# SECTION 4

# Graphing Motion: Distance, Velocity, and Acceleration

## Section Overview

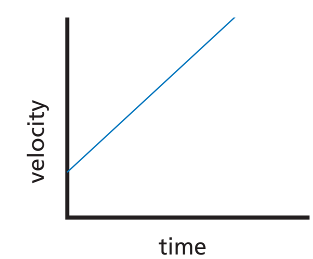
Students use a motion detector to investigate the motion of a cart as it moves on an inclined plane. They predict how the distance the cart travels changes with respect to time and identify graphs corresponding to various stages of the cart's motion, including when the cart is at rest. Students also predict the changes in velocity with respect to time and sketch graphs to compare the changing slope of distance vs. time with the constant slope of velocity vs. time. They observe how a constantly changing velocity yields a curved distance-time graph as the cart travels on the inclined plane. By observing the changes in velocity, they are given a concrete example of acceleration. Acceleration is finally defined and more velocity-time graphs are sketched to establish how acceleration can be determined from the slope of a velocity-time graph.

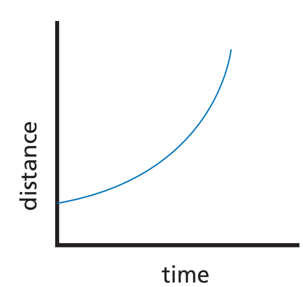
## Background Information

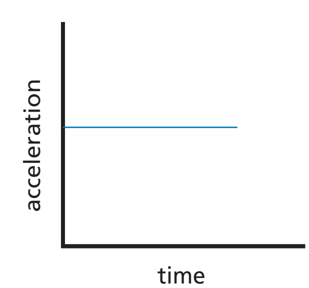
Acceleration is the rate of change of velocity, or the change in velocity per unit time. A change in velocity (speed with direction) occurs due to a change in speed and/or direction. In the *Investigate*, with the cart being pushed up the ramp, an object is uniformly changing velocity from one value in one direction (called positive) to a value in the opposite direction (called negative), and passes through the zero velocity point where the direction changes. A particularly difficult concept to grasp is that at this zero velocity point, the acceleration is the same as in the decreasing- and increasing-speed phases.

Students should continue to use the same equipment as they study objects with changing velocities (acceleration). Older motion detectors need about 50 cm of leeway in front before they can accurately take measurements. Newer models need only about 5 cm from the detector for proper operation. Small variations in position data can dramatically affect the velocity-time graph. Affixing an index card or some other flat, rigid object to the cart can make for a better surface to reflect the sound waves. If the detector is not properly aimed, or the detection area is not clear, the data may not be indicative of the actual motion.

Acceleration is easier to understand with the use of a graph. Acceleration vs. time and distance vs. time graphs may be easily derived from the velocity-time graph as shown below.




The area underneath the line represented in a velocity-time graph is the total distance traveled by an object during any particular time interval.

The slope of the $v$ vs. $t$ graph is equal to the acceleration.

## Crucial Physics

- Acceleration = change in velocity over a given time.
  - $a = \Delta v / \Delta t$
  - There is an acceleration when
    a) There is an increase in speed.
    b) There is a decrease in speed.
    c) There is a turn (a change in direction).
- The slope of a velocity vs. time graph is equal to the acceleration.

| Learning Outcomes | Location in the Section | Evidence of Understanding |
|---|---|---|
| **Measure** a change in velocity (acceleration) of a cart on a ramp using a motion detector. | ***Investigate***<br>Step 3 | Students use the points on a graph produced by a motion detector to measure a change in velocity. |
| **Construct** graphs of the motion of a cart on a ramp. | ***Investigate***<br>Steps 2-7 and 11 | Students collect data for the cart's motion on an inclined plane and sketch distance-time and velocity-time graphs. |
| **Define** acceleration using words and an equation. | ***Investigate***<br>Step 3<br><br>***Physics Talk*** | Students learn about acceleration by studying the slope of the *v-t* graph. They also learn to put it in a word equation. |
| **Calculate** speed, distance, and time using the equation for acceleration. | ***Physics to Go***<br>Questions 7-10 and 13-16 | Students solve problems to calculate speed, distance, and time by using the equation for acceleration and velocity. |
| **Interpret** distance-time and velocity-time graphs for different types of motion. | ***Investigate***<br>Steps 2-7 and 11-12 | Students interpret how the slopes of *d-t* and *v-t* graphs vary for the motion of a cart when it changes speed and direction. |

# Section 4 Materials, Preparation, and Safety

## Materials and Equipment

| PLAN A | | |
|---|---|---|
| **Materials and Equipment** | **Group (4 students)** | **Class** |
| Ruler, metric, 30 cm | 1 per group | |
| Ring stand, large | 1 per group | |
| Rod, aluminum, 12 in. (length) x 3/8 in. (diameter) (to act as crossarm) | 1 per group | |
| Holder, right angle (to act as crossarm) | 1 per group | |
| Inclined plane ramp for lab cart | 1 per group | |
| Dynamics cart | 1 per group | |
| Index cards, pkg. 100 | | 1 per class |
| Motion detector, probe and interface* | | 1 per class |
| Computer, station or calculator, CBL or equivalent system* | 1 per group | |

*Additional items needed not supplied

| PLAN B | | |
|---|---|---|
| **Materials and Equipment** | **Group (4 students)** | **Class** |
| Ruler, metric, 30 cm | | 1 per class |
| Ring stand, large | | 1 per class |
| Rod, aluminum, 12 in. (length) x 3/8 in. (diameter) (to act as crossarm) | | 1 per class |
| Holder, right angle (to act as crossarm) | | 1 per class |
| Inclined plane ramp for lab cart | | 1 per class |
| Dynamics cart | | 1 per class |
| Index cards, pkg. 100 | | 1 per class |
| Motion detector, probe and interface* | | 1 per class |
| Computer, station or calculator, CBL or equivalent system* | | 1 per class |

*Additional items needed not supplied

**Note:** Time, Preparation, and Safety requirements are based on Plan A, if using Plan B, please adjust accordingly.

## Time Requirement

Approximately 80 minutes are required to complete the experiment.

## Teacher Preparation

- See the preparation suggestion for *Section 3* about the use of the motion detector and related equipment.
- Do not allow the motion detector to be struck by a cart when the cart is rolling on the ramp, as this may damage the probe.
- Placing a "sail" or similar surface on the cart when it is rolling on the incline will improve reflection and lead to improved data collection if the detector has trouble "seeing" the cart. As discussed above, make certain the area used for good data collection is free of clutter (students' books, other equipment, etc.).

## Safety Requirements

- Many of the dynamics carts being used in labs have wheels with extremely low friction, and will roll off a table with even a slight incline. Instruct the students to invert the carts on the table when they are not in use to keep them from rolling off.
- If the experiment is done on a lab table, make certain that all materials are away from the edge to keep them from falling to the floor. Students should wear appropriate shoes in case an object falls on their feet.

# Meeting the Needs of All Students

## Differentiated Instruction: Augmentation and Accommodations



| Learning Issue | Reference | Augmentation and Accommodations |
|---|---|---|
| Following complex directions | ***Investigate*** Steps 1-7 | **Augmentation**<br>• Students with organization, reading, and attention issues could easily be overwhelmed and give up when following complex directions. Break the task down into smaller steps with reasonable time limits. Model the equipment setup and the data to be recorded. Check in with the class to monitor understanding and frustration level after each step.<br>• Use two different colors to draw *d-t* and *v-t* graphs as a visual cue to show that these graphs represent different aspects of the cart's motion.<br>• Assign a person in each group to be in charge of reading directions orally and making sure that students follow the directions step-by-step.<br>• Focus on one type of motion at a time. Have a whole-group discussion after students collect data and sketches for the cart traveling down the ramp. Then repeat this process for motion up the ramp.<br>**Accommodation**<br>• Students may need direct instruction to review *d-t* graphs and learn about *v-t* graphs before they begin this *Investigate*. Some students are unable to deduce concepts from data and may need to see the big picture before they can make sense of the smaller tasks in this *Investigate*. |
| Organizing data | ***Investigate*** Steps 1-7 | **Augmentation**<br>• Students need a method to help them organize all of the predictions, graphs, and comparisons they are asked to record in this *Investigate*. Instruct students to write the number and letter preceding each task before they record their data (*1.a), 1.b), 1.c)*, and so on). Model what an organized log page might look like.<br>**Accommodation**<br>• Give students a table that is numbered and provides adequate space to record data or answer each step. |
| Learning a new math concept by reading a paragraph | ***Investigate*** Step 2.c) | **Augmentation**<br>• This is probably the first time students have been introduced to tangent lines. Use the paragraph description and diagrams of examples and non-examples to teach this concept to students. Point out that tangent lines are used for curved graph sketches that represent changing quantities.<br>**Accommodation**<br>• Understanding tangent lines may impede the progress of students in completing the *Investigate*. Instruct students to skip *2.c)* and come back to it at the end of the *Investigate*. |
| Sketching graphs | ***Investigate*** Steps 2-7, 11.a) | **Augmentation**<br>• Students are asked to compare graphs and do calculations with the data they collect. Remind students that their graphs should have labeled axes and scales, and the lines should be sketched with accuracy. Model two well-drawn graphs that students can refer to as they are working.<br>• Model how to use the "TRACE" function to identify data points on a line. |
| Applying new learning | ***Investigate*** Step 8 | **Augmentation**<br>• For students with attention and organization issues, this step could be used as an informal assessment to gauge students' understanding at this point. If students understand the graphs for motion of a cart on an incline, they should be able to answer *Step 8* with accuracy. |

| Learning Issue | Reference | Augmentation and Accommodations |
|---|---|---|
| Locating information in a table | ***Investigate*** Step 9 | **Augmentation**<br>• Students with visual-spatial and/or memory issues have trouble turning pages to locate and record information from a table. Provide students with a ruler or index card to mark the page that has a table. The ruler or index card can also be used to help students visually scan columns and rows to find information on a table.<br>**Accommodation**<br>• Students will be more successful if they can look at a table or graph and the corresponding questions side-by-side. Provide a copy of tables that are not located on the same page as the questions. On exams, place tables and graphs on the same page as the corresponding questions. |
| Solving problems with data in a table | ***Investigate*** Step 12 | **Augmentation**<br>• Students with visual-spatial and math issues struggle to solve problems with numbers in a table because they are being asked to scan a series of numbers, locate the number that corresponds to each quantity in the equation, and then perform the calculation. Provide students with a ruler or index card to single out the row of numbers they are using for each problem.<br>**Accommodation**<br>• Provide students with a copy of the table. Instruct students to write the corresponding symbols next to each value on the table and then solve the problems. It is very important for students who need this accommodation to show their work to check for common calculation errors. |
| Differentiating scalar and vector quantities | ***Physics Talk*** | **Augmentation**<br>• Scalar and vector quantities are a recurring topic in physics that students struggle to understand. Create a two-column chart that defines scalar on the left side and vector on the right side. Then post the chart and add examples of each throughout the year as students learn new quantities. This chart can also be copied in student logs. |
| Vocabulary | ***Physics to Go*** Question 8 | **Augmentation**<br>• Explain that uniformly means "at a constant rate" or "the same amount for each chunk of time." |

NOTES

## Strategies for Students with Limited English-Language Proficiency

| Learning Issue | Reference | Augmentation |
|---|---|---|
| Following complex procedures<br><br>Vocabulary comprehension | ***Investigate*** | Break down the *Investigate* into smaller chunks to allow students to comprehend each portion of the *Investigate* before moving on to the next one. This will allow them to get comfortable by following the procedures outlined within each step, and to internalize new concepts and any new vocabulary that is introduced within a step. Lead a brief class discussion after each step to allow students the opportunity to demonstrate knowledge and to use the vocabulary. |
| Comprehension | ***Physics Talk*** | Have students read a section of text. Then connect the reading back to the portion of the *Investigate* that addressed that concept. Breaking the reading into smaller portions and providing direct connections with hands-on learning will solidify content for English learners as well as kinesthetic learners. |
| Reading comprehension | ***Physics Talk***<br>Describing Types of Motion Using Graphs | Some students may have the ability to grasp the concepts of the investigation but may stumble over technical terms. Provide a supplemental vocabulary list and practice using these words in sentences. Possible terms include "slope," "incline," "inclined plane," "horizontal," "vertical," "elapsed," "simultaneously," and "instantaneous." Collaborate with the students' math teachers to determine what level of comprehension students have obtained for reading technical graphs and recognizing the meaning of slope. |
| Vocabulary comprehension | ***Physics Talk***<br>Vector and Scalar Quantities | Students may have difficulty visualizing the difference between vector quantities and scalar quantities. Point out that the motion detector can record negative velocities when objects are moving toward it. The negative sign is an indication of direction in one dimension. Speed is always zero or positive, so it is a scalar quantity. Acceleration, which was also shown to be positive and negative in the *Investigate*, is another example of a vector quantity.<br>Students may infer incorrectly that negative acceleration means that an object is slowing down. Point out that negative acceleration can also mean that an object is moving faster in a negative direction. In either case, velocity is decreasing, so the acceleration is negative. |
| Answering higher-order questions | ***Physics To Go***<br>Questions 1–5 | ELL students who are visually oriented would benefit from thinking graphically about the first five exercises. Pair up students with different learning styles. Have the students work together to sketch graphs of the situations in each of the first five exercises. Then have them work together to formulate in words an answer to each question. |

NOTES

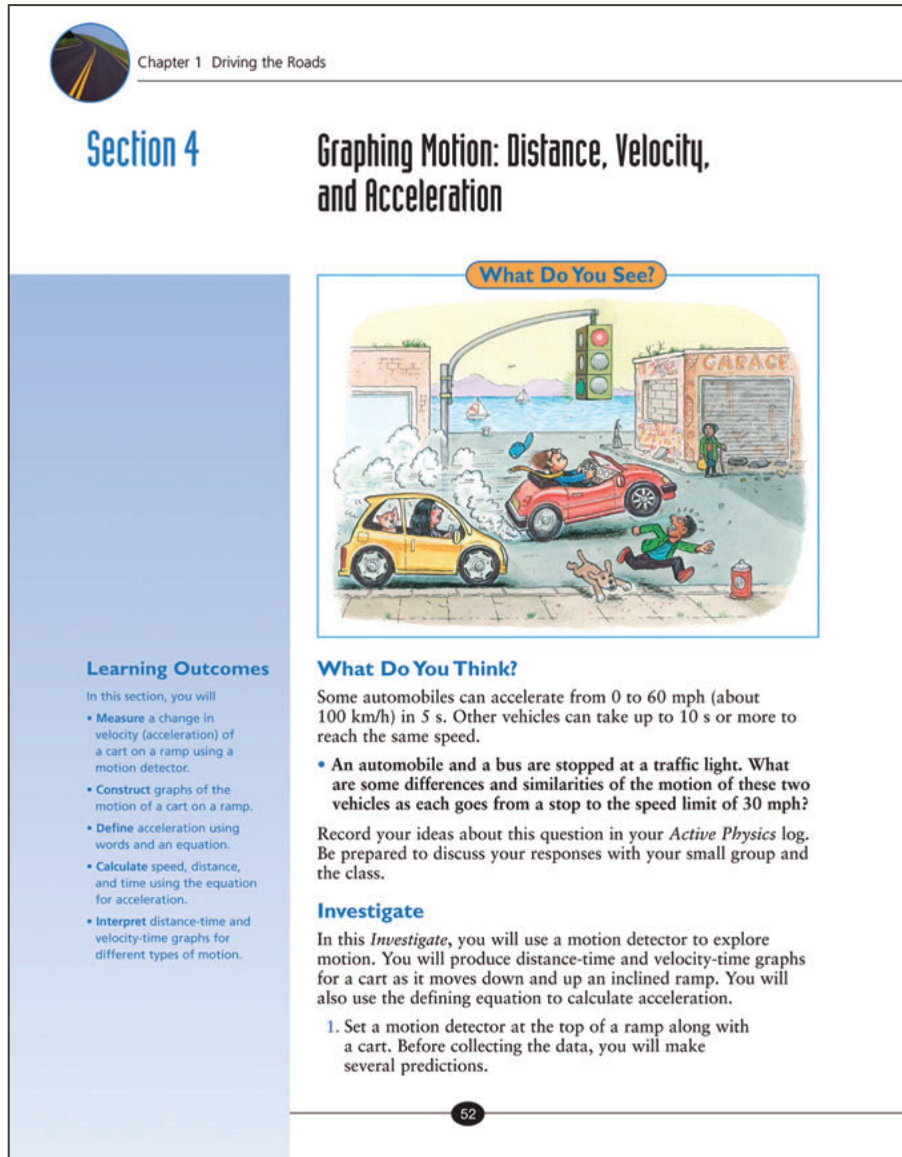
# SECTION 4

# Teaching Suggestions and Sample Answers

## What Do You See?

Students are likely to comment on the automobile passing a stoplight at breakneck speed, while the other automobile stops a short distance away from it. The person running, the hat flying, and the smoke swirling provide a focus for engaging students in the *What Do You See?* illustration.

