SECTION 3

Average Speed: Following Distance and Models of Motion

Section Overview

This section defines speed and reaction distance, and presents different models to analyze speed and motion. Students use strobe photos to analyze constant motion at a slow and then a fast speed. They learn the distinction between speed and velocity, both graphically and mathematically, using a motion detector. They sketch graphs and make predictions to investigate how the graphs vary with a change in direction and speed. These investigations create a backdrop for defining reaction distance. Students then review different position-time graphs with varying slopes that reflect a change in the position of a person traveling at different speeds. By studying equations and comparing their graphs, students learn the difference between instantaneous and average speed and how speed affects reaction distance. Units of speed as tools of measurement are also discussed in relation to driving speeds and collection of data.

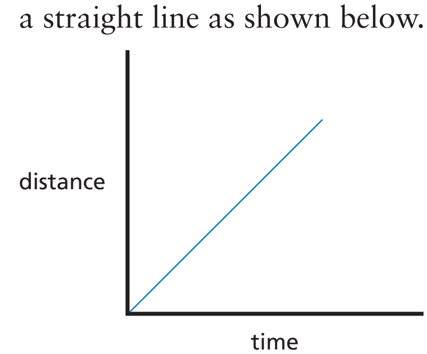
Background Information

Kinematics is the study of motion. In physics, the motion of a body is observed, and then, using measurement and graphs, that motion is analyzed. To do this analysis, tools of measurement must be established, which are appropriate for the object in motion and the speed at which it is moving. For example, a geologist who studies the movement of plates within Earth's crust would measure the distances in inches (or cm), and the time in years or even thousands of years. When measuring the speed of an electron in a particle accelerator, distances are measured in meters or kilometers, and time in millionths of seconds.

Motion maps are images of an object at uniform intervals, essentially looking like a strobe photograph of an object as it travels. Strobe photographs are multiple-exposure pictures taken in a darkened room with the shutter of the camera continuously open. In darkness, no image is recorded by the film, but when a bright flash occurs in an instant, an image is recorded. A strobe is a device that emits a bright short-duration flash at regular intervals. Because the flash is so short, the object appears stationary for any given image. If the object is moving during the dark periods between the flashes, a series of separated images will appear on the film. If these images are equally spaced, it is usually assumed that the object is traveling with constant speed in a straight line.

Understanding speed is critical to understanding motion. Suppose one travels a total distance of 100 mi from one city to the next in two hours. If on the return trip 30 minutes are spent fixing a flat tire, the total time of travel changes to 2.5 h, and the average speed is 100 mi/2.5 h or 40 mi/h. Instantaneous speed, on the other hand, is the speed of travel at any given moment. For example, on the return trip, even though the average speed was 40 mi/h, the instantaneous speed may have been 65 mi/h at any particular moment. Instantaneous speed is the speed shown on the speedometer.

A graphical analysis of uniform motion uses collected data plotted onto a graph. Putting the information onto a distance-time graph will produce a straight line as shown below.

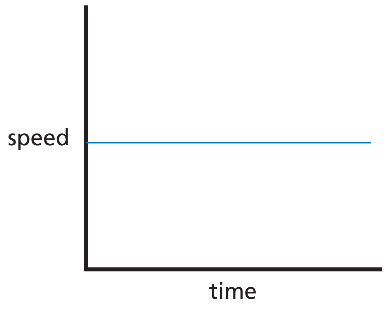


A straight line indicates uniform or constant motion. The slope of that line ($\Delta d/\Delta t$) gives the speed.
$\Delta d = d_2 - d_1$ = meters (m)
(or miles or another unit of distance)
and $\Delta t = t_2 - t_1$ = seconds (s) (or hours).

Therefore, the unit for the slope is mi/s (or mi/h if miles and hours are used).

For distance, d_2 often represents the final distance. In most situations d_1 is the starting point and is often indicated by zero. Similarly, Δt represents change in time, where t_2 is the final or end time and t_1 is the initial time.

The speed-time graph of the same object (traveling with uniform velocity) can be obtained by taking the speed from the distance-time graph, at various times, and plotting it against time on a speed-time graph. The resulting line will be a horizontal straight line, which reinforces the concept of constant motion as shown in the diagram below.



To find the distance an object travels while experiencing constant motion, you find the area under the graph. This will be a rectangle with the top line being the graph, the bottom line being the time axis, the left side the distance axis, and the right side will be a line drawn from the graph to the time axis.

Rectangle Area = length of side × the width of the side or, $A = l \times w$.

Therefore,
$d = v \times t$ since length is speed and width is time.

Mathematically, the equation
$v = d/t$

will give the rearranged equation to solve for d as
$d = v \times t$.

In later sections, students will move from the study of speed to the study of velocity. The concept is essentially the same, except that speed is only the magnitude or how fast something is moving, whereas velocity is the speed and the direction in which the object is moving.

Crucial Physics

- Average velocity = total distance traveled over a given time.
  - $v = \Delta d/\Delta t$
- Average velocity and instantaneous velocity do not have to be equal.
- The slope of a displacement vs. time graph is equal to the velocity.

Learning Outcomes	Location in the Section	Evidence of Understanding
Define and contrast average speed and instantaneous speed.	***Investigate*** Step 7 ***Physics Talk***	Students determine the total distance traveled in each trial to determine average speed. Students define instantaneous speed and contrast it with average speed in a sample problem.
Use strobe photos, graphs, and an equation to describe speed.	***Investigate*** Steps 1-7	Students sketch diagrams of strobe photos to show automobiles traveling at different speeds and arrive at the equation for average speed.
Use a motion detector to measure speed.	***Investigate*** Steps 4-7	Students obtain graphs using a motion detector to measure the velocity of an object.
Construct graphs of your motion.	***Investigate*** Steps 5 and 6	Students produce graphs by walking toward and then away from the motion detector at different speeds and in different directions.
Interpret distance-time graphs.	***Investigate*** Steps 5-7 ***Physics Talk***	Students read graphs to predict and determine distance, time, and average speed. Students study the slope of distance-time graphs to interpret speed.
Calculate speed, distance, and time using the equation for average speed.	***Physics to Go*** Questions 4-7 and 9-10	Students calculate speed, distance, and time in different questions.

NOTES

CHAPTER 1

Section 3 Materials, Preparation, and Safety

Materials and Equipment

PLAN A

Materials and Equipment	Group (4 students)	Class
Computer, station or calculator, CBL or equivalent system*		1 per class
Motion detector, probe and interface*	1 per group	

*Additional items needed not supplied

PLAN B

Materials and Equipment	Group (4 students)	Class
Computer, station or calculator, CBL or equivalent system*		1 per class
Motion detector, probe and interface*	1 per group	

*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

During the class each group of students will require approximately 1.5 class periods or 60 minutes to do the experiment and gather their data.

Teacher Preparation

- Become familiar with the motion detectors and the software that controls their output.
- Instructions come with the equipment, but you should use it yourself before putting it into the classroom. The experiment takes less time if you are aware of the near and far limits of range. Run several trials to be certain that the detector is functioning properly and giving appropriate data.
- Prepare a list of the keystrokes required by your software to erase one graph and get ready to gather new data. Some programs ask several questions before recording data. You should know the best responses to reduce delay.
- Check an appropriate sampling rate for your machine.
- To prepare for the class, set up the detector and computer ahead of time. Put masking tape on the floor to mark the range and perhaps another piece of tape to indicate the lane so that students stay "on track."
- A student may not reflect the sound waves used by the motion detector well enough for the detector to determine his or her position accurately. This occurs because clothing often absorbs more of the sound than it reflects. Give the student a hard surface to hold, such as a section of cardboard, to provide a better reflecting surface.
- Motion detectors will often locate nearby objects that provide good reflections and "lock in" on those objects. Make certain the area that will be used is clear of obstructions and extraneous material to prevent this problem.

Safety Requirements

- Students who are using the equipment will be watching the computer to see the graphs produced and may not watch where they are walking. To prevent a student from accidentally walking into the lab equipment, make certain that the area is clear of any materials that may present a danger.
- The computer (or calculator) that is being used must be placed in a safe position to prevent it from falling and damaging equipment.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Conceptualizing motion from a still image	***Investigate*** Step 1 ***Physics to Go*** Questions 1 and 2	**Augmentation** • Students who are visual learners will benefit from the strobe photos if they can conceptualize how the still photos represent motion. This concept is a leap for many students. Show students examples of real-life strobe photos. Use the sample in *Physics Talk* or the Internet. • Use a small car to demonstrate how strobe photos are taken. To help students visualize images frozen in motion, say "snapshot" at regular one-second intervals.
Copying sketches from a textbook	***Investigate*** Steps 1 and 2	**Augmentation** • Students with fine-motor issues may have trouble sketching the strobe photos from the textbook. Copying a sketch requires alternating attention between the book and paper, making it difficult for some students to draw an accurate sketch in a timely manner. Direct students to trace the cars by placing their log book page on top of the strobe photos in their textbook. **Accommodation** • For students with more significant fine-motor issues, copy the textbook page for them to tape into their logs.
Following directions Sketching accurate graphs	***Investigate*** Steps 4-6	**Augmentation** • Students with short attention spans have a difficult time following directions for a series of tasks and completing them within a reasonable time limit. • Model the use of the motion detector before you begin the *Investigate* to show students proper usage. • Model a graph that has accurate scales. • Model a table to organize the sketched graphs. **Accommodation** • Provide a worksheet with blank graphs that have an appropriate scale on them. Model how to sketch graphs accurately on the blank grids. • Provide students with a two-column table that already has motion described in words. Require students to sketch the graph of that motion in the other column.
Obtaining information from a graph	***Investigate*** Step 7 ***Physics Talk*** Describing Motion and Speed Using a Distance-Time Graph ***Physics to Go*** Question 3	**Augmentation** • Students with visual-spatial, sequential, or mathematical issues struggle to use graphs for problem solving. This task requires that students copy a graph accurately, read the scales to obtain correct values for distance and time, and then perform a calculation with a new equation. Provide direct instruction to show students how to complete this step. Give a few examples, and then give students an opportunity to practice independently. Remind students that by calculating average speed they are finding the slope of the graph. **Accommodation** • Color-code practice graphs to match the variables in the formula. For example, the distance axis and scale could be red, and the "*d*" in the formula could be red. This strategy provides a visual cue for visual learners and students who may not be consistently focused.

