrac{36.9\text{ m/s} - 8.10\text{ m/s}}{6.00\text{ s}} = 4.80\text{ m/s}^2$

acceleration = 4.80 m/s^2
displacement = area under graph
area under graph = area of rectangle + area of triangle

$$= (8.10\text{ m/s}\times12.00\text{ s}) + \frac{1}{2}(12.00\times57.6\text{ m/s}) = 443\text{ m}$$