You might want to ask students what the artist is trying to depict and how the illustration relates to the concept of speed in relation to distance.



Chapter 1 Driving the Roads

Section 4

Graphing Motion: Distance, Velocity, and Acceleration

What Do You See?



**Learning Outcomes**

In this section, you will

- **Measure** a change in velocity (acceleration) of a cart on a ramp using a motion detector.
- **Construct** graphs of the motion of a cart on a ramp.
- **Define** acceleration using words and an equation.
- **Calculate** speed, distance, and time using the equation for acceleration.
- **Interpret** distance-time and velocity-time graphs for different types of motion.

**What Do You Think?**

Some automobiles can accelerate from 0 to 60 mph (about 100 km/h) in 5 s. Other vehicles can take up to 10 s or more to reach the same speed.

- **An automobile and a bus are stopped at a traffic light. What are some differences and similarities of the motion of these two vehicles as each goes from a stop to the speed limit of 30 mph?**

Record your ideas about this question in your *Active Physics* log. Be prepared to discuss your responses with your small group and the class.

**Investigate**

In this *Investigate*, you will use a motion detector to explore motion. You will produce distance-time and velocity-time graphs for a cart as it moves down and up an inclined ramp. You will also use the defining equation to calculate acceleration.

1. Set a motion detector at the top of a ramp along with a cart. Before collecting the data, you will make several predictions.

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## Students' Prior Conceptions

This section builds directly on the measurement of distance and time used to create graphs of motion in the previous section. A visual and kinesthetic benefit of this section derives from the use of the motion sensor to obtain and to interpret real-time graphs of motion. Cognitive research indicates that student understanding is enhanced and they learn best about abstract mathematical models when actively using sensors and technology. This is particularly true when students are asked to predict and to interpret velocity vs. time graphs for motions of objects.

1. **Velocity is another word for speed. An object's speed and velocity are always the same.** Encourage students to understand that speed is a scalar quantity; it only has magnitude associated with appropriate dimensional units. Velocity is a vector quantity that has magnitude, units, and direction. It is important to emphasize that a negative direction does not imply slowing down; an object can move with negative velocity and increasing or decreasing speed. A good opening gambits for class discussion is asking students to describe the velocity of a vehicle that moves forward with a given speed and then stops and reverses to move backward along the same path with the same speed. That speed, as read by the speedometer, is constant, but the velocity is positive when the vehicle is moving forward, away from the origin of motion, and negative when the vehicle moves back toward the origin of motion. To complicate matters, the latter is true whether the vehicle reverses gears and merely backs up or

## What Do You Think?

To generate enthusiasm, this preliminary question is designed to elicit prior knowledge. Students' initial answers will serve to demonstrate prior learning. It will give students the chance to transfer what they already know to the concepts they will be learning. Because of students' familiarity with driving, most students will be able to come up with at least two correct answers. At this point, the accuracy of their responses should not be of concern.

Encourage students to consider how the information provided in the question can be useful in arriving at an answer.

**What Do You Think?**

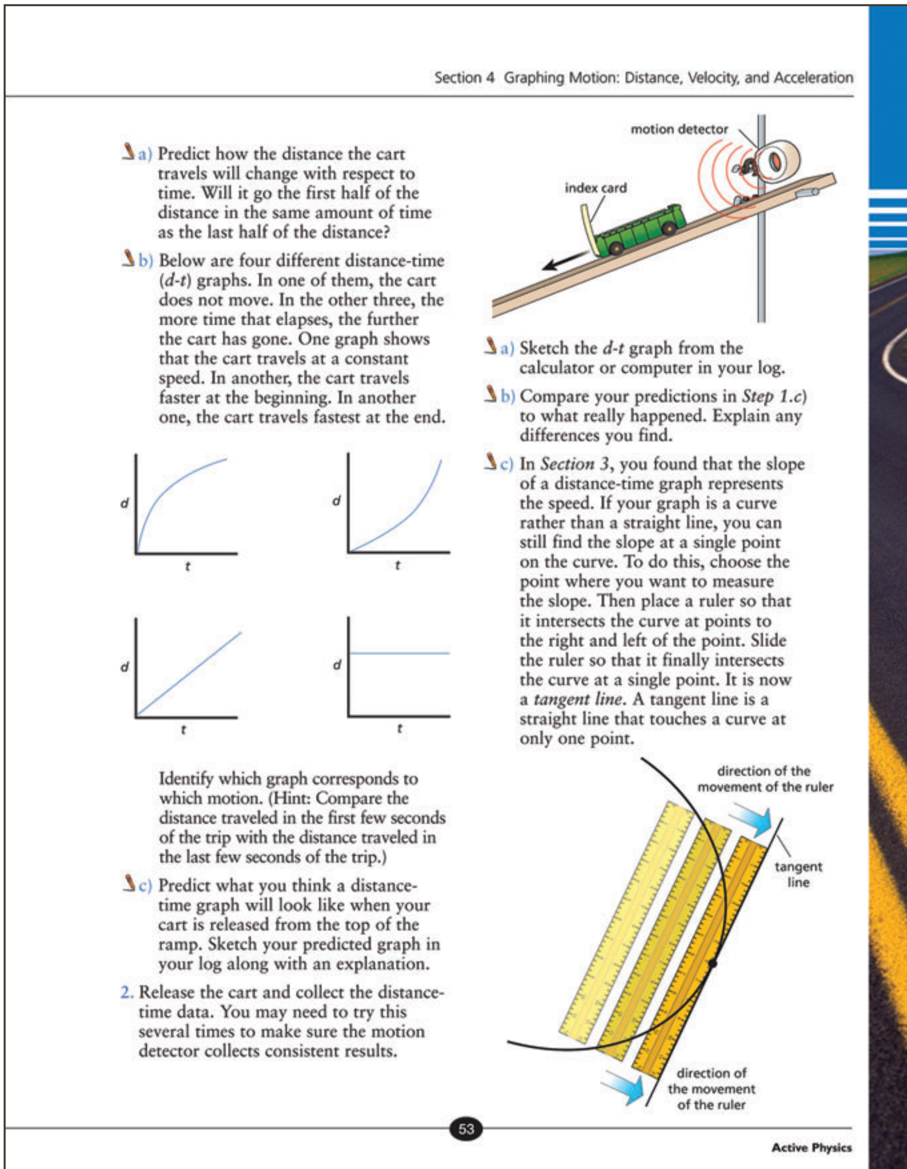
**A Physicist's Response**

- Both the bus and the automobile have the same initial and final speed, and accelerate by changing their speed from 0 to 30 mi/h (about 50 km/h). However, a bus takes more time to accelerate to 30 mi/h than an automobile. The bus also requires a larger distance than the automobile to reach a speed of 30 mi/h.

turns around, faces the origin with the front of the vehicle, and moves toward the origin.

2. **Acceleration is confused with speed.** Speed is distance divided by time. The value of speed may increase, decrease, or stay the same. Only when there is a change in the speed of an object is there acceleration. By definition, acceleration is the change in the velocity of an object. (Remember that velocity is a vector with magnitude and direction.)
3. **Acceleration always means that an object is speeding up.** Yes, students become mystified when faced with these conditions: speeding up with positive change in velocity and positive acceleration, or speeding up with negative velocity and negative acceleration; and slowing down with a positive velocity and a negative acceleration. An instructional strategy is to remind students that acceleration is the change in the velocity divided by time. Mathematically, they should interpret this to be the second velocity (whether positive or negative) minus the first velocity (whether positive or negative) divided by the change in time, which is always positive. Students can learn to evaluate these various situations as they apply the mathematical principle that subtracting a negative number yields a positive value for that number.
4. **Acceleration always occurs in the same direction as an object is moving.** This alternative notion emerges when students analyze the situation of a vehicle moving forward while slowing down. The motion of the vehicle is forward but the net acceleration of the vehicle is negative, opposite the direction of the moving object.
5. **If an object has a speed of zero (even instantaneously), it has no acceleration.** In this section, it is important for students to understand that a force can act upon a vehicle to stop its forward motion and to bring the speed to zero, but the force may also continue to act upon the vehicle, pushing it in the opposite direction and increasing its instantaneous speed from zero to another value. This preconception may hinder student understanding of what happens in vehicle collisions and what happens to conservation of momentum in later chapters of *Active Physics*.

## NOTES




a) Predict how the distance the cart travels will change with respect to time. Will it go the first half of the distance in the same amount of time as the last half of the distance?

b) Below are four different distance-time (*d*-*t*) graphs. In one of them, the cart does not move. In the other three, the more time that elapses, the further the cart has gone. One graph shows that the cart travels at a constant speed. In another, the cart travels faster at the beginning. In another one, the cart travels fastest at the end.



Identify which graph corresponds to which motion. (Hint: Compare the distance traveled in the first few seconds of the trip with the distance traveled in the last few seconds of the trip.)

c) Predict what you think a distance-time graph will look like when your cart is released from the top of the ramp. Sketch your predicted graph in your log along with an explanation.

2. Release the cart and collect the distance-time data. You may need to try this several times to make sure the motion detector collects consistent results.



a) Sketch the *d*-*t* graph from the calculator or computer in your log.

b) Compare your predictions in *Step 1.c)* to what really happened. Explain any differences you find.

c) In *Section 3*, you found that the slope of a distance-time graph represents the speed. If your graph is a curve rather than a straight line, you can still find the slope at a single point on the curve. To do this, choose the point where you want to measure the slope. Then place a ruler so that it intersects the curve at points to the right and left of the point. Slide the ruler so that it finally intersects the curve at a single point. It is now a *tangent line*. A tangent line is a straight line that touches a curve at only one point.





## Investigate

**1.a)**

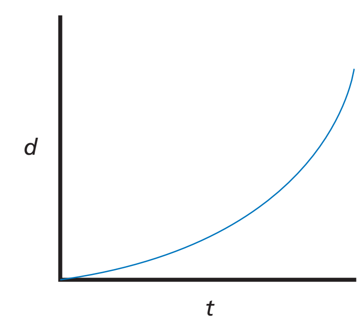
The cart will cover the last half of the distance in less time because it is traveling at a faster speed.

**1.b)**

Answers should be (starting from the left graph to the right): decreasing speed, increasing speed, constant speed, and zero speed.

**1.c)**

Students should realize after *Section 3* that a constant-speed graph will be linear, so the predicted graph should be curved, similar to the one below.




**2.a)**

The data points should follow a locus that is not scattered. The graph should look like the graph for *Step 1.c)*.

**2.b)**

Unless there is an exceptional amount of friction, the graphs should not deviate much from the graph of *Step 1.c)*.

**2.c)**

Starting from the top, the first two lines are tangent to the curve, and the bottom line is not.

**2.d)**

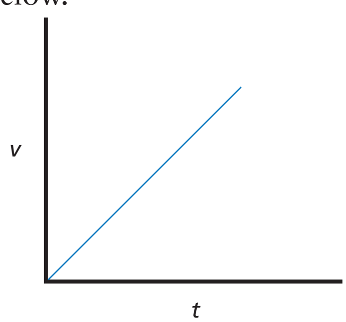
The slope of the *d-t* graph steadily increases because the velocity (slope) continually increases as the cart accelerates.

**2.e)**

The *v-t* graph should be a straight line ascending from lower values to higher values. The slope of the *v-t* graph is constant, because the rate of change of velocity (acceleration) is constant.

**3.a)**

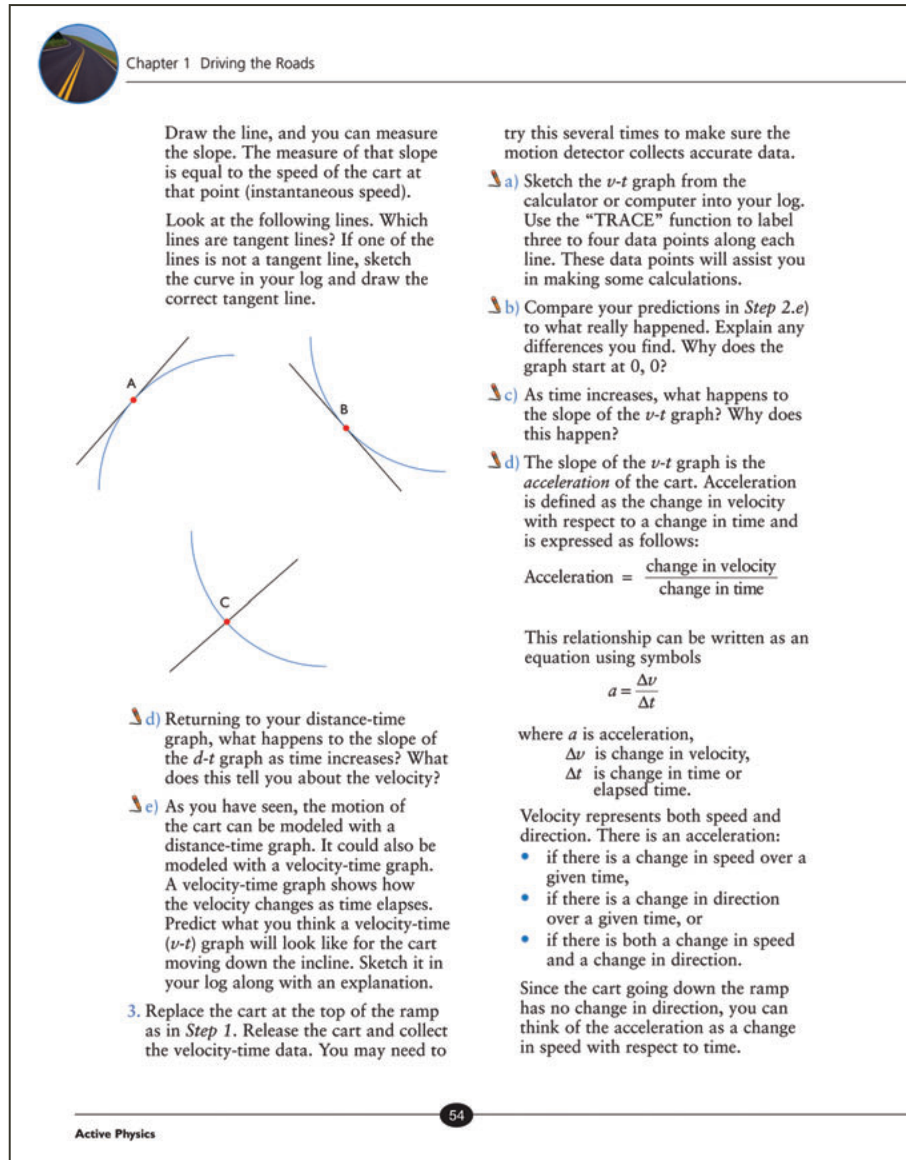
The *v-t* graph should be linear with a positive slope. The graph should appear like the one shown below.




**3.b)**

The actual graph should look like the prediction made in *Step 2.e)*. If the motion detector started to take data exactly when the cart was released, the graph should start at (0, 0). More likely, the graph will be displaced to the right if the detector is started early, or displaced upward if the cart is moving before the detector starts collecting data.