Learning Issue	Reference	Augmentation and Accommodations
Solving word problems	***Investigate*** Step 8 ***Physics to Go*** Questions 4, 5, 6, 7, 9, 10	**Augmentation** • Students with mathematical and executive-function issues struggle to solve multi-step problems. Point out to students that they should have eight answers when they are finished with *Step 8* of the *Investigate*. • Provide direct instruction on how to use the formula before students begin to solve the problems. Use the sections following this investigation as resources. Some students may shut down when faced with a new task that has not been taught. If students learn to solve the problems incorrectly, it might be difficult for them to relearn the skill correctly. **Accommodation** • Provide a worksheet with blank problem-solving boxes for students. (See Problem-Solving Box information and table at the bottom of this page.)
Reading comprehension Extracting important concepts from reading	***Physics Talk***	**Augmentation** • Students with reading, mathematical, and attention issues struggle with longer reading assignments that are laden with math concepts. Use a graphic organizer, or class note-taking strategy, to understand the concept of motion described in different ways. • Provide direct instruction for the new formula and give many opportunities for guided practice, especially if this is the first formula that students learn in the class. • Explain and model how to use the formula circle. This strategy allows students to manipulate formulas, even if they have not yet learned this skill in algebra.
Sketching graphs	***Physics to Go*** Question 11	**Augmentation** • Students struggle to label the correct axes on a graph and set up reasonable scales on each axis. Provide a model graph for students to reference, remind students to use previous work from this section to help them, and/or help students recognize the pattern (+0.25 s) for the reaction-time scale. **Accommodation** • Provide students with a graph that already has labels and scales. Ask them to sketch the coordinates and slopes to check for understanding.
Using academic vocabulary	***Physics to Go*** Question 12	**Augmentation** • Have students use their new academic vocabulary; for example speed, reaction time, reaction distance, and so on. Using vocabulary in their own writing helps students retain more and gain a deeper understanding.

Problem-Solving Box

Students need a way to systematically organize information when solving problems. Use a graphic organizer for problem solving that takes students through the steps. Explicitly teach the way a student can extract necessary information from a word problem by thinking aloud while solving the problem. This organizer can slowly be faded out as students become more independent. An example of a problem-solving graphic organizer is provided to the right.

WANT:	**GIVEN:**	**FORMULA:**
Solve:		**Check:**

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Reading comprehension Identifying parts of speech	***Investigate*** Step 8.f)	Students may be confused by constructions in English in which the part of speech is different from what might be expected. For example, in "automobile lengths" the term "automobile" is used as an adjective. Explain that "automobile lengths" refers to using the length of an automobile as a "yardstick." A driver cannot stop and get out of their vehicle to measure the following distance with a tape measure. Instead, drivers estimate how far ahead the next vehicle is by imagining how many cars could be placed between their vehicle and the next vehicle.
Vocabulary comprehension	***Investigate*** Steps 1 and 2	Certain terms may have cognates in an ELL student's primary language. Ask students to make a list of cognates for technical terms such as "position," "distance," "rapidly," and "velocity." When you describe a physics situation for the class, try to refer back to these cognates while you use a synonym. For example, give the instruction, "Now walk faster, or more rapidly." This extra clarification will help reinforce vocabulary that students need to acquire.
Reading comprehension Identifying parts of speech	***Physics Talk***	In reading the terms "following distance," "braking distance," and "stopping distance," students may read the first word as a verb. Explain that verbs and nouns can be used as adjectives. Other similar terms to look out for in the section include "reaction distance," "reaction time," and "quantity symbol." The terms become even more confusing if an additional adjective is added, for example, "safe following distance." Help students decompose the meaning by starting from the end and working backward. First, they should look at "following distance," and then decide how "safe" further modifies the meaning. Explain that hyphens are an exception to this approach. For example, to understand "multiple-exposure photo," first look at "multiple-exposure" and then see how this modifies "photo." It may help students to illustrate confusing terms with diagrams in their *Active Physics* log. Then they can refer back to the diagrams when they come across one of the words in a word problem.
Reading comprehension	***What Do You Think Now?***	Provide additional practice using technical terms in the section. One way to do this is to ask students to include certain terms in their responses for *What Do You Think Now?* Possible terms in this activity include "elapsed time," "following distance," "average speed," and "instantaneous speed."
Vocabulary comprehension	***Physics to Go*** Question 8	In *Physics to Go, Question 8*, students may be confused when following distance is described using units of time. A historical explanation may help them understand why the term "following distance" is used. Explain that in older driver's education manuals, following distance was recommended to be one car length for every 10-mi/h of speed. Current guidelines recommend a "distance" of 2 s.

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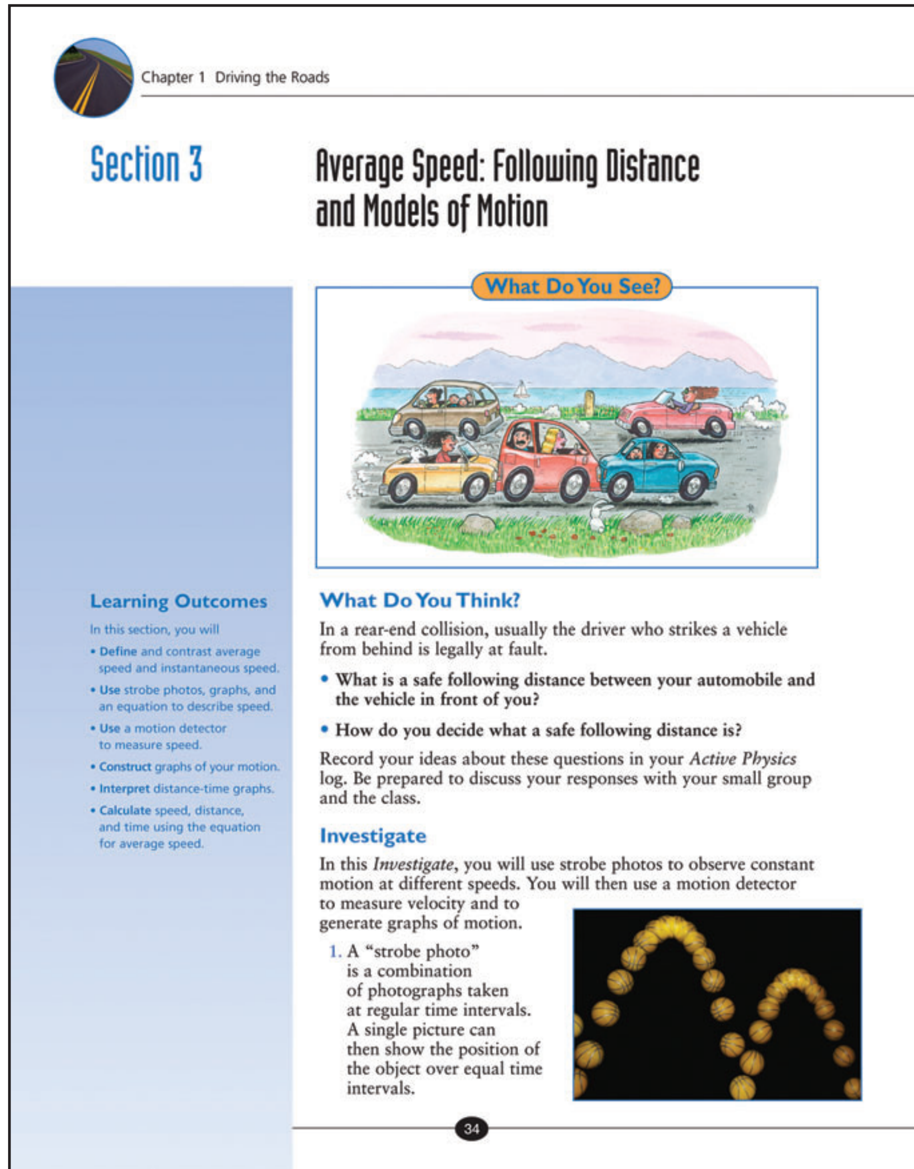
SECTION 3

Teaching Suggestions and Sample Answers


Chapter 1 Driving the Roads

Section 3

Average Speed: Following Distance and Models of Motion

What Do You See?

Learning Outcomes

In this section, you will

- **Define** and contrast average speed and instantaneous speed.
- **Use** strobe photos, graphs, and an equation to describe speed.
- **Use** a motion detector to measure speed.
- **Construct** graphs of your motion.
- **Interpret** distance-time graphs.
- **Calculate** speed, distance, and time using the equation for average speed.

What Do You Think?

In a rear-end collision, usually the driver who strikes a vehicle from behind is legally at fault.