The cart will start with zero velocity, so if the timer and the cart start at the same time, the graph should begin at (0, 0). The slope is a constant because the cart's speed is constantly increasing as it goes down the plane.



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Draw the line, and you can measure the slope. The measure of that slope is equal to the speed of the cart at that point (instantaneous speed).

Look at the following lines. Which lines are tangent lines? If one of the lines is not a tangent line, sketch the curve in your log and draw the correct tangent line.

A B C

d) Returning to your distance-time graph, what happens to the slope of the *d-t* graph as time increases? What does this tell you about the velocity?

e) As you have seen, the motion of the cart can be modeled with a distance-time graph. It could also be modeled with a velocity-time graph. A velocity-time graph shows how the velocity changes as time elapses. Predict what you think a velocity-time (*v-t*) graph will look like for the cart moving down the incline. Sketch it in your log along with an explanation.

3. Replace the cart at the top of the ramp as in *Step 1*. Release the cart and collect the velocity-time data. You may need to try this several times to make sure the motion detector collects accurate data.

a) Sketch the *v-t* graph from the calculator or computer into your log. Use the "TRACE" function to label three to four data points along each line. These data points will assist you in making some calculations.

b) Compare your predictions in *Step 2.e)* to what really happened. Explain any differences you find. Why does the graph start at 0, 0?

c) As time increases, what happens to the slope of the *v-t* graph? Why does this happen?

d) The slope of the *v-t* graph is the *acceleration* of the cart. Acceleration is defined as the change in velocity with respect to a change in time and is expressed as follows:

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$$

This relationship can be written as an equation using symbols

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

where $a$ is acceleration,
$\Delta v$ is change in velocity,
$\Delta t$ is change in time or elapsed time.

Velocity represents both speed and direction. There is an acceleration:

- if there is a change in speed over a given time,
- if there is a change in direction over a given time, or
- if there is both a change in speed and a change in direction.

Since the cart going down the ramp has no change in direction, you can think of the acceleration as a change in speed with respect to time.

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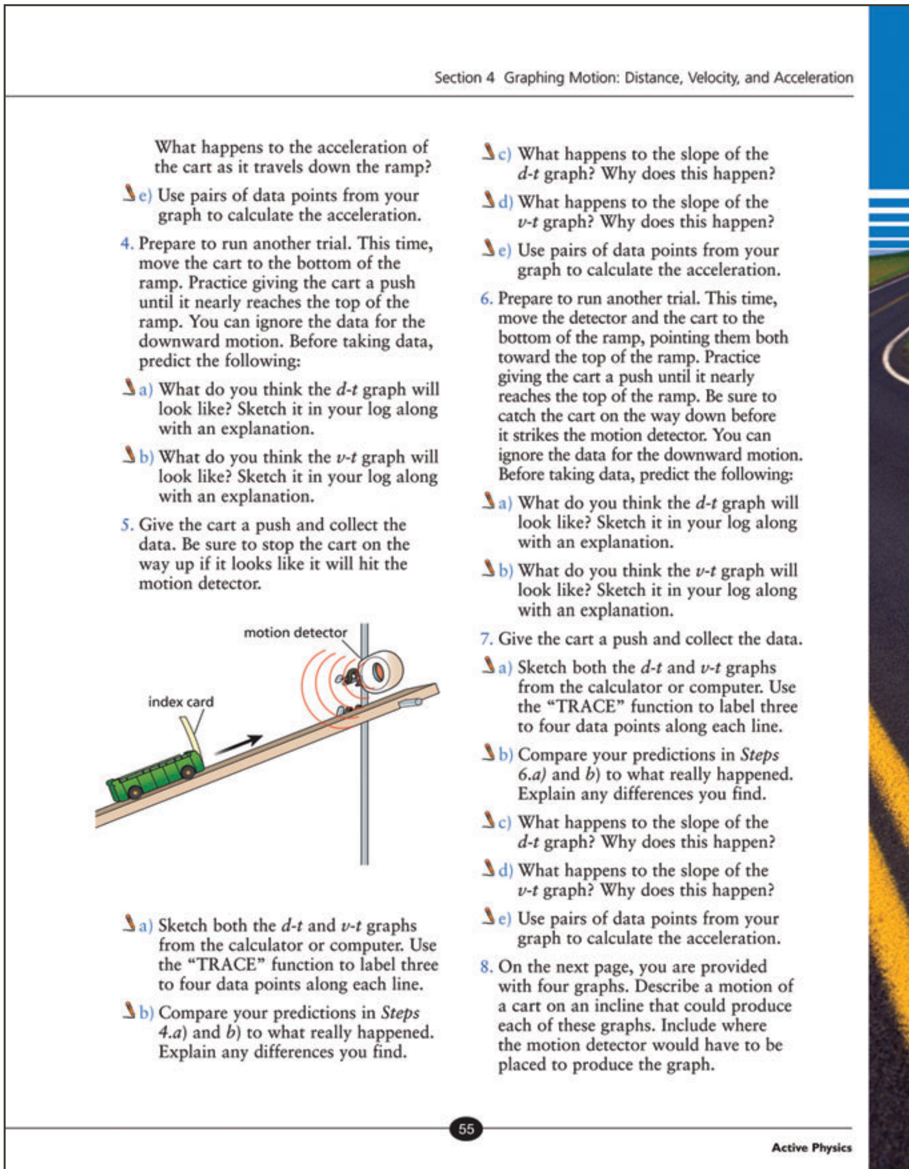
**3.c)**

As time increases, the slope of the line remains. This happens because the velocity increases at a constant rate for the cart going down the plane.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What happens to the acceleration of the cart as it travels down the ramp?

e) Use pairs of data points from your graph to calculate the acceleration.

4. Prepare to run another trial. This time, move the cart to the bottom of the ramp. Practice giving the cart a push until it nearly reaches the top of the ramp. You can ignore the data for the downward motion. Before taking data, predict the following:

a) What do you think the *d-t* graph will look like? Sketch it in your log along with an explanation.

b) What do you think the *v-t* graph will look like? Sketch it in your log along with an explanation.

5. Give the cart a push and collect the data. Be sure to stop the cart on the way up if it looks like it will hit the motion detector.



a) Sketch both the *d-t* and *v-t* graphs from the calculator or computer. Use the "TRACE" function to label three to four data points along each line.

b) Compare your predictions in *Steps 4.a)* and *b)* to what really happened. Explain any differences you find.

c) What happens to the slope of the *d-t* graph? Why does this happen?

d) What happens to the slope of the *v-t* graph? Why does this happen?

e) Use pairs of data points from your graph to calculate the acceleration.

6. Prepare to run another trial. This time, move the detector and the cart to the bottom of the ramp, pointing them both toward the top of the ramp. Practice giving the cart a push until it nearly reaches the top of the ramp. Be sure to catch the cart on the way down before it strikes the motion detector. You can ignore the data for the downward motion. Before taking data, predict the following:

a) What do you think the *d-t* graph will look like? Sketch it in your log along with an explanation.

b) What do you think the *v-t* graph will look like? Sketch it in your log along with an explanation.

7. Give the cart a push and collect the data.

a) Sketch both the *d-t* and *v-t* graphs from the calculator or computer. Use the "TRACE" function to label three to four data points along each line.

b) Compare your predictions in *Steps 6.a)* and *b)* to what really happened. Explain any differences you find.

c) What happens to the slope of the *d-t* graph? Why does this happen?

d) What happens to the slope of the *v-t* graph? Why does this happen?

e) Use pairs of data points from your graph to calculate the acceleration.

8. On the next page, you are provided with four graphs. Describe a motion of a cart on an incline that could produce each of these graphs. Include where the motion detector would have to be placed to produce the graph.

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**3.d)**

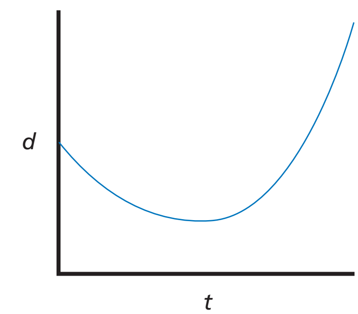
The acceleration remains constant for the cart traveling down the ramp.

**3.e)**

Students can choose points by moving the cursor over the graph and recording the associated points. Points farther apart are better than the ones very close together for calculating the acceleration.

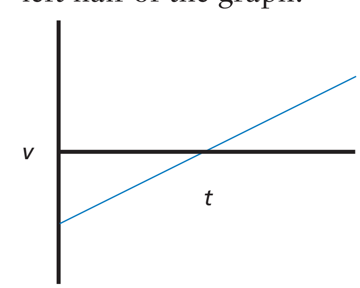
**4.a)**

This experiment mimics (with smaller acceleration) the act of throwing something straight up and letting it fall down. The *d-t* graph should resemble a parabola as shown below (if moving away from the detector is positive).




**4.b)**

The *v-t* graph should appear as shown below. In this graph and the graph for *4.a)*, the students should be concerned only with the left half of the graph.




**5.a)**

The graphs collected should appear similar to those shown above in *4.a)* and *b)*.

**5.b)**

The actual graphs may differ if the students stop the carts before they begin to come down the plane.

**5.c)**

The slope of the *d*-*t* graph starts out negative, and increases to zero, then continues increasing to positive values. That means the velocity started out negative (with the *x*-axis going down the plane, away from the detector), increases to zero, and then becomes positive as the cart goes back down the plane.

**5.d)**

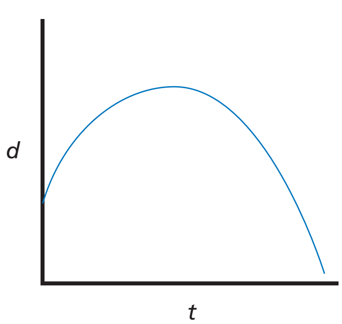
The slope of the *v*-*t* graph is positive and constant because the velocity steadily increases (positive acceleration).

**5.e)**

Students calculate acceleration using pairs of data points from the graphs.

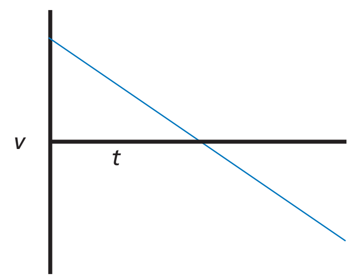
**6.a)**

The *d*-*t* graph should look like the one shown below. The cart moves in the + *d* direction with an initial speed away from the detector, slows to a stop, and then reverses direction to come back toward the detector.



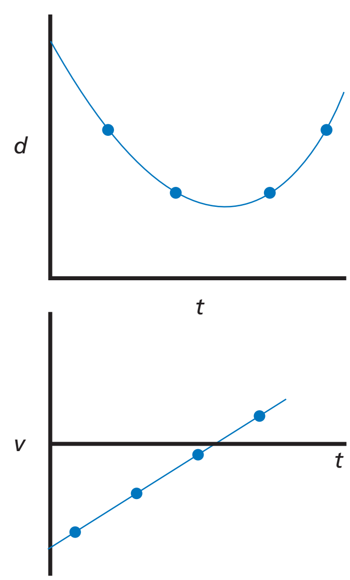

**6.b)**

The *v*-*t* graph should look like the one shown below. The cart starts up the plane with a certain velocity, becomes zero at the peak of the rise, and then gains speed on the way down. The slope everywhere is negative (negative acceleration).




**7.a)**

The student graphs should appear similar to the ones below.




**7.b)**

Students will discuss their data.

**7.c)**

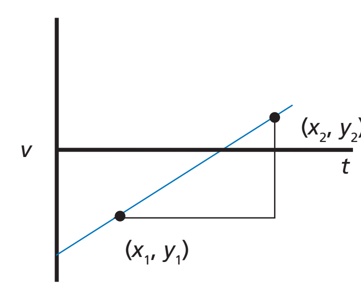
The slope change reflects the changing velocity of the cart as it starts and then moves away from the detector again, going down the plane. The value of the slope increases as the cart gains speed.

**7.d)**

The slope of the *v*-*t* graph remains the same as the cart rises and then rolls back down the plane. The slope is constant because the acceleration (which is the slope of the *v*-*t* graph) is a constant, and always in the same direction.

**7.e)**

Students should choose two data points from the *v*-*t* graph to calculate the acceleration. Data points near the beginning of the rise, and toward the end of the recorded motion, will most likely provide the most accurate result.



NOTES

**8.**

Look at the four graphs on the adjacent *Student Edition* page. The two graphs on the left both show increasing speed and would represent a cart moving down an incline, away from a motion detector at the top. The two graphs on the right both show decreasing speed, and would represent a cart moving up an incline with an initial speed when the detector is located at the bottom of the ramp.

**9.a)**

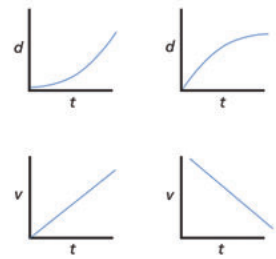
The acceleration data is located at the top of the third column in the table at the end of *Section 7* of the *Student Edition*.

**10.**

Students read about conversions.

**1-4a Blackline Master**






9. You will now take a closer look at acceleration in a straight line. Look at the automobile data provided at the end of this chapter on pages 116-117. The tables contain a lot of information including fuel economy, passenger accommodations, acceleration, and braking. In this section, you will be concerned with acceleration.

a) Record in your log where the acceleration information is located on the automobile table.

10. The speed on the table provided by automobile manufacturers is given in miles per hour (mi/h or mph), but the distances are recorded in feet and the time in seconds. To analyze this data more easily, it is helpful to record the speed in feet per second (ft/s). The table at right converts miles per hour to feet per second. Note that there are 60 min in 1 h and 60 s in 1 min. You should also note that there are 5280 ft in 1 mi. When you convert 60 mi/h to 88 ft/s, the conversion looks like the following:

$$\left(60\frac{\text{mi}}{\text{h}}\right)\left(\frac{1\text{ h}}{60\text{ min}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right)\left(\frac{5280\text{ ft}}{1\text{ mi}}\right)=88\frac{\text{ft}}{\text{s}}$$

If you deal with the units in the same way that you deal with the numbers, you will see that the miles cancel miles, hours cancel hours, and minutes cancel minutes.

$$\left(60\frac{\cancel{\text{mi}}}{\cancel{\text{h}}}\right)\left(\frac{1\cancel{\text{h}}}{60\cancel{\text{min}}}\right)\left(\frac{1\cancel{\text{min}}}{60\text{ s}}\right)\left(\frac{5280\text{ ft}}{1\cancel{\text{mi}}}\right)=88\frac{\text{ft}}{\text{s}}$$

You should notice that to convert 60 mi/h to 88 ft/s, the 60 mi/hr was multiplied by fractions that always equaled 1 (for example, 1 h and 60 min are the same value of time). Multiplying by 1/1 keeps the value the same.