- **What is a safe following distance between your automobile and the vehicle in front of you?**
- **How do you decide what a safe following distance is?**

Record your ideas about these questions 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 strobe photos to observe constant motion at different speeds. You will then use a motion detector to measure velocity and to generate graphs of motion.

1. A "strobe photo" is a combination of photographs taken at regular time intervals. A single picture can then show the position of the object over equal time intervals.

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What Do You See?

Your students will give you a range of responses when you ask them what the illustration depicts. If you want to be more specific, ask them how they think it relates to the title of this section. This approach will help guide them toward the purpose of the *What Do You See?* illustration. Students will begin to take an active interest in the topic, and you might find how quickly the depicted scene can lead to an understanding of physics concepts. At this point, encourage students to answer why the artist has chosen to represent dangerous driving.

Students' Prior Conceptions

The value of this section is introducing students to another language of science and mathematics, and encouraging students to build fundamental skills of interpreting motion through graphical analysis of data.

1. **The location of an object can be described by stating its distance from a given point (ignoring direction).** You must highlight the notion that a student defines a start position within a frame of reference in order to describe motion, either with words or with mathematics. This is the key to support student understating of steady and accelerated motion and to establish the foundation for using vectors. Specific tools are available for students to measure distance and time for various motions and to note the direction in which these motions are occurring along a straight line with reference to an origin. Using their exact measurements of distance, time, and direction, students can produce graphs of motion for analysis.

2. **Time is defined in terms of its measurement.** Time only moves linearly in one direction and subsequently becomes a constant variable in describing motion with distance vs. time or velocity vs. time graphs. Time is the *x*-axis variable.

What Do You Think?

Students will come up with a wide range of answers. Value their responses and encourage them to share their ideas with other students in their group. At this stage, it is important to see what they know of speed in terms of distance. Accepting all answers and posing questions will help generate responses for a few minutes. Ask students to write down their answers. You might want to lead a discussion on the idea of a vehicle following at a safe distance behind another. Point out to your students that they will be returning to the *What Do You Think?* questions for a more comprehensive discussion.

What Do You Think?

A Physicist's Response

A safe distance between your vehicle and the vehicle in front can be determined by the three-second rule. The separation distance provided by this rule allows a driver sufficient time to react to a sudden problem to safely bring a vehicle to a stop and avoid striking the vehicle in front. A physicist would use knowledge of road conditions, vehicle speed, and reaction time to decide on a safe following distance.

Investigate

1.

What is described as a "strobe" sketch in the text is actually equivalent to a time-lapse picture repeatedly exposed with a strobe light. The result is that although the object is moving all the time, the image only appears at regular intervals when the strobe light flashes because the image is taken in the dark.

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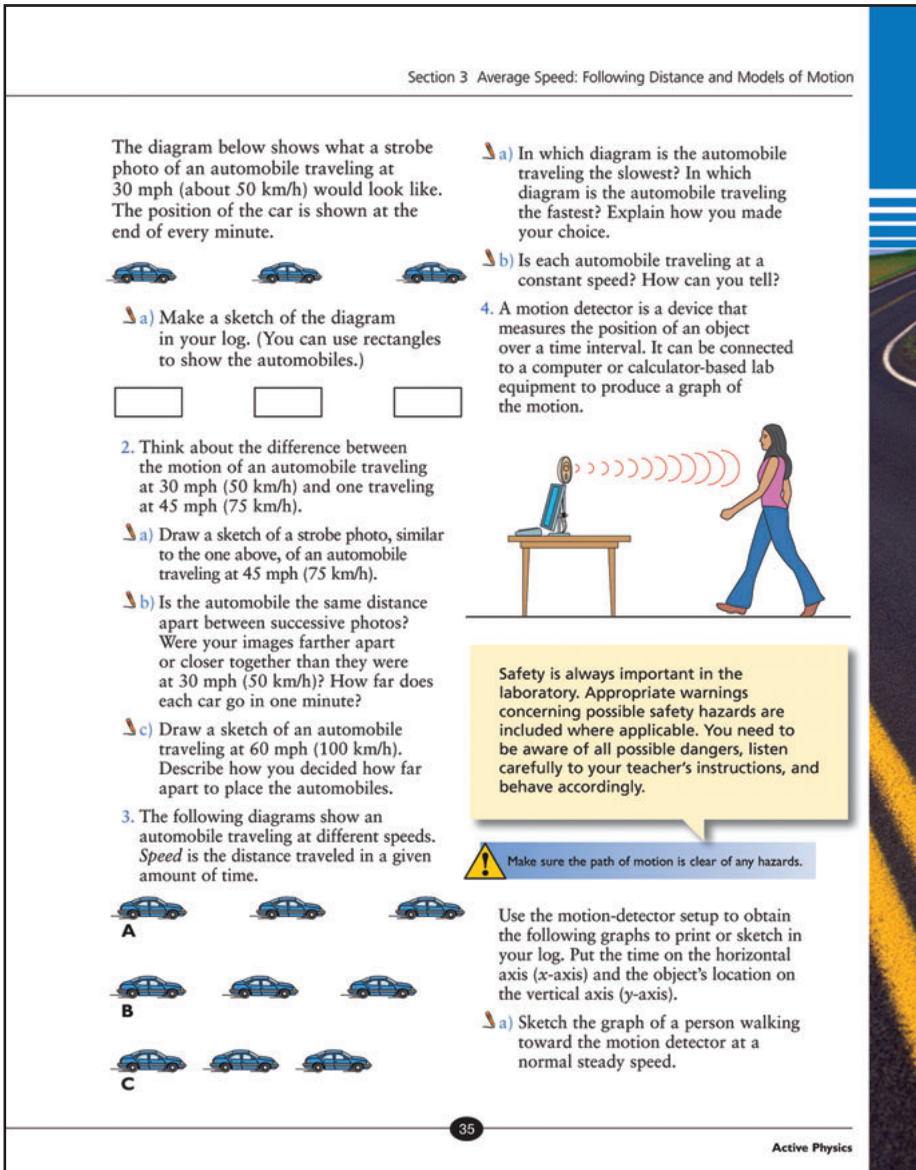

Section 3 Average Speed: Following Distance and Models of Motion

The diagram below shows what a strobe photo of an automobile traveling at 30 mph (about 50 km/h) would look like. The position of the car is shown at the end of every minute.

a) Make a sketch of the diagram in your log. (You can use rectangles to show the automobiles.)

2. Think about the difference between the motion of an automobile traveling at 30 mph (50 km/h) and one traveling at 45 mph (75 km/h).

a) Draw a sketch of a strobe photo, similar to the one above, of an automobile traveling at 45 mph (75 km/h).

b) Is the automobile the same distance apart between successive photos? Were your images farther apart or closer together than they were at 30 mph (50 km/h)? How far does each car go in one minute?

c) Draw a sketch of an automobile traveling at 60 mph (100 km/h). Describe how you decided how far apart to place the automobiles.

3. The following diagrams show an automobile traveling at different speeds. *Speed* is the distance traveled in a given amount of time.

A

B

C

a) In which diagram is the automobile traveling the slowest? In which diagram is the automobile traveling the fastest? Explain how you made your choice.

b) Is each automobile traveling at a constant speed? How can you tell?

4. A motion detector is a device that measures the position of an object over a time interval. It can be connected to a computer or calculator-based lab equipment to produce a graph of the motion.

Safety is always important in the laboratory. Appropriate warnings concerning possible safety hazards are included where applicable. You need to be aware of all possible dangers, listen carefully to your teacher's instructions, and behave accordingly.

Make sure the path of motion is clear of any hazards.

Use the motion-detector setup to obtain the following graphs to print or sketch in your log. Put the time on the horizontal axis (*x*-axis) and the object's location on the vertical axis (*y*-axis).

a) Sketch the graph of a person walking toward the motion detector at a normal steady speed.

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1.a)

If the students do not feel comfortable sketching automobiles, suggest that they draw rectangles instead.

2.

Because the automobile is moving with constant speed in a straight line, the images are equally spaced. Also, the greater the speed, the further apart the images will be.

2.a)

The sketch should show the automobiles with larger, uniform distances between them.

2.b)

Yes, the automobile is the same distance apart in each of the successive photos (indicating constant speed), but further apart than for the automobile going 30 mi/h. In one minute, the 30 mi/h automobile goes $\frac{1}{2}$ mile, and the 45 mi/h automobile goes $\frac{3}{4}$ of a mile. (A car going 60 mi/h goes 1 mile in one minute).

2.c)

The automobiles should be twice the distance apart as they were for 30 mi/h. The distance between images will be doubled because the speed is doubled.

3.a)

The diagram where the automobiles are closest together will represent the slowest speed (diagram C), and furthest upon the fastest (diagram A).

3.b)

Yes, each automobile is traveling with constant speed in the diagrams. This can be determined by measuring the distance between each automobile. If the distance between images is the same for equal time intervals, the automobiles have constant speed, assuming that the flash rate for the pictures shown is constant.

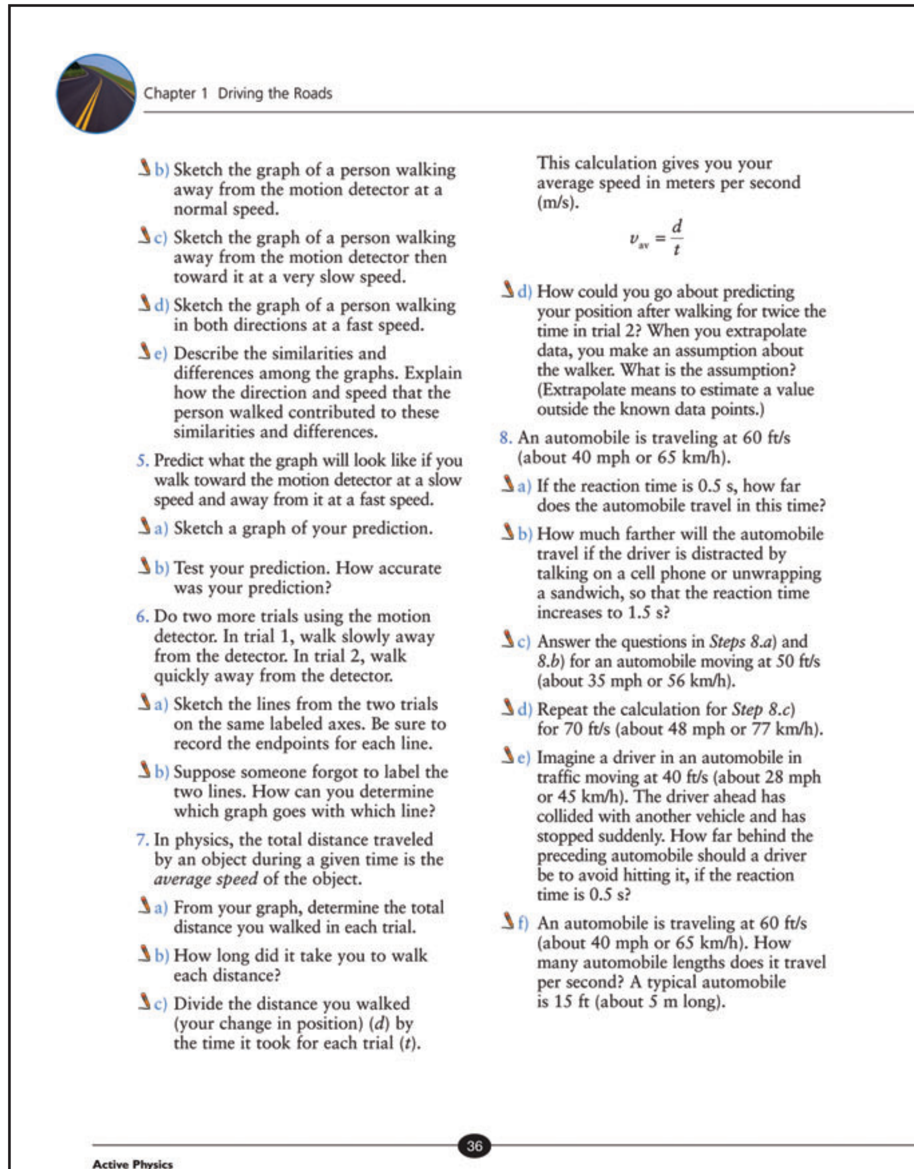
4.

For this *Investigate*, the students should set up the software to give a position vs. time plot. A motion detector typically gives the position of an object by sending out an ultrasonic pulse and then listening for the reflection from the object being measured. This is essentially the same echolocation procedure used by bats to fly in dark caves, or cameras with autofocus to lock onto an object, although cameras typically use an electromagnetic wave rather than sound.

CHAPTER 1

Teaching Tip

Motion detectors from different companies use different software platforms. You should familiarize yourself with the operation of the detector, and check to make certain it is operating correctly before having the students try this *Investigate*. If you or the students are having difficulty getting a good graph of the students' motion, have the students hold a large, solid, flat object such as the cardboard cover from a copy-paper box, or a whiteboard to better reflect the signal back to the detector.



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b) Sketch the graph of a person walking away from the motion detector at a normal speed.

c) Sketch the graph of a person walking away from the motion detector then toward it at a very slow speed.

d) Sketch the graph of a person walking in both directions at a fast speed.

e) Describe the similarities and differences among the graphs. Explain how the direction and speed that the person walked contributed to these similarities and differences.

5. Predict what the graph will look like if you walk toward the motion detector at a slow speed and away from it at a fast speed.

a) Sketch a graph of your prediction.

b) Test your prediction. How accurate was your prediction?

6. Do two more trials using the motion detector. In trial 1, walk slowly away from the detector. In trial 2, walk quickly away from the detector.

a) Sketch the lines from the two trials on the same labeled axes. Be sure to record the endpoints for each line.

b) Suppose someone forgot to label the two lines. How can you determine which graph goes with which line?

7. In physics, the total distance traveled by an object during a given time is the *average speed* of the object.

a) From your graph, determine the total distance you walked in each trial.

b) How long did it take you to walk each distance?

c) Divide the distance you walked (your change in position) (d) by the time it took for each trial (t).

This calculation gives you your average speed in meters per second (m/s).

$$v_{av} = \frac{d}{t}$$

d) How could you go about predicting your position after walking for twice the time in trial 2? When you extrapolate data, you make an assumption about the walker. What is the assumption? (Extrapolate means to estimate a value outside the known data points.)

8. An automobile is traveling at 60 ft/s (about 40 mph or 65 km/h).

a) If the reaction time is 0.5 s, how far does the automobile travel in this time?

b) How much farther will the automobile travel if the driver is distracted by talking on a cell phone or unwrapping a sandwich, so that the reaction time increases to 1.5 s?

c) Answer the questions in *Steps 8.a)* and *8.b)* for an automobile moving at 50 ft/s (about 35 mph or 56 km/h).

d) Repeat the calculation for *Step 8.c)* for 70 ft/s (about 48 mph or 77 km/h).

e) Imagine a driver in an automobile in traffic moving at 40 ft/s (about 28 mph or 45 km/h). The driver ahead has collided with another vehicle and has stopped suddenly. How far behind the preceding automobile should a driver be to avoid hitting it, if the reaction time is 0.5 s?

f) An automobile is traveling at 60 ft/s (about 40 mph or 65 km/h). How many automobile lengths does it travel per second? A typical automobile is 15 ft (about 5 m long).

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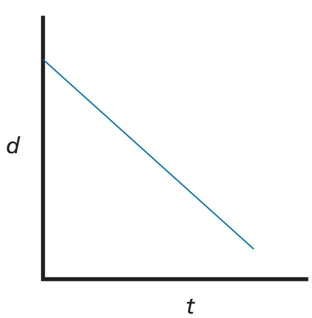
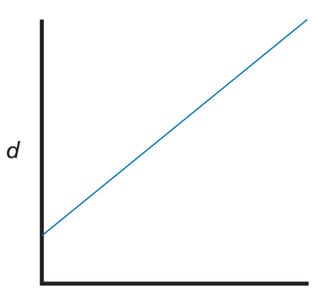
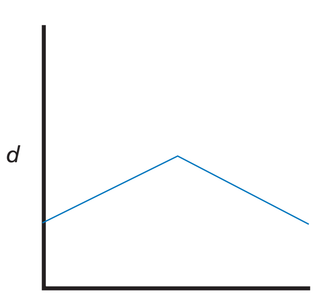
4.a)



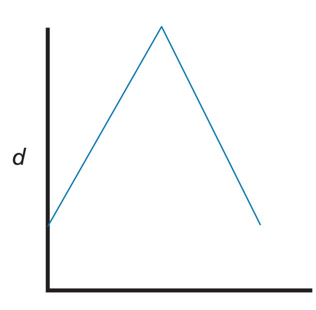
4.b)



4.c)



4.d)



4.e)

When a person walks away from the detector, the graphs have a positive slope. When a person walks toward the detector, the graphs have a negative slope. The graphs have different slopes when a person walks at different speeds and reverses direction, producing peaks in two of them.

5.a)

Students will sketch a graph of their predictions.

5.b)

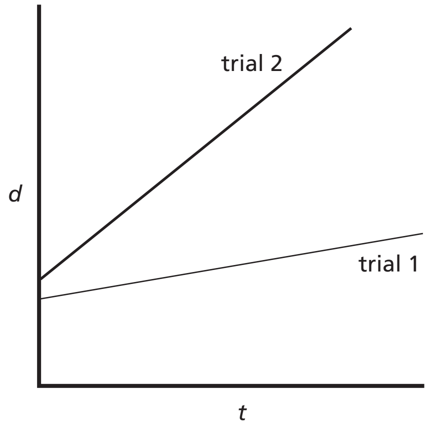
The prediction of a steeper slope when walking away from the motion detector at a fast speed will be confirmed as accurate.

6.

The slope of the graph will depend upon the direction of motion. Walking toward a detector gives a decreasing distance and a negative slope; walking away, a positive slope. If this is not the case, the software can be adjusted to show this. Older motion detectors do not work well at distances less than 0.50 m or greater than 3 m. Also, the area where the student is walking should be clear of extraneous equipment, people, etc., since the detector may lock onto these objects rather than the person moving.

6.a)

The sketches should look like the graph below. Students' endpoints will vary.



6.b)

Students can determine which line belongs to which trial by looking at the slope. The steeper slope will be the trial with faster motion.

7.

Students can choose distances and times from their data table or graph to use for the calculations in this step, or make their own measurements with a stopwatch and meter stick.

7.a)

Displacement $= x_{(\text{final})} - x_{(\text{initial})}$

7.b)

Elapsed time $= t_{(\text{final})} - t_{(\text{initial})}$

7.c)

Students divide the value they obtained in *7.a)* by the one in *7.b)* to obtain their average speed. Check that the units used are m/s.