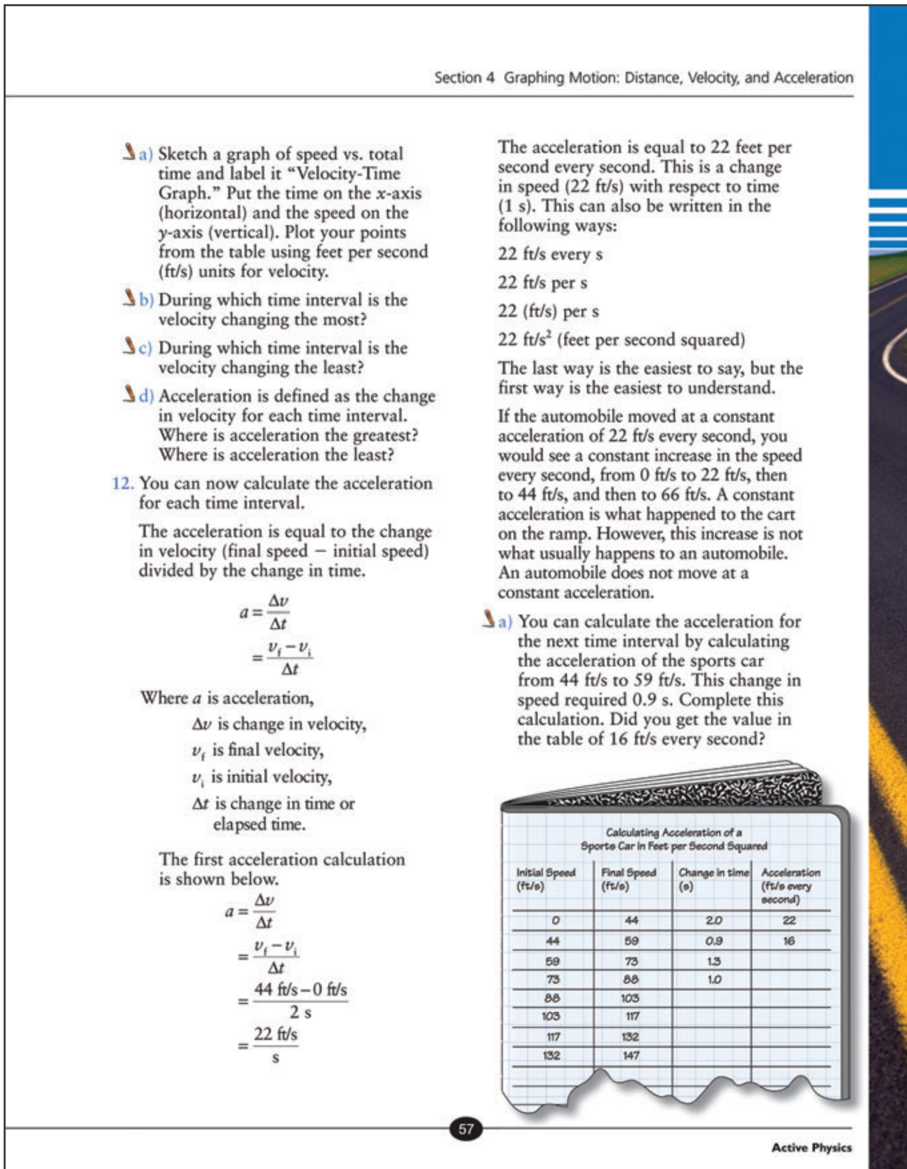
The following table was constructed on a spreadsheet. You can use the conversions in this table to give you a sense of the different units and to help you answer some of the questions in this chapter.

| | A | B | C | D |
|---|---|---|---|---|
| 1 | Common Speed Conversions | | | |
| 2 | United States | | Canada | |
| 3 | mph | ft/s | m/s | km/h |
| 4 | 0 | 0 | 0 | 0 |
| 5 | 10 | 15 | 5 | 16 |
| 6 | 20 | 29 | 9 | 32 |
| 7 | 30 | 44 | 13 | 49 |
| 8 | 40 | 59 | 18 | 65 |
| 9 | 50 | 73 | 23 | 81 |
| 10 | 60 | 88 | 27 | 97 |
| 11 | 70 | 103 | 31 | 113 |
| 12 | 80 | 117 | 36 | 130 |
| 13 | 90 | 132 | 41 | 146 |
| 14 | 100 | 147 | 45 | 162 |

11. The sports car's acceleration data from the table at the end of the chapter is shown below with miles per hour changed to feet per second.

**Acceleration Data of a Sports Car in Feet per Second**

| Final speed (ft/s) | Total time (s) |
|---|---|
| 0 | 0.0 |
| 44 | 2.0 |
| 59 | 2.9 |
| 73 | 4.2 |
| 88 | 5.2 |
| 103 | 6.6 |
| 117 | 8.7 |
| 132 | 10.9 |
| 147 | 13.3 |





a) Sketch a graph of speed vs. total time and label it "Velocity-Time Graph." Put the time on the *x*-axis (horizontal) and the speed on the *y*-axis (vertical). Plot your points from the table using feet per second (ft/s) units for velocity.

b) During which time interval is the velocity changing the most?

c) During which time interval is the velocity changing the least?

d) Acceleration is defined as the change in velocity for each time interval. Where is acceleration the greatest? Where is acceleration the least?

12. You can now calculate the acceleration for each time interval.

The acceleration is equal to the change in velocity (final speed − initial speed) divided by the change in time.

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{\Delta t}$$

Where $a$ is acceleration,

$\Delta v$ is change in velocity,

$v_f$ is final velocity,

$v_i$ is initial velocity,

$\Delta t$ is change in time or elapsed time.

The first acceleration calculation is shown below.

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{\Delta t} = \frac{44 \text{ ft/s} - 0 \text{ ft/s}}{2 \text{ s}} = \frac{22 \text{ ft/s}}{\text{s}}$$

The acceleration is equal to 22 feet per second every second. This is a change in speed (22 ft/s) with respect to time (1 s). This can also be written in the following ways:

22 ft/s every s

22 ft/s per s

22 (ft/s) per s

22 ft/s² (feet per second squared)

The last way is the easiest to say, but the first way is the easiest to understand.

If the automobile moved at a constant acceleration of 22 ft/s every second, you would see a constant increase in the speed every second, from 0 ft/s to 22 ft/s, then to 44 ft/s, and then to 66 ft/s. A constant acceleration is what happened to the cart on the ramp. However, this increase is not what usually happens to an automobile. An automobile does not move at a constant acceleration.

a) You can calculate the acceleration for the next time interval by calculating the acceleration of the sports car from 44 ft/s to 59 ft/s. This change in speed required 0.9 s. Complete this calculation. Did you get the value in the table of 16 ft/s every second?

Calculating Acceleration of a Sports Car in Feet per Second Squared

| Initial Speed (ft/s) | Final Speed (ft/s) | Change in time (s) | Acceleration (ft/s every second) |
|---|---|---|---|
| 0 | 44 | 2.0 | 22 |
| 44 | 59 | 0.9 | 16 |
| 59 | 73 | 1.3 | |
| 73 | 88 | 1.0 | |
| 88 | 103 | | |
| 103 | 117 | | |
| 117 | 132 | | |
| 132 | 147 | | |



**11.a)**

Students sketch the graph.

**11.b)**

The velocity changes the most when (change in position)/(time interval) has the maximum value. The greatest change in velocity per unit time is from 0 to 2 s with a change in speed of 22 ft/s.

**11.c)**

Velocity changes least when (change in position)/(time interval) has the minimum value. The lowest change per time was 10.9 s to 13.3 s with a change of 6.25 ft/s.

**11.d)**

Acceleration is the greatest from 0 to 2 s (the first time interval) and least for the last time interval in the table of 10.9 – 13.3 s.

**12.a)**

Yes, 16.3 ft/s.

CHAPTER 1

**12.b)**

The accelerations for the remaining time intervals (all in ft/second squared) are (59–73) 11, (73–88) 15, (88–103) 11, (103–117) 6.7, (117–132) 6.8, and (132–147) 6.3.

**12.c)**

The steepest slope for the graph should correspond to the greatest acceleration of the car, so the steepest slope occurs at the beginning of the graph from 0 to 2 s.

## Physics Talk

Students read how Galileo applied mathematics to study the change in the speed of falling objects. His technique of using a water clock enabled him to measure small increments of time. He realized that by using an inclined plane he could "slow down" the effects of gravity, which allowed him to investigate how falling objects change speed. Galileo described this change in speed in quantitative terms.

A demonstration of how a water clock works and a discussion with students on Galileo's method of making measurements with precision should give them a clearer picture of how a water clock was used to measure time. This *Physics Talk* illustrates how Galileo arrived at the definition of acceleration with his experiment of balls rolling down an inclined plane. To highlight the concept of acceleration, ask your class to write down the definition of acceleration in their *Active Physics* logs. Draw their attention to the motion of the cart that traveled down the incline in the *Investigate*, and how its speed changed at a regular rate, in the same manner as Galileo's balls rolling down an inclined plane. Emphasize that constant acceleration is represented by a straight line on the velocity-time graph. It is important for students to understand that the change in speed with respect to time remains the same in the case of constant acceleration.

The distinction between speed and velocity is drawn when students consider an automobile traveling around a curve. As they read why velocity is a vector quantity, your discussion should focus on why speed is considered to be different from velocity and how velocity can be controlled

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b) Work with your group members to complete the Calculating Acceleration of a Sports Car in Feet per Second Squared table in your log.

c) Compare the table with the velocity-time graph you sketched in *Step 11.a)*.

Recall that the slope of the velocity-time graph is equal to the acceleration. Where does the table indicate the greatest acceleration took place? Where does the graph have the steepest slope?

**Physics Talk**

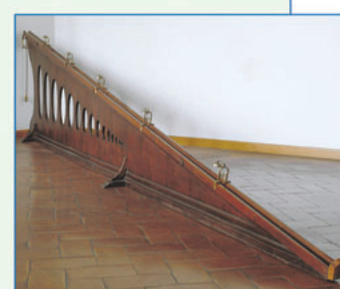
### CHANGING SPEED

#### Acceleration

When things change speed, it is usually noticeable. The motion of a falling object is a common example of something changing speed. Galileo Galilei, an Italian scientist, was the first person to apply mathematics to the study of the change in the speed of a falling object. To describe the change quantitatively, he needed to make measurements. In the *Investigate*, you used a motion detector to make measurements of **acceleration**. Since Galileo lived in the 1600s, he did not even have access to clocks and had to devise original ways to measure time with accuracy and precision. One technique he used involved a water clock. In a water clock, water flows through a funnel into a bowl. The more time that elapses, the more water is collected.

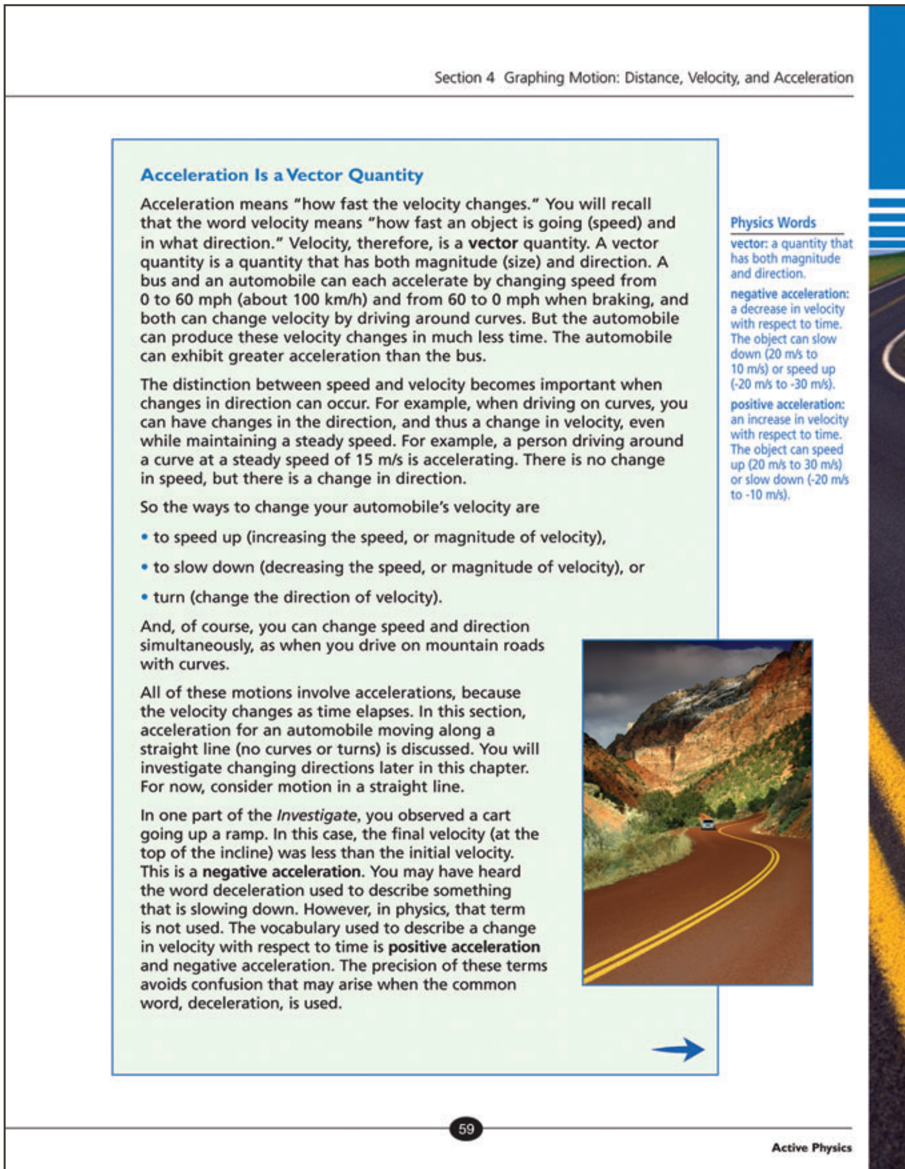
**Physics Words**
acceleration: the change in velocity with respect to a change in time.

To help him explore falling objects, he first investigated balls rolling down an incline. He thought that a ball rolling down an incline was like watching a falling object in "slow motion."



Through his experimentation with balls rolling down inclines, Galileo found that if he looked at the change in speed with respect to the change in time, the value remained the same as the ball descended the ramp. He then defined this as acceleration. The definition of acceleration as change in velocity with respect to time is still in use today.

In this section, you observed, just as Galileo did with rolling balls, that a cart traveling down an inclined plane has a constant acceleration. The velocity of the cart changes at a regular rate and is represented by a straight line on the velocity vs. time graph.



Section 4 Graphing Motion: Distance, Velocity, and Acceleration

### Acceleration Is a Vector Quantity

Acceleration means "how fast the velocity changes." You will recall that the word velocity means "how fast an object is going (speed) and in what direction." Velocity, therefore, is a **vector** quantity. A vector quantity is a quantity that has both magnitude (size) and direction. A bus and an automobile can each accelerate by changing speed from 0 to 60 mph (about 100 km/h) and from 60 to 0 mph when braking, and both can change velocity by driving around curves. But the automobile can produce these velocity changes in much less time. The automobile can exhibit greater acceleration than the bus.

The distinction between speed and velocity becomes important when changes in direction can occur. For example, when driving on curves, you can have changes in the direction, and thus a change in velocity, even while maintaining a steady speed. For example, a person driving around a curve at a steady speed of 15 m/s is accelerating. There is no change in speed, but there is a change in direction.

So the ways to change your automobile's velocity are

- to speed up (increasing the speed, or magnitude of velocity),
- to slow down (decreasing the speed, or magnitude of velocity), or
- turn (change the direction of velocity).

And, of course, you can change speed and direction simultaneously, as when you drive on mountain roads with curves.

All of these motions involve accelerations, because the velocity changes as time elapses. In this section, acceleration for an automobile moving along a straight line (no curves or turns) is discussed. You will investigate changing directions later in this chapter. For now, consider motion in a straight line.

In one part of the *Investigate*, you observed a cart going up a ramp. In this case, the final velocity (at the top of the incline) was less than the initial velocity. This is a **negative acceleration**. You may have heard the word deceleration used to describe something that is slowing down. However, in physics, that term is not used. The vocabulary used to describe a change in velocity with respect to time is **positive acceleration** and negative acceleration. The precision of these terms avoids confusion that may arise when the common word, deceleration, is used.

**Physics Words**

**vector:** a quantity that has both magnitude and direction.

**negative acceleration:** a decrease in velocity with respect to time. The object can slow down (20 m/s to 10 m/s) or speed up (-20 m/s to -30 m/s).

**positive acceleration:** an increase in velocity with respect to time. The object can speed up (20 m/s to 30 m/s) or slow down (-20 m/s to -10 m/s).

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Active Physics

either by changing the speed, or by changing direction with or without a change in speed. Give the students some examples of scalar and vector quantities, and then ask them to give you some additional examples. Because these concepts might confuse students initially, point out that they will be revisiting scalar and vector quantities while studying other topics in *Active Physics*.