7.d)

In twice the time, the walker covers twice the distance, assuming that speed remains constant.

8.a)

Reaction distance (d_{reaction}) equals velocity times reaction time:

$$d_{\text{reaction}} = (v)(t_{\text{reaction}}) = (60 \text{ ft/s})(0.5 \text{ s}) = 30 \text{ ft}$$

8.b)

$$d_{\text{reaction}} = (v)(t_{\text{reaction}}) = (60 \text{ ft/s})(1.5 \text{ s}) = 90 \text{ ft}$$

or 1.5 times farther.

8.c)

$$d_{\text{reaction}} = (v)(t_{\text{reaction}}) = (50 \text{ ft/s})(0.5 \text{ s}) = 25 \text{ ft}$$

$$d_{\text{reaction}} = (v)(t_{\text{reaction}}) = (50 \text{ ft/s})(1.5 \text{ s}) = 75 \text{ ft.}$$

8.d)

$$d_{\text{reaction}} = (v)(t_{\text{reaction}}) = (70 \text{ ft/s})(0.5 \text{ s}) = 35 \text{ ft}$$

$$d_{\text{reaction}} = (v)(t_{\text{reaction}}) = (70 \text{ ft/s})(1.5 \text{ s}) = 105 \text{ ft.}$$

8.e)

$$d_{\text{reaction}} = (v)(t_{\text{reaction}}) = (40 \text{ ft/s})(0.5 \text{ s}) = 20 \text{ ft.}$$

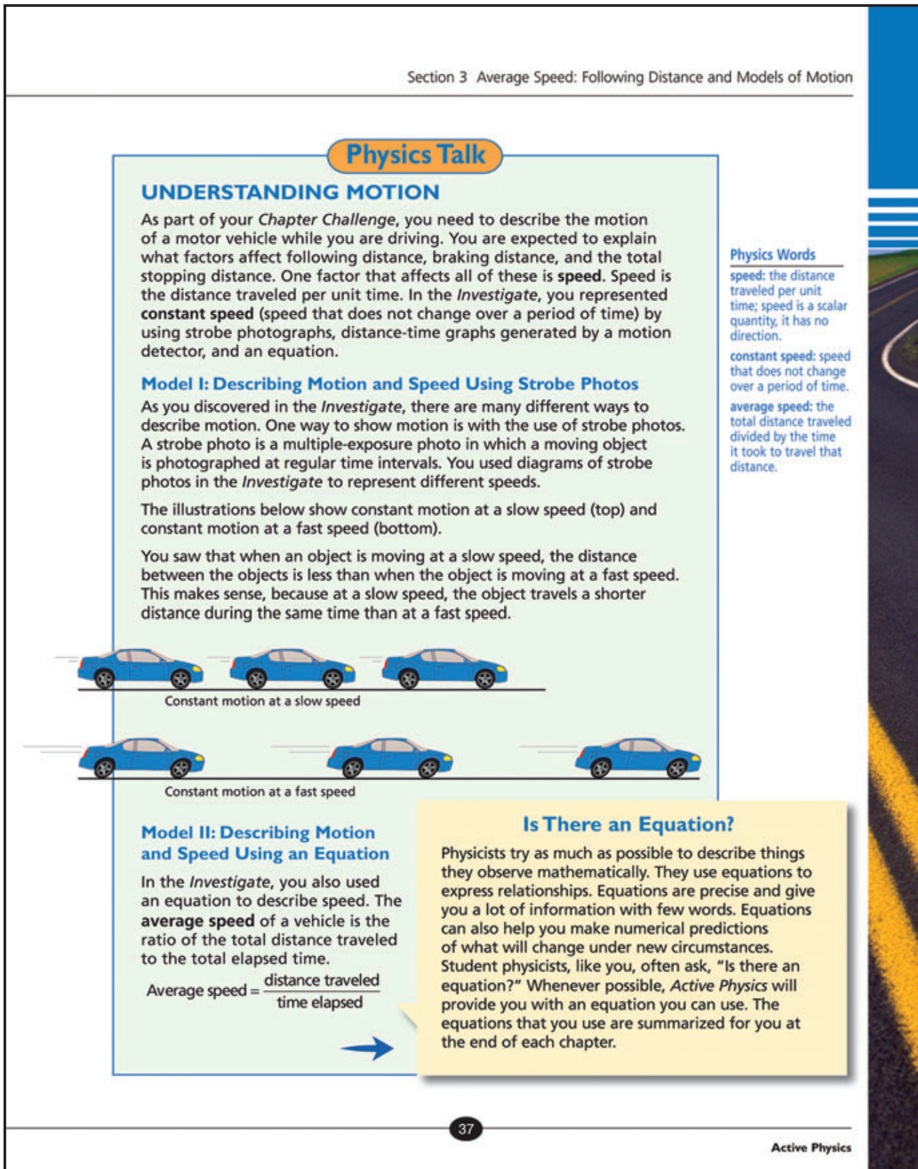
However, this does not include the distance required for the brakes to stop the car after they are applied. This is why the suggested following distance is usually 3 s, which would give a distance of 60 ft (20 ft/s)(3s).

8.f)

$60 \text{ ft}/15 \text{ ft} =$ 4 automobile-lengths.

CHAPTER 1

NOTES



Section 3 Average Speed: Following Distance and Models of Motion

Physics Talk

UNDERSTANDING MOTION

As part of your *Chapter Challenge*, you need to describe the motion of a motor vehicle while you are driving. You are expected to explain what factors affect following distance, braking distance, and the total stopping distance. One factor that affects all of these is **speed**. Speed is the distance traveled per unit time. In the *Investigate*, you represented **constant speed** (speed that does not change over a period of time) by using strobe photographs, distance-time graphs generated by a motion detector, and an equation.

Model I: Describing Motion and Speed Using Strobe Photos

As you discovered in the *Investigate*, there are many different ways to describe motion. One way to show motion is with the use of strobe photos. A strobe photo is a multiple-exposure photo in which a moving object is photographed at regular time intervals. You used diagrams of strobe photos in the *Investigate* to represent different speeds.

The illustrations below show constant motion at a slow speed (top) and constant motion at a fast speed (bottom).

You saw that when an object is moving at a slow speed, the distance between the objects is less than when the object is moving at a fast speed. This makes sense, because at a slow speed, the object travels a shorter distance during the same time than at a fast speed.

Constant motion at a slow speed

Constant motion at a fast speed

Model II: Describing Motion and Speed Using an Equation

In the *Investigate*, you also used an equation to describe speed. The **average speed** of a vehicle is the ratio of the total distance traveled to the total elapsed time.

$$\text{Average speed} = \frac{\text{distance traveled}}{\text{time elapsed}}$$

Is There an Equation?

Physicists try as much as possible to describe things they observe mathematically. They use equations to express relationships. Equations are precise and give you a lot of information with few words. Equations can also help you make numerical predictions of what will change under new circumstances. Student physicists, like you, often ask, "Is there an equation?" Whenever possible, *Active Physics* will provide you with an equation you can use. The equations that you use are summarized for you at the end of each chapter.

Physics Words

speed: the distance traveled per unit time; speed is a scalar quantity, it has no direction.

constant speed: speed that does not change over a period of time.

average speed: the total distance traveled divided by the time it took to travel that distance.