Before introducing the term negative acceleration, recall the steps of the *Investigate* in which the cart goes up an incline. Discuss student observations and ask them why "deceleration" is not used in physics. They should be able to differentiate between negative and positive acceleration. To be able to decide whether acceleration is positive or negative, students must have a coordinate system that determines which direction is positive. For a better perspective, ask them to classify the changes in velocity they have observed, in different situations, as positive or negative acceleration.

As motion is represented in different forms, it is important for students to understand how each description confirms the relationship between acceleration, velocity, and time. Students should sketch models of strobe pictures to show accelerated motion. Have them write out the mathematical equation for each quantity using words and symbols in their log. Encourage students who might want to draw a circle to represent the relationship among variables when giving the equation for acceleration. The sample problem demonstrates how the acceleration of a toy car can be determined. You could ask students to write similar problems, using different values for each quantity, to determine the acceleration of an object. This strategy should make it easier for them to calculate acceleration and manipulate the acceleration equation, further reinforcing student understanding of the concept.

The units for acceleration are often confusing for students. It is preferable to use the term "meters per second per second" in discussions and in written form instead of $m/s^2$ until the students become more comfortable with the concept of acceleration. When students are learning to represent motion through graphs, make sure they understand that the instantaneous speed can be found at any point on a curve of the distance-time graph, from the slope of the line tangent to the curve at that point. Point out to them that the value of the slope on a *d-t* graph, $\Delta d/\Delta t$, is the same at all points if the object is traveling with constant speed. Similarly, on a velocity-time graph the slope is a straight line when the object is undergoing constant acceleration. While comparing motion graphs, students will see that the graphs of different motions for an automobile will yield different slopes and that the slope of the *d-t* graph is velocity, while the slope of the *v-t* graph is acceleration. By sketching these graphs in their *Active Physics* log, the concept of accelerated motion will be further reinforced.



You will investigate negative acceleration further in *Section 5*. For motion in a straight line, positive acceleration means that the velocity of the object is increasing over time. Negative acceleration means that the velocity of the object is decreasing over time, if the object is moving in a straight line.

**Vector and Scalar Quantities**

A quantity that involves both direction and size (magnitude) is called a vector quantity. A quantity that has size, but not direction, is called a scalar quantity. Speed is a scalar quantity. It only indicates the change in position over a period of time in a straight line. Velocity is a vector quantity. It can indicate a change in position over a period of time and the direction.

### Describing Accelerated Motion Using Strobe Pictures

Recall that you used three different models to describe motion: strobe pictures, graphs, and equations. Each gives the same information, but in different forms. You will use the same models to describe acceleration.

Because the speed is always changing during constant acceleration, the strobe illustration below shows the automobiles moving greater distances during each second of travel.

### Describing Acceleration Using an Equation

In the *Investigate*, you used an equation to describe acceleration. You calculated acceleration by finding the change in velocity with respect to time.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$$

This relationship can be written as an equation using symbols.

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

where $a$ is acceleration,

$\Delta v$ is change in velocity,

$\Delta t$ is change in time or elapsed time.

Section 4 Graphing Motion: Distance, Velocity, and Acceleration

### Units for Measuring Acceleration

To calculate acceleration, you divide change in velocity by change in time $\frac{\Delta v}{\Delta t}$. The units for acceleration are then, by definition, velocity divided by time. Recall from the previous section, the units for velocity can be m/s or km/h. Assume that the time interval is measured in seconds. The units for acceleration would then be (m/s)/s or (km/h)/s. The change in velocity is given in meters per second every second, or kilometers per hour every second.

When writing the units for acceleration, the final units are often simplified. For example, the following all mean the same thing. The simplified units are read as meters per second squared.

$$\frac{\text{m/s}}{\text{s}}, \text{ or (m/s)/s} = \frac{\text{m}}{\text{s}^2} \text{ or m/s}^2$$

In the *Investigate*, you calculated acceleration in feet per second every second, or feet per second squared (ft/s$^2$).

### Using the Equation for Acceleration to Find Other Quantities

The defining equation for acceleration shows the relationship between acceleration, velocity, and time. If you know two of these, you can find the third.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$$

Using algebra, it follows that

$$\text{Change in velocity} = \text{acceleration} \times \text{time}$$

$$\text{Time} = \frac{\text{change in velocity}}{\text{acceleration}}$$

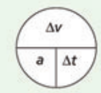
Using symbols, these equations can be written as

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

$$\Delta v = a \times \Delta t$$

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

As you did with the equations for speed in the previous section, you may find it helpful to use a circle, like the following:




By covering up the variable you wish to find, you can see the equation. To find change in velocity ($\Delta v$), cover up the $\Delta v$, and you see $a \times \Delta t$.

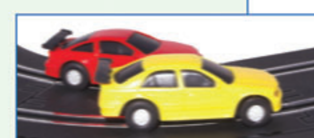
To find acceleration ($a$), cover up the $a$, and you see $\frac{\Delta v}{\Delta t}$.

To find time ($\Delta t$), cover up the $\Delta t$ and you see $\frac{\Delta v}{a}$.

There is only one definition of acceleration. Algebra allows you to write it in different forms.

### Sample Problem

At the start of a race, a toy car increases speed from 0 m/s to 5.0 m/s as the clock runs from 0 s to 2.0 s. Find the acceleration of the toy car.



***Strategy:*** Use the definition of acceleration as the change in velocity over a change in time.

***Given:***

Final velocity $(v_f) = 5.0$ m/s

Initial velocity $(v_i) = 0$ m/s

Final time $(t_f) = 2.0$ s

Initial time $(t_i) = 0$ s

***Solution:***

$$
\begin{aligned}
a &= \frac{\Delta v}{\Delta t} \\
&= \frac{v_f - v_i}{t_f - t_i} \\
&= \frac{5.0 \text{ m/s} - 0 \text{ m/s}}{2.0 \text{ s} - 0 \text{ s}} \\
&= \frac{5.0 \text{ m/s}}{2.0 \text{ s}} \\
&= 2.5 \text{ m/s}^2
\end{aligned}
$$

The acceleration is 2.5 m/s every second, and can be written and stated in three equivalent ways:

- 2.5 meters per second every second, or
- 2.5 (m/s)/s (meters per second per second), or
- 2.5 $\text{m/s}^2$ (meters per second squared).

**1-4b** **Blackline Master**

**CHAPTER 1**



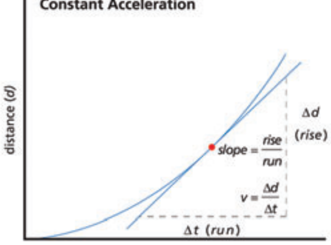
### Describing Acceleration Using Graphs

A third way to represent acceleration is with graphs. If distance is represented on the *y*-axis and the time is represented on the *x*-axis, then the graph showing constant acceleration is a curve. The slope of the **tangent line** to the curve at any point gives the instantaneous speed at that point. One such tangent is shown on the graph below. If you imagine tangents at different points, you can see that the slopes of the tangents increase as time increases. Thus, the speed is increasing during this time. An increasing speed during a time interval is an acceleration.

**Physics Words**

tangent line: a straight line that touches a curve in only one point.

If the velocity is represented on the *y*-axis and the time is represented on the *x*-axis, then the slope of the graph will be equal to the change in velocity with respect to time. The acceleration is equal to the value of the slope of the velocity-time graph. Notice that the slope has the same value at all points. You can conclude that since the slope of the *v-t* graph is constant, the acceleration is constant.



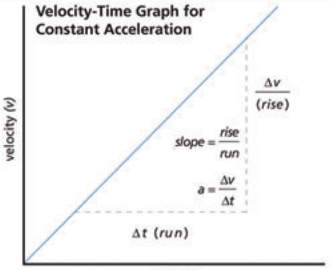

Distance-Time Graph for Constant Acceleration

### Describing Types of Motion Using Graphs

You can determine the general motion of an automobile by reviewing the distance vs. time graph, the corresponding velocity vs. time graph, and the corresponding acceleration vs. time graph. Each column in the table on the following page provides a way to describe the motion of an automobile.

**Note:** When interpreting graphs, you must always check to see if the *y*-axis represents distance, velocity, or acceleration. A horizontal line on a graph has very different meanings if the graph is a *d-t* graph, a *v-t* graph, or an *a-t* graph.

Use the Comparing Motion Graphs table on the next page to determine the general motion of an automobile. All of the three graphs in a column represent the same motion of the same car. One column gives the information in terms of changes in distance, another represents velocity, and the third acceleration over time.




Velocity-Time Graph for Constant Acceleration

## Checking Up

**1.**

Acceleration is the change in velocity with respect to a change in time and is represented using the following symbols: $a = \Delta v / \Delta t$.

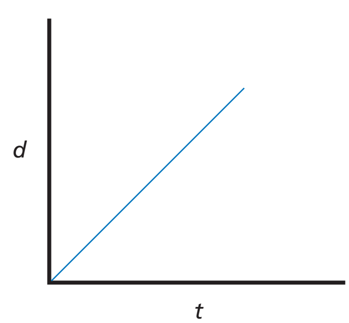
**2.**

The SI unit for measuring acceleration is $m/s^2$ (meters per second squared).

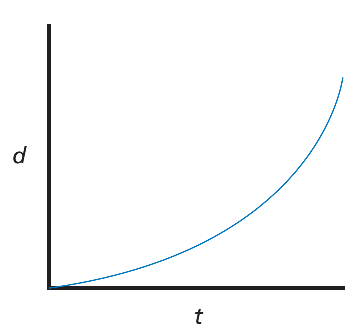
**3.**

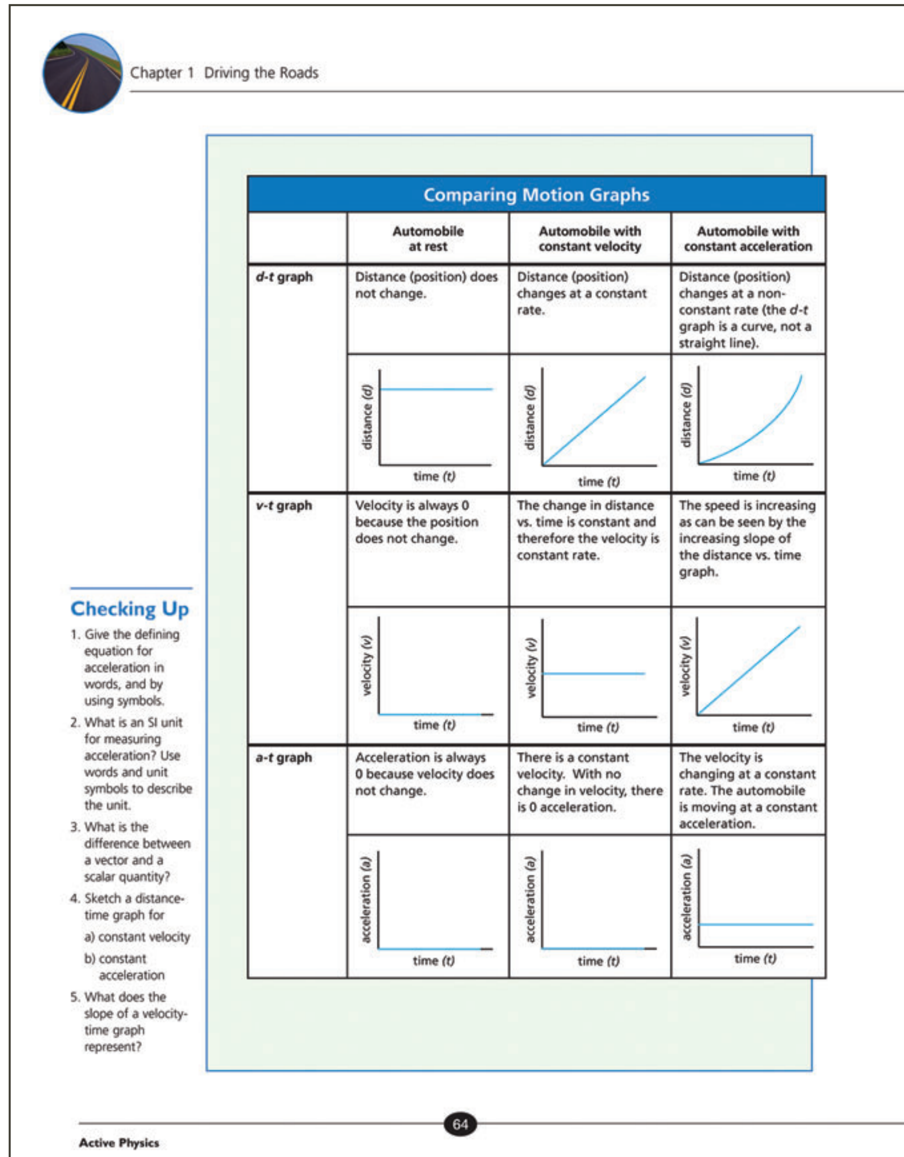
A vector quantity is a quantity that involves both size (magnitude) and direction. A scalar quantity involves size, but no direction.

**4.a)**




**4.b)**



Chapter 1  Driving the Roads

**Comparing Motion Graphs**

| | Automobile at rest | Automobile with constant velocity | Automobile with constant acceleration |
|---|---|---|---|
| *d-t* graph | Distance (position) does not change. | Distance (position) changes at a constant rate. | Distance (position) changes at a non-constant rate (the *d-t* graph is a curve, not a straight line). |
| | distance (*d*) / time (*t*) | distance (*d*) / time (*t*) | distance (*d*) / time (*t*) |
| *v-t* graph | Velocity is always 0 because the position does not change. | The change in distance vs. time is constant and therefore the velocity is constant rate. | The speed is increasing as can be seen by the increasing slope of the distance vs. time graph. |
| | velocity (*v*) / time (*t*) | velocity (*v*) / time (*t*) | velocity (*v*) / time (*t*) |
| *a-t* graph | Acceleration is always 0 because velocity does not change. | There is a constant velocity. With no change in velocity, there is 0 acceleration. | The velocity is changing at a constant rate. The automobile is moving at a constant acceleration. |
| | acceleration (*a*) / time (*t*) | acceleration (*a*) / time (*t*) | acceleration (*a*) / time (*t*) |

**Checking Up**

1. Give the defining equation for acceleration in words, and by using symbols.
2. What is an SI unit for measuring acceleration? Use words and unit symbols to describe the unit.
3. What is the difference between a vector and a scalar quantity?
4. Sketch a distance-time graph for
   a) constant velocity
   b) constant acceleration
5. What does the slope of a velocity-time graph represent?

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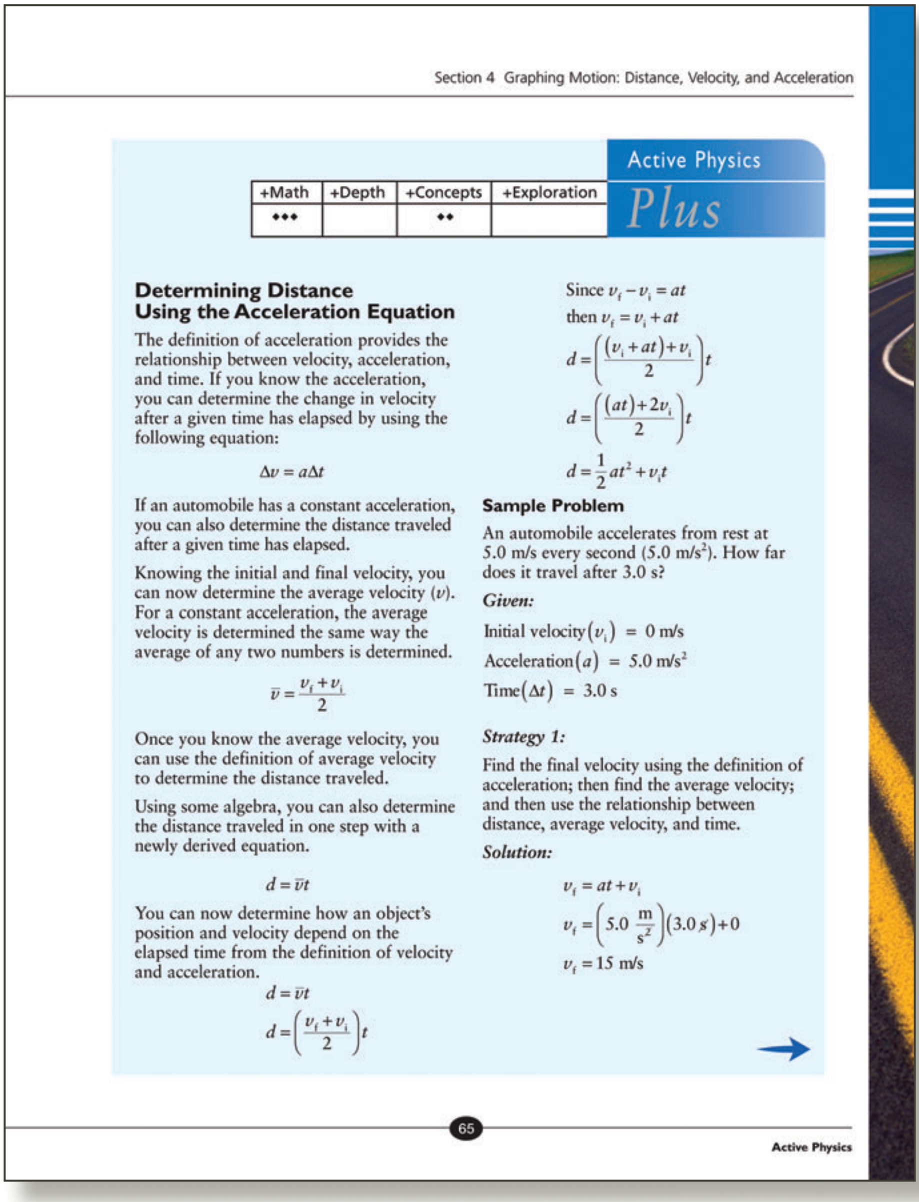
Active Physics

**5.**

The slope of the velocity-time graph represents the change in velocity with respect to time (acceleration).

**1-4c** **Blackline Master**



Section 4 Graphing Motion: Distance, Velocity, and Acceleration

Active Physics *Plus*

| +Math | +Depth | +Concepts | +Exploration |
|---|---|---|---|
| ••• | | •• | |

**Determining Distance Using the Acceleration Equation**

The definition of acceleration provides the relationship between velocity, acceleration, and time. If you know the acceleration, you can determine the change in velocity after a given time has elapsed by using the following equation:

$$\Delta v = a\Delta t$$

If an automobile has a constant acceleration, you can also determine the distance traveled after a given time has elapsed.

Knowing the initial and final velocity, you can now determine the average velocity ($v$). For a constant acceleration, the average velocity is determined the same way the average of any two numbers is determined.

$$\bar{v} = \frac{v_f + v_i}{2}$$

Once you know the average velocity, you can use the definition of average velocity to determine the distance traveled.

Using some algebra, you can also determine the distance traveled in one step with a newly derived equation.

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

You can now determine how an object's position and velocity depend on the elapsed time from the definition of velocity and acceleration.

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

$$d = \left(\frac{v_f + v_i}{2}\right)t$$

Since $v_f - v_i = at$

then $v_f = v_i + at$

$$d = \left(\frac{(v_i + at) + v_i}{2}\right)t$$

$$d = \left(\frac{(at) + 2v_i}{2}\right)t$$

$$d = \frac{1}{2}at^2 + v_i t$$

**Sample Problem**

An automobile accelerates from rest at 5.0 m/s every second (5.0 m/s²). How far does it travel after 3.0 s?

***Given:***

Initial velocity $(v_i)$ = 0 m/s

Acceleration $(a)$ = 5.0 m/s²

Time $(\Delta t)$ = 3.0 s

***Strategy 1:***

Find the final velocity using the definition of acceleration; then find the average velocity; and then use the relationship between distance, average velocity, and time.

***Solution:***

$$v_f = at + v_i$$

$$v_f = \left(5.0\ \frac{\text{m}}{\text{s}^2}\right)(3.0\ \text{s}) + 0$$

$$v_f = 15\ \text{m/s}$$

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Active Physics

## Active Physics Plus

*Active Physics Plus* draws the curious student to explore physics concepts in more depth and detail. To clarify the purpose of *Active Physics Plus*, make all students read the introduction to this section. You might want to ask a few students to demonstrate the mathematical relationship between acceleration, velocity, and time. When students use the formula $d = (v_i + v_f)(t/2)$ to determine distance using the definition of average velocity, emphasize that the acceleration for the period of time that the distance is being measured remains constant. Highlight the sample problem to show how to use the equation appropriately when the acceleration for which distance is being calculated has a constant value. The students venturing into this section can actively engage other students who are still in the early stages of understanding the concept of acceleration. Through this strategy, all students can eventually participate in developing their understanding of new concepts.

CHAPTER 1

## What Do You Think Now?

This is a good time to return to the *What Do You Think?* section and review the answers students gave earlier. It is an opportunity for you to gauge students' prior understanding of velocity. They should now be able to relate velocity to acceleration, and how the driver can adjust velocity to control following distance. You may want to provide answers given in *A Physicist's Response* and allow students to share their opinions. This review will clarify the finer aspects of velocity and acceleration. Students should by now have a more thorough understanding of the $a = \Delta v / \Delta t$ equation. Ask them to share their sketches of velocity-time graphs in small groups to compare and contrast the motion of each vehicle. Encourage them to describe how acceleration is illustrated in their graphs of motion.



Knowing that the final velocity is 15 m/s and the initial velocity equals 0, you can calculate the average velocity.

$$\bar{v} = \frac{v_f + v_i}{2} = \frac{15 \text{ m/s} + 0 \text{ m/s}}{2} = 7.5 \text{ m/s}$$

Using the definition of average velocity, the distance can be computed:

$$d = \bar{v}t = 7.5 \frac{\text{m}}{\cancel{\text{s}}} \times 3.0 \cancel{\text{s}} = 22.5 \text{ m}$$

***Strategy 2:***

Because acceleration, time, and initial velocity are provided, use the derived relationship of distance, acceleration, and time. There is no need to find the final velocity.

***Solution:***

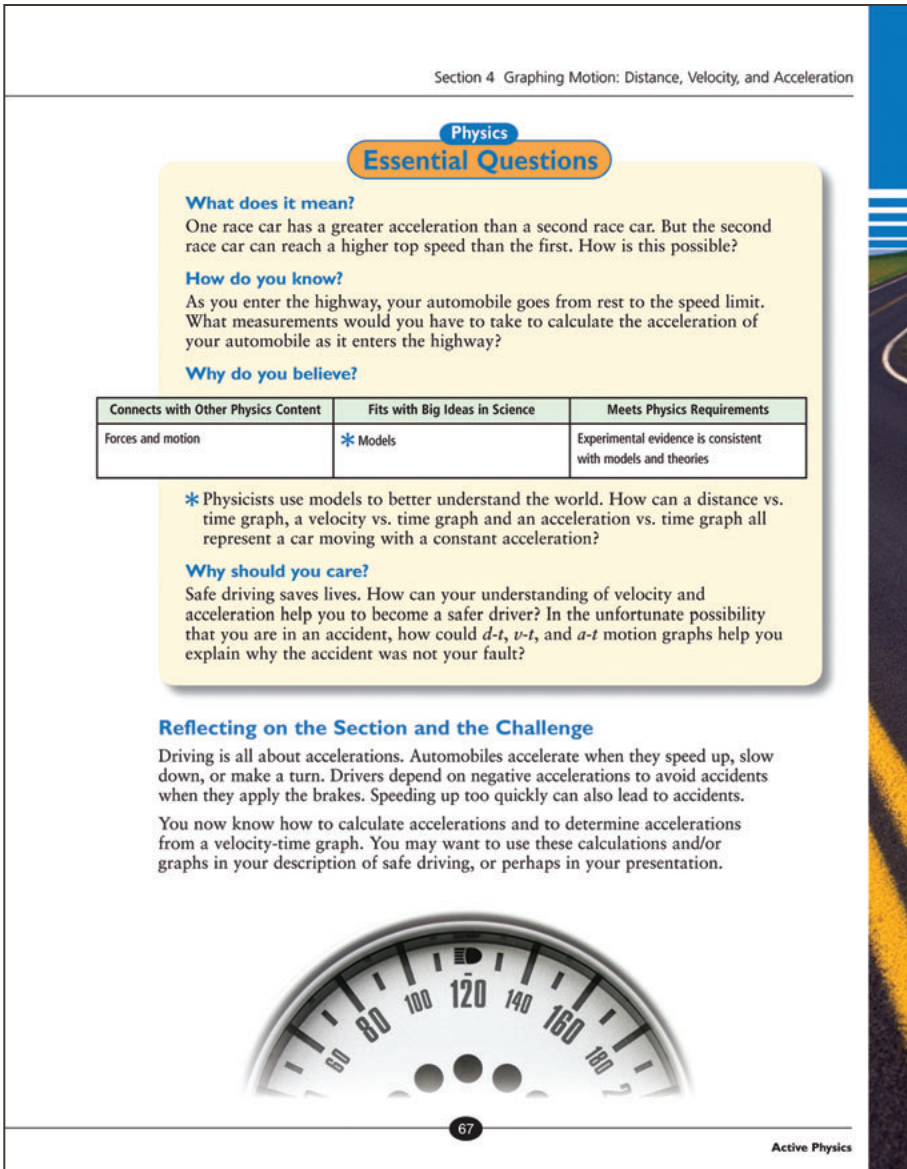
$$d = \frac{1}{2}at^2 + v_i t = \frac{1}{2}\left(5 \frac{\text{m}}{\cancel{\text{s}^2}}\right)(3 \cancel{\text{s}})(3 \cancel{\text{s}}) + 0 = 22.5 \text{ m}$$

### What Do You Think Now?

At the beginning of this section, you were asked the following:

- **An automobile and a bus are stopped at a traffic light. What are some differences and similarities of the motion of these two vehicles as each goes from a stop to the speed limit of 30 mph?**

How would you answer this question now? Now that you have investigated change in velocity over time, compare and contrast the motion of the vehicles using the term acceleration. Sketch a velocity-time graph for each vehicle.





Physics
**Essential Questions**

**What does it mean?**

One race car has a greater acceleration than a second race car. But the second race car can reach a higher top speed than the first. How is this possible?

**How do you know?**

As you enter the highway, your automobile goes from rest to the speed limit. What measurements would you have to take to calculate the acceleration of your automobile as it enters the highway?

**Why do you believe?**

| Connects with Other Physics Content | Fits with Big Ideas in Science | Meets Physics Requirements |
|---|---|---|
| Forces and motion | * Models | Experimental evidence is consistent with models and theories |

* Physicists use models to better understand the world. How can a distance vs. time graph, a velocity vs. time graph and an acceleration vs. time graph all represent a car moving with a constant acceleration?

**Why should you care?**

Safe driving saves lives. How can your understanding of velocity and acceleration help you to become a safer driver? In the unfortunate possibility that you are in an accident, how could *d-t*, *v-t*, and *a-t* motion graphs help you explain why the accident was not your fault?

**Reflecting on the Section and the Challenge**

Driving is all about accelerations. Automobiles accelerate when they speed up, slow down, or make a turn. Drivers depend on negative accelerations to avoid accidents when they apply the brakes. Speeding up too quickly can also lead to accidents.

You now know how to calculate accelerations and to determine accelerations from a velocity-time graph. You may want to use these calculations and/or graphs in your description of safe driving, or perhaps in your presentation.





## Reflecting on the Section and the Challenge

Students should be able to reflect on how drivers depend on negative acceleration to avoid accidents. They should be able to understand how velocity-time graphs can help them calculate the rate at which acceleration changes. They can use their calculations to highlight how speeding up in a short interval of time could lead to an accident. The results of their calculations will help the students describe the importance of safe driving in their *Chapter Challenge*.

## Physics Essential Questions

### What does it mean?

If the second car is able to accelerate for a longer time than the first car, it can continue to gain speed and reach a higher top speed, while the first car is traveling at its maximum speed.

### How do you know?

Acceleration is the change in speed during a given amount of time. You know that your beginning speed was 0 mi/h. You can measure your final speed. You can also measure the time required to get to that final speed. This change in speed divided by the time is the acceleration $a = \Delta v / \Delta t$.

### Why do you believe?

The acceleration vs. time graph would show a horizontal line. The velocity vs. time graph would show a straight ascending line. The slope of that line would be the acceleration. A distance vs. time graph would show a curved line. The slope of the tangent line at later times would be greater showing an increase in velocity.

### Why should you care?

The graphs and your understanding of distance, velocity and acceleration provide you with precision and language to describe what happened. It is more informative to explain that you were traveling at 30 mi/h than it is to say you were going at some intermediate speed.

## Physics to Go

**1.**

An object can have zero acceleration (no change in velocity) and a nonzero velocity. Such an object is called a "free particle" because it moves freely without changing velocity.

**2.**

An object can have zero velocity and nonzero acceleration. This happened, for example, with the cart rolling up and then down the inclined plane. At the top of the plane, the velocity was instantaneously zero, but it did not stay zero because it was constantly accelerated. The velocity decreased from a positive value, to zero, and through zero to negative values.

**3.**

If two automobiles have the same acceleration, they do not necessarily have the same velocity. Acceleration measures rate of change of velocity, not velocity itself. The velocity depends not only on the acceleration but also on the time the object has been accelerating, as well as on the initial velocity.

**4.**

If two automobiles have the same velocity, they do not necessarily have the same acceleration. For example, a ball at rest has zero velocity, and an arrow at the top of its flight when shot straight up has zero velocity (instantaneously). The ball has zero acceleration, but the arrow has a nonzero acceleration. The ball will remain at rest, but the arrow will not.

Chapter 1 Driving the Roads

### Physics to Go

1. Can a situation exist in which an object has zero acceleration and nonzero velocity? Explain your answer.
2. Can a situation exist in which an object has zero velocity and nonzero acceleration, even for an instant? Explain your answer.
3. If two automobiles have the same acceleration, do they have the same velocity? Why or why not?
4. If two automobiles have the same velocity, do they have the same acceleration? Why or why not?
5. Can an accelerating automobile be overtaken by an automobile moving with constant velocity?
6. Is it correct to refer to speed-limit signs instead of velocity-limit signs? Why or why not? What units are assumed for speed-limit signs in the United States?
7. Suppose an automobile were accelerating at 2 mi/h every 5 s and could keep accelerating for 2 min at that rate.
   a) How fast would it be going at $t = 2$ min?
   b) How far would it be from the starting line?
8. At an international auto race, a race car leaves the pit after a refueling stop and accelerates uniformly to a speed of 75 m/s in 9 s to rejoin the race.
   a) What is the race car's acceleration during this time?
   b) What was the race car's average speed during the acceleration?
   c) How far does the race car go during the time it is accelerating?
   d) A second race car leaves after its pit stop and accelerates to 75 m/s in 8 s. Compared to the first race car, what is this race car's acceleration, average speed during the acceleration, and distance traveled?
9. During a softball game, a player running from second base to third base reaches a speed of 4.5 m/s before she starts to slide into third base. When she reaches third base 1.3 s after beginning her slide, her speed is reduced to 0.6 m/s.
   a) What is the player's acceleration during the slide?
   b) What was the distance of her slide?
   c) If she had slid for only 1.1 s, how fast would she have been moving when she reached third base? (Assume she had the same acceleration as before.)
   d) Which of these two trials would get her from second base to third base faster?

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Active Physics

**5.**

An automobile that is accelerating may be starting from a lower initial velocity than the automobile that is traveling at constant speed. An example would be an automobile stopped at a stoplight that starts to accelerate when the light turns green. If an automobile rolling through the light has a high velocity, it might easily pass the automobile that accelerates as the light turns green.