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Active Physics

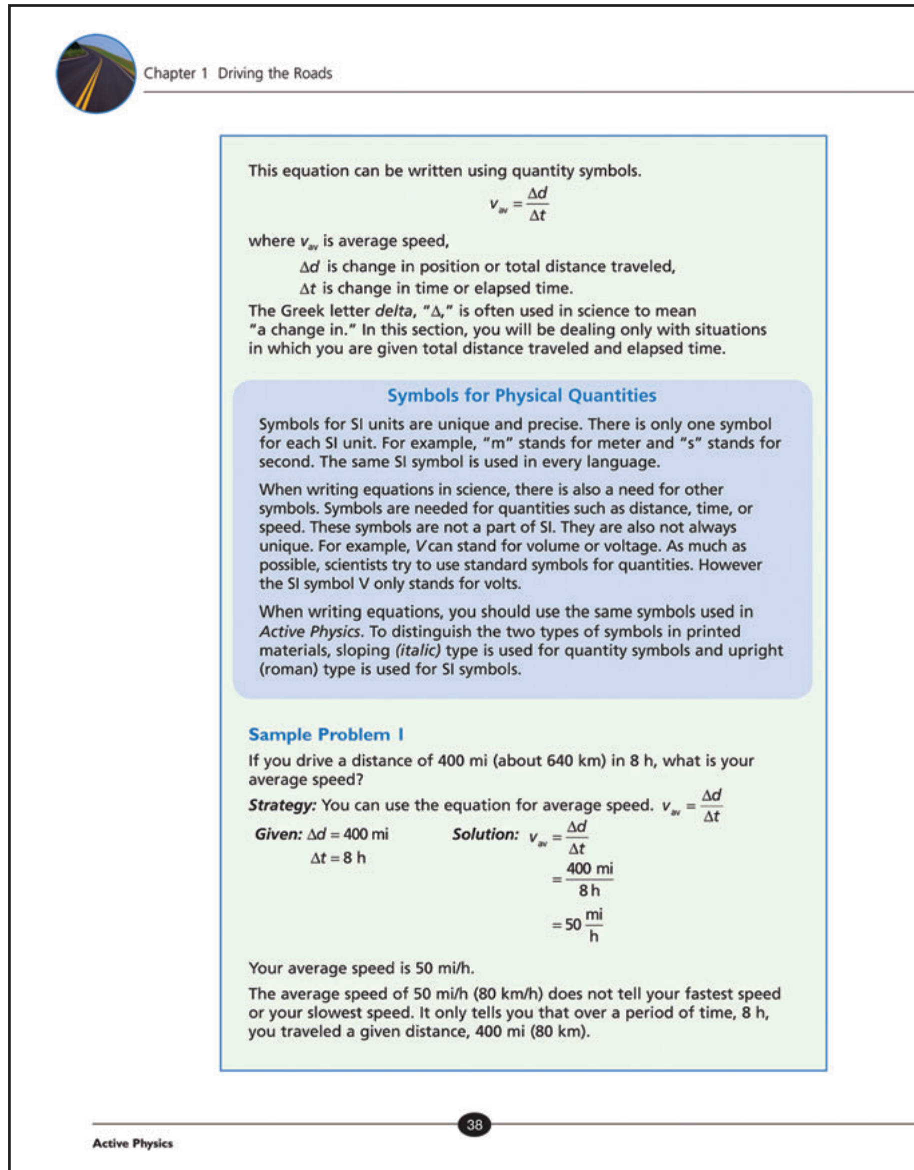
Physics Talk

Students review illustrations of a strobe photo showing constant motion at a slow speed and constant motion at a fast speed. Remind them of their sketches in the *Investigate* in which they used strobe photos and motion detectors. Discuss how motion is defined through average and instantaneous speed and have students study the distance-time graphs of an object that represent different types of motion. You will find the distance-time graphs provide strong visuals for data. As students are introduced to the concept of velocity, have them study the slopes of distance-time graphs that reflect the varying speed and direction of an object in motion. By calculating the speed, distance, or time of travel in sample problems, they should rewrite the equation for average speed. You could also use this equation to highlight the importance of reaction distance. While students learn more about the SI system of measurement, it is important to realize that their grasp of this system will gradually improve as they become more familiar with it.

Because maintaining a safe speed is essential to safety, students are introduced to the Doppler effect to explain how an automobile's speed can be accurately determined by another person who is watching the automobile pass from a distance.

You might want to explain the Doppler effect in the *Physics Talk* by citing an example of the frequency shift that is readily observable at racetracks as a race car zooms past the cameras and the stands. Tell students that, in this case, the engine noise replaces the horn as the sound emitter. Mention that exactly the same principle is used in a radar gun which measures the speed of a pitch in a baseball game. Another example you could touch on is the Doppler effect in the "sonic boom," which is heard when a plane breaks the "sound barrier." To check if students understand how police use the Doppler effect in radar guns, ask them to write a brief summary of the Doppler effect in their *Active Physics* logs.

To provide a conceptual basis for the effect, draw students' attention to the two diagrams in the text that show the circular waves being generated by a moving source and a stationary source in the section titled *Speed and the Doppler Effect*. Ask the students to indicate in which direction the moving source is going, where the observed frequency would be higher, where it would be lower, and where there would be no change in frequency.



This equation can be written using quantity symbols.

$$v_{av} = \frac{\Delta d}{\Delta t}$$

where v_{av} is average speed,

Δd is change in position or total distance traveled,

Δt is change in time or elapsed time.

The Greek letter *delta*, "Δ," is often used in science to mean "a change in." In this section, you will be dealing only with situations in which you are given total distance traveled and elapsed time.

Symbols for Physical Quantities

Symbols for SI units are unique and precise. There is only one symbol for each SI unit. For example, "m" stands for meter and "s" stands for second. The same SI symbol is used in every language.

When writing equations in science, there is also a need for other symbols. Symbols are needed for quantities such as distance, time, or speed. These symbols are not a part of SI. They are also not always unique. For example, *V* can stand for volume or voltage. As much as possible, scientists try to use standard symbols for quantities. However the SI symbol V only stands for volts.

When writing equations, you should use the same symbols used in *Active Physics*. To distinguish the two types of symbols in printed materials, sloping *(italic)* type is used for quantity symbols and upright (roman) type is used for SI symbols.

Sample Problem I

If you drive a distance of 400 mi (about 640 km) in 8 h, what is your average speed?

Strategy: You can use the equation for average speed. $v_{av} = \frac{\Delta d}{\Delta t}$

Given: $\Delta d = 400$ mi
$\Delta t = 8$ h

Solution:
$$v_{av} = \frac{\Delta d}{\Delta t} = \frac{400\text{ mi}}{8\text{ h}} = 50\ \frac{\text{mi}}{\text{h}}$$

Your average speed is 50 mi/h.

The average speed of 50 mi/h (80 km/h) does not tell your fastest speed or your slowest speed. It only tells you that over a period of time, 8 h, you traveled a given distance, 400 mi (80 km).

Section 3 Average Speed: Following Distance and Models of Motion

Before your vehicle started moving, the speed was 0 mi/h. When you stopped your vehicle at the end of the trip, your speed was again 0 mi/h. During the trip you probably slowed down and sped up as you drove along. You may have stopped for a meal. The speedometer reading at any moment during the trip is your **instantaneous speed**, which is the speed at a given moment. Instantaneous speed is the speed measured during an instant.

Physics Words

instantaneous speed: the speed at a given moment.

Using the Equation for Speed to Find Other Quantities

Equations are a powerful mathematical tool. Using the equation for average speed, you are not limited to just solving for speed. If you know the average speed and the time it took you to travel that speed, you can find the distance you traveled in that time. You can also find the time traveled if you know the distance traveled and the average speed.

$$\text{Average speed} = \frac{\text{distance traveled}}{\text{time elapsed}}$$

Using algebra, it follows that

$$\text{Distance} = \text{average speed} \times \text{time}$$

$$\text{Time} = \frac{\text{distance}}{\text{average speed}}$$

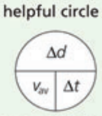
Using quantity symbols these equations can be written as

$$v_{av} = \frac{\Delta d}{\Delta t}$$

$$\Delta d = v_{av} \times \Delta t$$

$$\Delta t = \frac{\Delta d}{v_{av}}$$

You can use the following helpful circle to do your calculations:



By covering up the variable you wish to find, you can see the equation.

To find average speed (v_{av}), cover up the (v_{av}) and you see $\frac{\Delta d}{\Delta t}$.

To find distance (Δd), cover up (Δd) and you see $v_{av} \times \Delta t$.

To find time (Δt), cover up (Δt) and you see $\frac{\Delta d}{v_{av}}$.

It is important to note that there is one equation for average speed, but you can write it in three equivalent ways.

Sample Problem 2

You are traveling at 35 mph (about 50 ft/s) and your reaction time is 0.2 s. Calculate the distance you travel during your reaction time.

Strategy: You can rewrite the equation for average speed to solve for distance traveled.

$$\Delta d = v_{av} \times \Delta t$$

Remember that ft/s means $\frac{\text{ft}}{\text{s}}$.

Given: $\Delta t = 0.2 \text{ s}$

$v_{av} = 50 \text{ ft/s}$

Solution: $\Delta d = v_{av} \times \Delta t$

$$\Delta d = 50 \frac{\text{ft}}{\cancel{\text{s}}} \times 0.2 \cancel{\text{s}}$$

$$= 10 \text{ ft}$$

Calculations and Units

In physics, when you do calculations, it is very important to pay close attention to the units in your answer. Notice how in the previous calculation the units for seconds (s) in the top and bottom of the equation cancel out, leaving feet (ft), the unit for distance that you need for your answer. Checking to see if the units make sense is a tool that physicists use to ensure that their calculations make sense and that they have not made a mistake.

Sample Problem 3

In an automobile collision, it was determined that a car traveled 150 ft before the brakes were applied.

a) If the car had been traveling at the speed limit of 40 mph (60 ft/s), what was the driver's reaction-time (time it took to apply the brakes)?

b) Witnesses say that the driver appeared to be under the influence of alcohol. Does your reaction-time data support the witnesses' testimony?

Strategy:

a) You can rewrite the equation for average speed to solve for time elapsed.

$$\Delta t = \frac{\Delta d}{v_{av}}$$

Section 3 Average Speed: Following Distance and Models of Motion

Given: $\Delta d = 150 \text{ ft}$

$v_{av} = 60 \text{ ft/s or } 60 \dfrac{\text{ft}}{\text{s}}$

Solution: $\Delta t = \dfrac{\Delta d}{v_{av}}$

$$\Delta t = \dfrac{150 \cancel{\text{ft}}}{60 \dfrac{\cancel{\text{ft}}}{\text{s}}}$$

$$= 2.5 \text{ s}$$

Note, mathematically, $\dfrac{\text{ft}}{\dfrac{\cancel{\text{ft}}}{\text{s}}} = \cancel{\text{ft}} \times \dfrac{\text{s}}{\cancel{\text{ft}}} = \text{s}$

b) Reaction time with distractions was measured in *Section 1*. The reaction time of 2.5 s seems very slow. The driver has the reaction time of someone who could be under the influence of alcohol.

Speed and Velocity

In *Active Physics*, you will often explore the same topic several times. Being exposed to the same topic at different times and in different situations helps you learn and understand the topic better. The difference between speed and velocity will be explored at different times in this book. Velocity will also be explored in greater depth in later chapters.

A term you often hear used when talking about speed is velocity. **Velocity** is speed in a given direction. Velocity always includes both speed and direction.

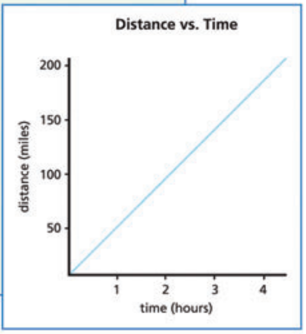
Physics Words

velocity: the speed in a given direction.