**6.**

You are not really using language incorrectly when talking about "speed limits" because it is assumed that the vehicles are going in a certain direction on the road where the speed limit is posted. Technically, the sign means "the magnitude of your velocity should not exceed this value." In the United States the units are not designated, and "Speed Limit 70" means 70 mi/h. Most other countries assume km/h in their posted speed limits, and they usually do not include the units either.

**7.a)**

An automobile that accelerates at 2 mi/h/5 s would have an increase in speed of

$\Delta v = a \times \Delta t$.

Thus, $\Delta v = (2 \text{ mi/h})/(5 \text{ s}) \times 120 \text{ s} = 48 \text{ mi/h}$.

**7.b)**

Starting from rest, the distance covered by the automobile can be given by $d = v_{\text{average}} \Delta t$. The automobile's average velocity would be the

$$\frac{\text{initial speed (0)} - \text{final speed (48)}}{2} = 24 \text{ mi/h}.$$

The distance covered then would be

$d = (24 \text{ mi/h})(1/30 \text{ h}) = 0.8 \text{ mi}$.

**Note:** The units of time changed so they would solve both problems in hours to cancel out and leave a unit of distance, miles.

**8.a)**

The car's acceleration, $a$, is $a = \Delta v/\Delta t = (75 \text{ m/s} - 0)/(9 \text{ s}) = 8.33 \text{ m/s}^2$.

**8.b)**

The car's average speed, $v_{\text{average}} = (v_i + v_f)/2 = (75 \text{ m/s} + 0)/2 = 37.5 \text{ m/s}$.

**8.c)**

The distance the car goes $d = v_{\text{average}} t = (37.5 \text{ m/s})(9 \text{ s}) = 337.5 \text{ m}$.

**8.d)**

The second car's acceleration is greater, average speed is the same, but the distance traveled in 8 s is less than the distance covered in 9 s by the first car.

**9.a)**

The player's acceleration during the slide is

$a = \Delta v/\Delta t = (0.6 \text{ m/s} - 4.5 \text{ m/s})/(1.3 \text{ s}) = -3 \text{ m/s}^2$.

**9.b)**

The distance of the player's slide is calculated by first determining the average velocity

$v_{\text{average}} = (v_i + v_f)/2 = (4.5 \text{ m/s} + 0.6 \text{ m/s})/2 = 2.55 \text{ m/s}$.

Then the distance,

$d = v_{\text{average}} \times t = 2.55 \text{ m/s} \times 1.3 \text{ s} = 3.315 \text{ m}$.

**9.c)**

The acceleration of the player's slide

$a = \Delta v/\Delta t = (v_f - v_i)/\Delta t$

$-3 \text{ m/s}^2 = (v_f - 4.5 \text{ m/s})/(1.1 \text{ s})$

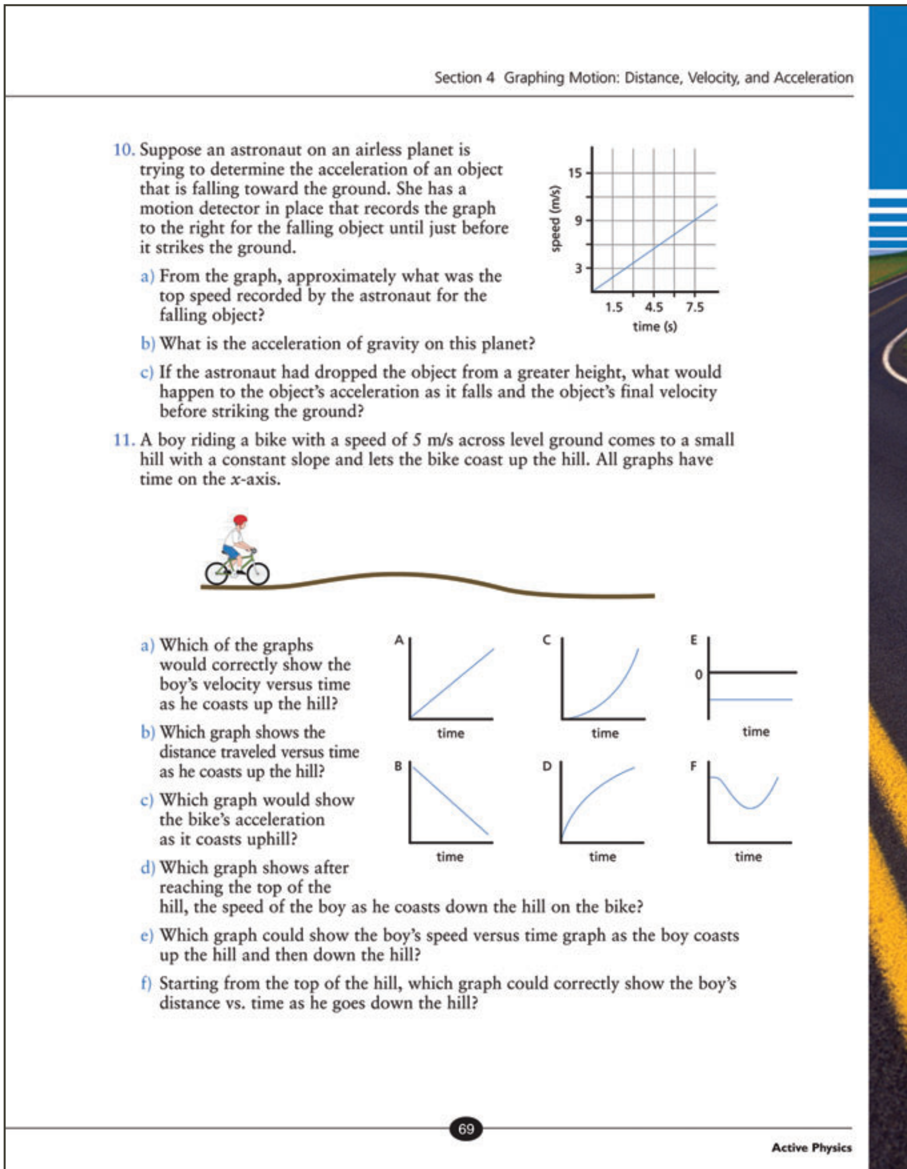
$v_f = 1.2 \text{ m/s}$.

**9.d)**

When the runner slides for 1.1 s, she is running for 0.2 s more than her 1.3 s slide. She has a higher average speed for that time than if she were sliding and slowing down. Also, when she slides for 1.1 s, her average speed during the slide is larger because she doesn't slow down as much. Because her average speed is higher for both parts of the trip, she must arrive in less time than when she slides for 1.3 s.

NOTES

## NOTES



Section 4 Graphing Motion: Distance, Velocity, and Acceleration

10. Suppose an astronaut on an airless planet is trying to determine the acceleration of an object that is falling toward the ground. She has a motion detector in place that records the graph to the right for the falling object until just before it strikes the ground.



a) From the graph, approximately what was the top speed recorded by the astronaut for the falling object?

b) What is the acceleration of gravity on this planet?

c) If the astronaut had dropped the object from a greater height, what would happen to the object's acceleration as it falls and the object's final velocity before striking the ground?

11. A boy riding a bike with a speed of 5 m/s across level ground comes to a small hill with a constant slope and lets the bike coast up the hill. All graphs have time on the *x*-axis.

a) Which of the graphs would correctly show the boy's velocity versus time as he coasts up the hill?

b) Which graph shows the distance traveled versus time as he coasts up the hill?

c) Which graph would show the bike's acceleration as it coasts uphill?

d) Which graph shows after reaching the top of the hill, the speed of the boy as he coasts down the hill on the bike?



e) Which graph could show the boy's speed versus time graph as the boy coasts up the hill and then down the hill?

f) Starting from the top of the hill, which graph could correctly show the boy's distance vs. time as he goes down the hill?

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Active Physics

**11.a)**

Graph B would show how the velocity decreases uniformly with time as the bike goes up the hill.

**11.b)**

Graph D would show how the distance covered is decreasing as the bike's velocity is decreasing as it coasts up the hill.

**11.c)**

Graph E would indicate a constant negative acceleration as the bike slows down.

**11.d)**

Graph A shows the speed of the bike increasing as it goes down the hill.

**11.e)**

Graph F shows decreasing speed as the bike goes up the hill, and increasing speed as the bike goes down the hill.

**11.f)**

Graph C shows the boy's distance vs. time as he accelerates going down the hill.

CHAPTER 1

**10.a)**

From the endpoint of the graph, the highest speed would be approximately 15 m/s.

**10.b)**

Using values from the graph, $v_i = 0$ m/s and $v_f = 9$ m/s.

The change in time for this increase in velocity was 7.5 s.

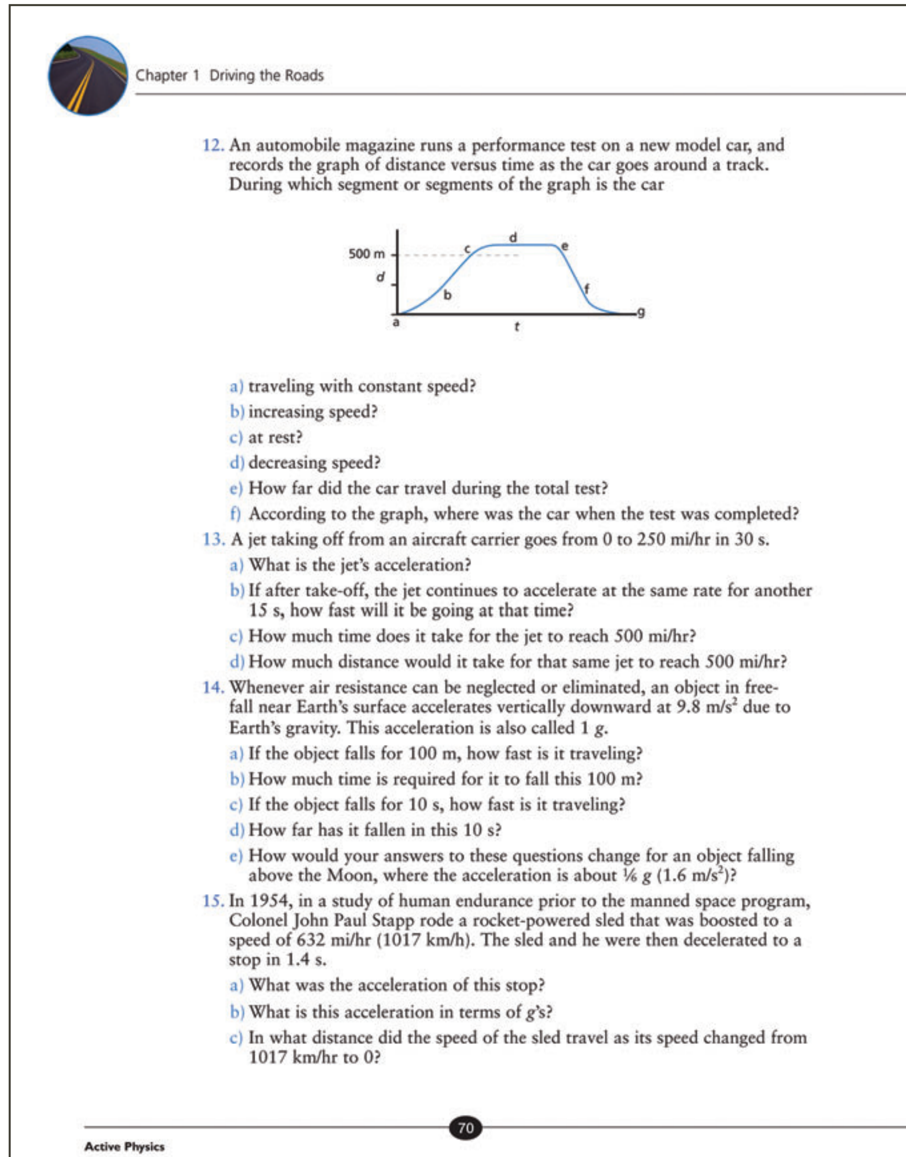
Using the acceleration formula

$a = \Delta v / \Delta t$

$a = (9 \text{ m/s} - 0 \text{ m/s}) / 7.5 \text{ s} = 1.2 \text{ m/s}^2$.

**10.c)**

Because the slope of the line is a constant, the acceleration is constant. When the object falls a larger distance the acceleration remains the same, but the final velocity increases.


Chapter 1 Driving the Roads

12. An automobile magazine runs a performance test on a new model car, and records the graph of distance versus time as the car goes around a track. During which segment or segments of the graph is the car



a) traveling with constant speed?
b) increasing speed?
c) at rest?
d) decreasing speed?
e) How far did the car travel during the total test?
f) According to the graph, where was the car when the test was completed?

13. A jet taking off from an aircraft carrier goes from 0 to 250 mi/hr in 30 s.
a) What is the jet's acceleration?
b) If after take-off, the jet continues to accelerate at the same rate for another 15 s, how fast will it be going at that time?
c) How much time does it take for the jet to reach 500 mi/hr?
d) How much distance would it take for that same jet to reach 500 mi/hr?

14. Whenever air resistance can be neglected or eliminated, an object in free-fall near Earth's surface accelerates vertically downward at 9.8 $m/s^2$ due to Earth's gravity. This acceleration is also called 1 *g*.
a) If the object falls for 100 m, how fast is it traveling?
b) How much time is required for it to fall this 100 m?
c) If the object falls for 10 s, how fast is it traveling?
d) How far has it fallen in this 10 s?
e) How would your answers to these questions change for an object falling above the Moon, where the acceleration is about ⅙ *g* (1.6 $m/s^2$)?

15. In 1954, in a study of human endurance prior to the manned space program, Colonel John Paul Stapp rode a rocket-powered sled that was boosted to a speed of 632 mi/hr (1017 km/h). The sled and he were then decelerated to a stop in 1.4 s.
a) What was the acceleration of this stop?
b) What is this acceleration in terms of *g*'s?
c) In what distance did the speed of the sled travel as its speed changed from 1017 km/hr to 0?

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**12.a)**

Segment c-d has a constant slope on a *d-t* graph, indicating constant speed.

**12.b)**

Segments a-b and e-f are showing increasing speed, although e-f shows the object moving back toward the starting point.

**12.c)**

Segment d-e shows the object at rest.

**12.d)**

Segments b-c and f-g show decreasing speed.

**12.e)**

The automobile travels a total distance of 1200 m—600 m away and 600 m returning to the start (0 m) position.

**12.f)**

The automobile was back at the starting point at a time, *t*, later on. Returning to the starting point means returning to the zero-meter position, but the object cannot return to the zero-time position, since that would mean traveling backward in time!

**13.a)**

$a = \Delta v / \Delta t$

$a = (250 \text{ mi/h})/30 \text{ s} = 8.3 \text{ mi/h/s}$.

**13.b)**

$a = \Delta v / \Delta t$ or $\Delta v = a\Delta t$

$\Delta v = 8.3 \text{ mi/h/s}(15 \text{ s}) = 125 \text{ mi/h}$

Since $\Delta v = v_f - v_i$,

$125 \text{ mi/h} = v_f - 250 \text{ mi/h}$

and $v_f = 375$ mi/h.

**13.c)**

$a = \Delta v / \Delta t$ or $\Delta t = \Delta v / a =$

$(500 \text{ mi/h})/(8.33 \text{ mi/h/s}) = 60$ s.

**13.d)**

$v_f^2 = v_i^2 + 2ad$

$(500 \text{ mi/h})^2 = 0^2 + 2(8.3 \text{ mi/h/s})d$

$d = 1.5 \times 10^4 (\text{mi/h})(\text{s})$.

Converting seconds to hours using 1 h/3600 s gives

$d = 1.5 \times 10^4 (\text{mi/h})(\text{s}) \times$

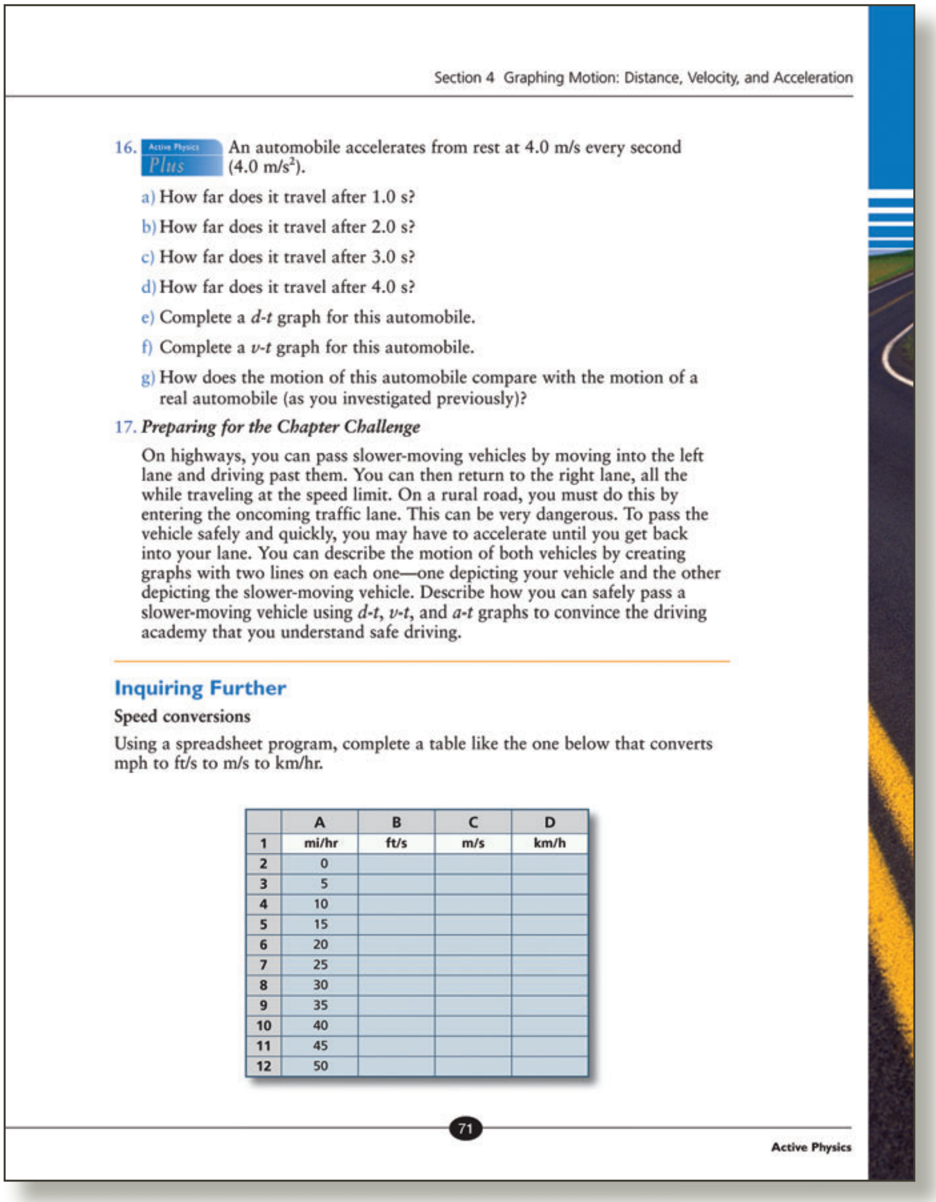
$(1 \text{ h}/3600 \text{ s}) = 4.2$ mi.

**14.a)**

$v_f^2 = 2ad$,

$v_f^2 = 2(9.8 \text{ m/s}^2)(100 \text{ m}) =$

$1960 \text{ m}^2/\text{s}^2$ and $v_f = 44.3$ m/s.



Section 4 Graphing Motion: Distance, Velocity, and Acceleration

16. Active Physics Plus An automobile accelerates from rest at 4.0 m/s every second (4.0 $m/s^2$).

a) How far does it travel after 1.0 s?

b) How far does it travel after 2.0 s?

c) How far does it travel after 3.0 s?

d) How far does it travel after 4.0 s?

e) Complete a *d-t* graph for this automobile.

f) Complete a *v-t* graph for this automobile.

g) How does the motion of this automobile compare with the motion of a real automobile (as you investigated previously)?

17. ***Preparing for the Chapter Challenge***

On highways, you can pass slower-moving vehicles by moving into the left lane and driving past them. You can then return to the right lane, all the while traveling at the speed limit. On a rural road, you must do this by entering the oncoming traffic lane. This can be very dangerous. To pass the vehicle safely and quickly, you may have to accelerate until you get back into your lane. You can describe the motion of both vehicles by creating graphs with two lines on each one—one depicting your vehicle and the other depicting the slower-moving vehicle. Describe how you can safely pass a slower-moving vehicle using *d-t*, *v-t*, and *a-t* graphs to convince the driving academy that you understand safe driving.

**Inquiring Further**

**Speed conversions**

Using a spreadsheet program, complete a table like the one below that converts mph to ft/s to m/s to km/hr.

| | A | B | C | D |
|---|---|---|---|---|
| 1 | mi/hr | ft/s | m/s | km/h |
| 2 | 0 | | | |
| 3 | 5 | | | |
| 4 | 10 | | | |
| 5 | 15 | | | |
| 6 | 20 | | | |
| 7 | 25 | | | |
| 8 | 30 | | | |
| 9 | 35 | | | |
| 10 | 40 | | | |
| 11 | 45 | | | |
| 12 | 50 | | | |

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**14.b)**

$d = \frac{1}{2}a\left(t^2\right)$

$t = \left(2d/a\right)^{1/2} =$

$\left[\left(2\times 100\text{ m}\right)/\left(9.8\text{ m/s}^2\right)\right]^{1/2} = 4.5\text{ s.}$

**14.c)**

$v_f = v_i + at;\quad v_f =$

$0\text{ m/s} + \left(9.8\text{ m/s}^2\right)\left(10\text{ s}\right) = 98\text{ m/s.}$

**14.d)**

$d = \frac{1}{2}a\left(t^2\right)$

$d = \frac{1}{2}\left(9.8\text{ m/s}^2\right)\left(10\text{ s}\right)^2 = 490\text{ m.}$

**14.e)**

On the Moon, where the acceleration due to gravity is 1/6 g, the answers would be 18 m/s, 11.1 s, 16.3 m/s, and 81.7 m.

**15.a)**

Converting 1012 km/hr to m/s gives you
(1,017,000 m/h)(1 h/3600 s) = 282.5 m/s.
Using $a = (\Delta v)/(\Delta t) =$
(0 m/s – 282.5 m/s)/(1.4 s) =
–201.8 $m/s^2$.

**15.b)**

To get the acceleration in *g*'s, divide the sled's acceleration (−201.8 $m/s^2$ by the acceleration of gravity (9.8 $m/s^2$) to get 20.6 *g*'s.

**15.c)**

$v_f^2 = v_i^2 + 2ad$ and solving for $d$ gives $d = \left(v_f^2 - v_i^2\right)/\left(2a\right) =$
(0 m/s – 282.5 m/s)/(1.4 s) =
–201.8 $m/s^2$.

**16.a)**

$v_{\text{average}} = \left(v_i + v_f\right)/2$

$v_{\text{average}} = \left(4\text{ m/s} + 0\text{ m/s}\right)/2 =$

2 m/s, and $d = v_{\text{average}}\left(t\right) =$

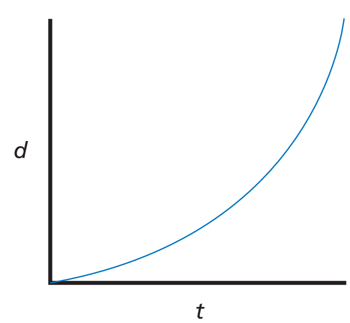
$\left(2\text{ m/s}\right)\left(1\text{ s}\right) = 2\text{ m.}$

**16.b-d)**

Similarly, distances for 2, 3, and 4 would be 8 m, 18 m and 32 m.

**16.e)**

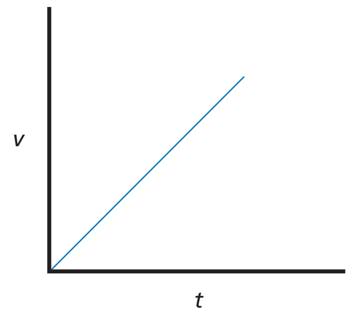
The *d-t* graph would look like the one below.




CHAPTER 1

**16.f)**

The *v-t* graph would appear as shown below.




**16.g)**

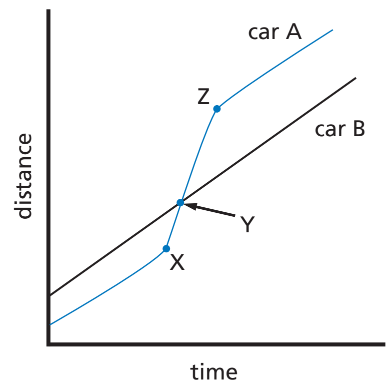
The relative motion of this automobile (acceleration of 4 m/s$^2$) to that of the real automobile shown at the end of *Section 7* is mainly a comparison of accelerations. The "Touring Sedan" has a listed speed of 35 mi/h (approximately 16 m/s) after 2 seconds of acceleration or an acceleration of 8 m/s$^2$ (8 m/s divided by 2 s). This is significantly higher than the vehicle in *Question 16*. However, by the time the "Touring Sedan" has reached a speed of 60 mi/h, (approximately 27 m/s) in 7.2 seconds, the average acceleration has dropped to 3.7 m/s$^2$ (27 m/s divided by 7.2 s). This is very close to the value given for the theoretical automobile in the question.

**17.**

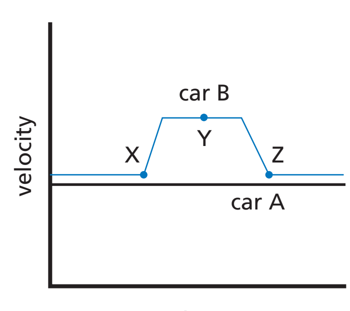
***Preparing for the Chapter Challenge***

The *Preparing for the Chapter Challenge* graphs should appear as follows:

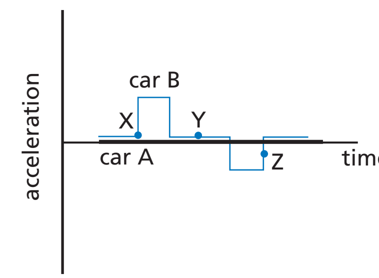
The *d-t* graph shows car A will start out initially behind car B, and the two cars have matching velocities as seen from the equal slopes of the lines. At point X, car A starts to accelerate to a higher speed, passing car B at point Y, where each car's distance from the start is equal, and continues at a greater speed to point Z. At point Z, car A begins to slow down to again match the velocity (slope of the line) of car B, but now car A is ahead of car B as shown by its higher position along the distance axis.




The same process as described in the previous paragraph is also shown on the *v-t* graph below. Car A increases velocity at point X until it is traveling faster than car B. At some point, where the area under the thin line matches the area under the thick line, near point Y, car A passes car B. Car A continues at a higher speed moving ahead of car B, and then slows down during interval Z. After interval Z, the cars again match speeds, with car A ahead.




Finally, the *a-t* graph below shows the cars both traveling with zero acceleration (constant velocity) until car A accelerates at point X to pass car B. Car A then returns to a constant velocity higher than car B, but also zero acceleration, while passing through region Y. After passing car B, car A slows down (negative acceleration) at point Z, until it is again traveling with constant speed.




## Inquiring Further

The students' table should be the same as follows.

| mi/h | ft/s | m/s | km/h |
|---|---|---|---|
| 0 | 0.0 | 0 | 0 |
| 5 | 7.3 | 2.2 | 8.1 |
| 10 | 14.7 | 4.5 | 16.3 |
| 15 | 22.0 | 6.7 | 24.4 |
| 20 | 29.3 | 9.0 | 32.6 |
| 25 | 36.7 | 11.2 | 40.7 |
| 30 | 44.0 | 13.4 | 48.8 |
| 35 | 51.3 | 15.7 | 57.0 |
| 40 | 58.7 | 17.9 | 65.1 |
| 45 | 66.0 | 20.2 | 73.3 |
| 50 | 73.3 | 22.4 | 81.4 |

NOTES

## SECTION 4 QUIZ

**1-4d** **Blackline Master**

1. If an automobile's velocity changes from 25 m/s to 15 m/s in 2 s, then what is its acceleration?

   a) –5 $m/s^2$  b) 7.5 $m/s^2$

   c) 13 $m/s^2$  d) 20 $m/s^2$

2. A strobe photograph is taken of four automobiles undergoing different motions. Which diagram below represents an automobile undergoing constant acceleration?

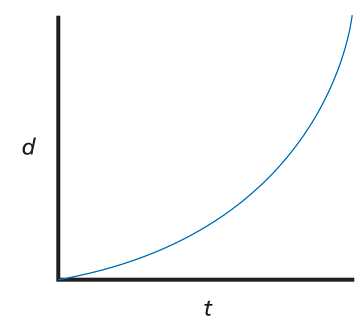
   a) 

   b) 

   c) 

   d) 

3. The graph to the right shows the *d*-*t* graph for an automobile. According to the graph, the object is




   a) traveling with a constant speed.

   b) undergoing constant acceleration.

   c) traveling with a decreasing velocity.

   d) slowing down and then speeding up.

4. A student completes the following two experiments with a cart on an inclined plane.

   Experiment 1: A cart is given a push up an inclined plane and released.

   Experiment 2: A cart is released from the top of an inclined plane.

   Which statement below best describes the velocity and acceleration of the cart in these experiments?

   a) In both experiments, the acceleration is down the plane.

   b) In both experiments, the velocity is down the plane.

   c) In both experiments, the velocity is up the plane and the acceleration is down the plane.

   d) In both experiments, the velocity is down the plane and the acceleration is up the plane.

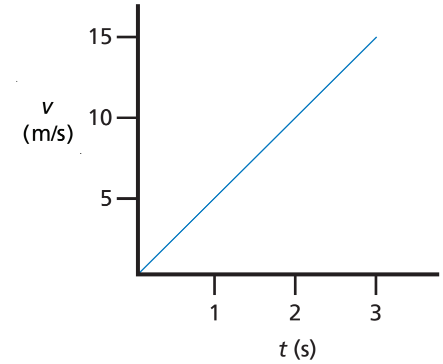
5. The graph represents the relationship between speed and time for an automobile moving in a straight line. Using any 1-s interval, find the automobile's acceleration.

a) 1.0 $m/s^2$

b) 0.0 $m/s^2$

c) 10 $m/s^2$

d) 5.0 $m/s^2$






## SECTION 4 QUIZ ANSWERS

1. a) The acceleration is given by $a = \Delta v/\Delta t$. The velocity changes from 25 to 15 (a change of 10 m/s) and the time change is 2 s, giving an acceleration of – 5 $m/s^2$. Choice *d)* comes from adding the velocities rather than subtracting them, Choice *b)* would be from using the average of the velocities, and Choice *c)* has no justification.

2. b) During acceleration the distance between the images of the automobile would increase at a constant rate. Choice *a)* is constant velocity, Choice *d)* is constant velocity then slowing, and Choice *c)* is random velocities.

3. b) For constant speed, the *d-t* graph would be a straight line. An object that is slowing down would be curved in the opposite direction, and a car that is speeding up and slowing down would be a combination of the constant acceleration graph and one for slowing down.

4. a) The students observed this in the *Investigate*. In both cases, the cart's acceleration is down the plane, although the velocities are in different directions.

5. d) The students should use the values from the graph to calculate the acceleration. For example, using $a = \Delta v/\Delta t$ gives $(10\text{ m/s} - 5\text{ m/s})/1\text{ s} = 5.0\text{ m/s}^2$. Choice *c)* comes from just using the top speed of 10 m/s for the acceleration, Choice *b)* is unrelated, and Choice *a)* may come from confusing a line at an angle of 45 degrees as always having a slope of one. In this case, since the axes are not equal the 45-degree rule does not hold.