Model III: Describing Motion and Speed Using a Distance-Time Graph

You investigated how to represent motion with strobe photos and with a mathematical equation. A third way to represent motion is with graphs. Graphs are a visual way to represent data. The graph at right shows an automobile traveling at a constant speed of 50 mi/h.

Notice that time is on the *x*-axis and distance is on the *y*-axis. By reading the coordinates on the graph, you can see that the automobile reached the 50 mi position at the end of 1 h; the 100 mi position at the end of 2 h; and the 150 mi position at the end of 3 h.



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Active Physics

1-3a Blackline Master

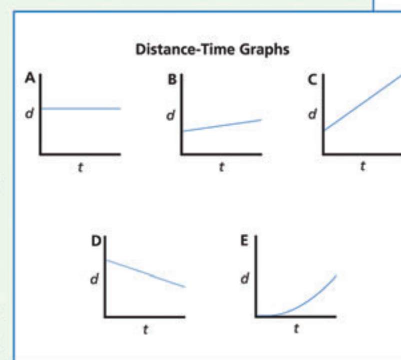
It is quite unrealistic to assume that an automobile could keep this speed of 50 mph for a full 3 h. If it did, however, you can see that the distance-time graph forms a straight line. Anytime an object moves at a constant speed, the distance-time graph is a straight line.

In the *Investigate*, you used a motion detector to generate graphs to represent your motion. You can determine the general motion of a person (a vehicle or any object) by reviewing a distance-time graph. Look at the following graphs. All graphs have the same time and distance scales.

Graph A: A person is at rest. As time increases, there is no change in the position of the person. The person is standing still.

Graph B: A person is traveling at a slow speed. As time increases, there is a small change in the position.

Graph C: A person is traveling at a fast speed. As time increases, there is a greater change in the position.



Notice that the slope of the graph indicates the speed of the person. A slow speed has a gradual slope. A fast speed has a steep slope. No motion has zero slope. The graph of a person at rest is a horizontal line with a slope of zero—representing a speed of zero.

Graph D: A person is traveling in the opposite direction of the person in the previous graphs. As time passes, the change in position is in the opposite direction.

Graph E: A person is changing speed. As time passes, the change in position is increasing for each second. Notice that a changing speed is a curve on a distance-time graph.

In the *Investigate*, you noticed that walking toward the motion detector produced a slope in one direction. Walking away from the motion detector produced a slope in the opposite direction. The slope was zero, or close to zero, when standing still.

Speed and the Slope of a Distance-Time Graph

You compared speeds by looking at the slope of lines on distance-time graphs. You can also use the slopes of distance-time graphs to obtain a quantitative (number) value for speed. The slope of a line is the rise (change along the *y* dimension) divided by the run (change along the *x* dimension). If you look at a distance-time graph, the rise is the distance covered and the run is time taken. Distance divided by time is the equation you used to calculate speed.

$$\text{slope} = \frac{\text{rise}}{\text{run}} \qquad v_{av} = \frac{\Delta d}{\Delta t}$$

The measure of the slope of a *d* vs. *t* graph is equal to the speed of the object.

More about the SI System: Units for Measuring Speed and Velocity

In *Active Physics*, speed and velocity (speed in the direction of motion) in the classroom is measured in meters per second (m/s). Notice that the unit for speed or velocity is made up of a combination of two of the SI base units, meters (m) and seconds (s). These are called derived SI units.

Other units can also be used for speed. For example, highway speeds could be measured in kilometers per hour (km/h). The movement of Earth's crust could be measured in centimeters per year (cm/yr).

Kilometers and Miles

Highway signs and speed limits in the United States of America are given in miles per hour (mi/h or mph). Almost every other country in the world uses kilometers to measure long distances. A kilometer is a little less than two-thirds of a mile (1.0 km ≈ 0.6 mi). Kilometers per hour (km/h) is used to measure highway driving speed. For shorter distances, such as stopping distances and experiments in a science class, speed is measured in meters per second, m/s.

You will use miles per hour when working with driving speeds, but meters per second for data you collect in class. It is important to be able to understand and compare measurements.

There are mathematical conversions that can help you convert from miles per hour to kilometers per hour and meters per second. To help you relate the speed with which you are comfortable to the data you collect in class, the chart at the right gives approximate comparisons. It shows standard speed limits for the United States and Canada.

Speed-Limit Conversion Table

United States (Imperial)		Canada (Metric)	
mph	ft/s	km/h	m/s
20	29	30	8
30	44	50	14
50	73	80	22
70	102	100	28

CHAPTER 1

Speed and the Doppler Effect

Driving safely is everybody's responsibility. Part of safe driving is obeying the speed limit. All roads have a speed limit. This speed limit is posted for some roads but not for all. As a driver, you must know the speed limit of roads without a posting. Most people are aware that going too fast is dangerous. An accident at a high speed results in much greater damage than at slower speeds. However, traveling too slowly can also be dangerous and can result in accidents.

You can find out if you are speeding by reading the speedometer in the car. You can also calculate the speed by using posted mile markers on some roads. If you measure the time it takes your vehicle to travel between two mile-markers, you can find the speed of the vehicle by using the equation for average speed, $v = \frac{\Delta d}{\Delta t}$.

You can also get a sense of the speed of a passing vehicle by listening carefully to the sound of the engine and the tires on the road. Sound travels in waves. The shorter the wavelength, the higher the pitch (frequency). The longer the wavelength, the lower the pitch. As you stand on the side of a street, you can hear the change in pitch of a vehicle as it moves past you. In auto racing, the shift in pitch is quite noticeable. As the race car approaches, you hear a high pitch, and as the car departs, you hear a low pitch. The change in pitch of the sound is indicative of the speed of the car. The driver of the vehicle would not notice any change in pitch, because the driver is traveling along with the source of the sound.

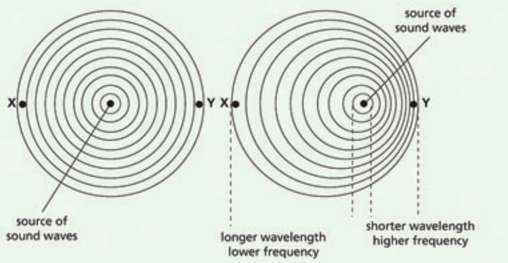
Physics Words

Doppler effect: the change in the pitch, or frequency of a sound (or the frequency of a wave) for an observer that is moving relative to the source of the sound (or source of the wave).

The change in pitch is called the **Doppler effect.** It is named in honor of Christian Doppler, an Austrian physicist and mathematician, who was one of the first to analyze this phenomenon. He noticed that the pitch (frequency) of a train whistle was higher as the train approached and lower as the train departed.

To help you understand why this effect occurs, look at the diagrams on the following page of a stationary source of sound and a moving source. In the first diagram, the sound source is stationary. A person standing at position X and one standing at position Y would hear the same frequency of sound. In the second diagram, the sound source is moving to the right. As the sound waves approach position Y, they are closer together than if the source were stationary. A person at this position would hear a higher frequency sound. The source is moving away from position X. As the sound waves approach that position, they are farther apart. A person standing at X would hear a lower frequency sound. You will learn more about sound waves in a later chapter.

Section 3 Average Speed: Following Distance and Models of Motion



Is there an equation for the Doppler effect? The equation relating the increased frequency and the speed of the train is given by

$$f = \frac{f_0 \cdot s}{s - v}$$

where f is the observed frequency when the train is moving;

f_0 is the frequency when the train is at rest;

v is the speed of the train; and

s is the speed of sound, about 340 m/s.

Using the Doppler effect for sound waves is not an effective way of measuring a precise speed of a moving vehicle. Police use radar guns that use the Doppler effect for microwaves. The police radar sends out microwaves of a certain frequency. These microwaves reflect off the vehicle. If the vehicle is stationary, the reflected microwaves have the same frequency as the emitted microwaves.

If the vehicle is moving toward the radar gun, the reflected microwaves have a higher frequency. If the vehicle is moving away from the radar gun, the reflected microwaves have a lower frequency. The emitted frequency and the reflected frequency are compared electronically and the radar gun determines the speed.

The Doppler effect is also used to measure the speed of galaxies at huge distances from Earth. The frequency of the light from the galaxies is shifted to lower frequencies. Astronomers interpret this to mean that the galaxies are moving away from Earth. By calculating the speed of many galaxies, astronomers form theories about the birth and structure of the universe.

Checking Up

1.

Average speed of a vehicle is the total distance it travels divided by the time it took to travel that distance, while instantaneous speed is the speed at any given instant.

2.

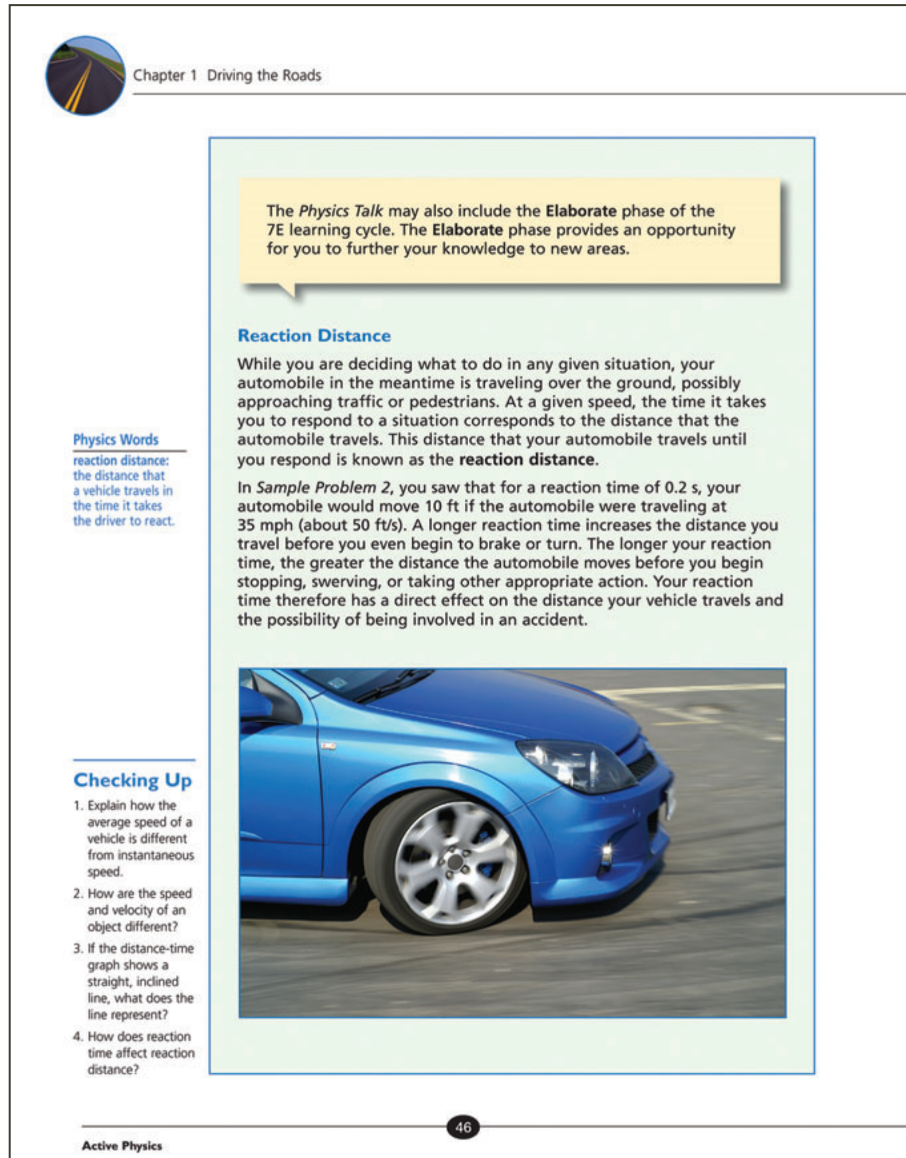
Speed is the distance traveled per unit time. Speed is a scalar quantity and has no direction, but velocity is speed in a given direction.

3.

The straight, inclined line on a distance-time graph represents constant speed. The slope of the line is the object's speed.

4.

Reaction time increases or decreases the reaction distance depending on how fast the driver of a vehicle responds to a situation.



Chapter 1 Driving the Roads

The *Physics Talk* may also include the **Elaborate** phase of the 7E learning cycle. The **Elaborate** phase provides an opportunity for you to further your knowledge to new areas.

Reaction Distance

While you are deciding what to do in any given situation, your automobile in the meantime is traveling over the ground, possibly approaching traffic or pedestrians. At a given speed, the time it takes you to respond to a situation corresponds to the distance that the automobile travels. This distance that your automobile travels until you respond is known as the **reaction distance**.

In *Sample Problem 2*, you saw that for a reaction time of 0.2 s, your automobile would move 10 ft if the automobile were traveling at 35 mph (about 50 ft/s). A longer reaction time increases the distance you travel before you even begin to brake or turn. The longer your reaction time, the greater the distance the automobile moves before you begin stopping, swerving, or taking other appropriate action. Your reaction time therefore has a direct effect on the distance your vehicle travels and the possibility of being involved in an accident.

Physics Words

reaction distance: the distance that a vehicle travels in the time it takes the driver to react.

Checking Up

1. Explain how the average speed of a vehicle is different from instantaneous speed.
2. How are the speed and velocity of an object different?
3. If the distance-time graph shows a straight, inclined line, what does the line represent?
4. How does reaction time affect reaction distance?

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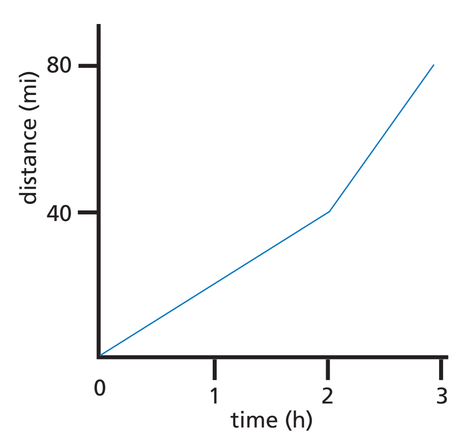
Active Physics

Active Physics Plus

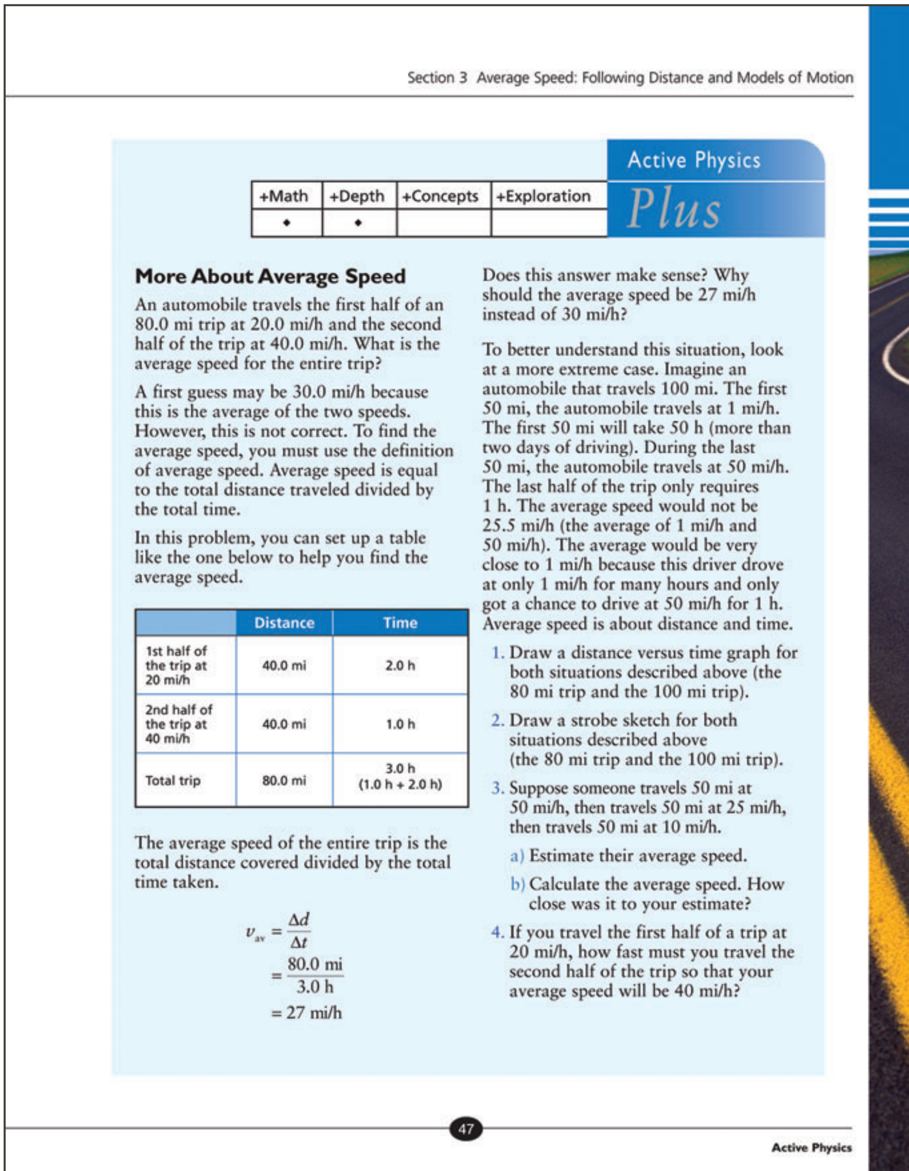
Students understand the difference between taking the average of different speeds and calculating the value of average speed. The concept of average speed is explained in further detail. The *Active Physics Plus* provides an opportunity to emphasize how average speed is calculated and it means that the total distance traveled is divided by the total time. You may want to ask students to share their findings with others in the class.

1.

The distance vs. time graph for the 80-mi trip should look similar to the one at right. The distance vs. time graph for the 100-mi trip should look similar to the one on the following page.



CHAPTER 1



Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
•	•		

More About Average Speed

An automobile travels the first half of an 80.0 mi trip at 20.0 mi/h and the second half of the trip at 40.0 mi/h. What is the average speed for the entire trip?

A first guess may be 30.0 mi/h because this is the average of the two speeds. However, this is not correct. To find the average speed, you must use the definition of average speed. Average speed is equal to the total distance traveled divided by the total time.

In this problem, you can set up a table like the one below to help you find the average speed.

	Distance	Time
1st half of the trip at 20 mi/h	40.0 mi	2.0 h
2nd half of the trip at 40 mi/h	40.0 mi	1.0 h
Total trip	80.0 mi	3.0 h (1.0 h + 2.0 h)

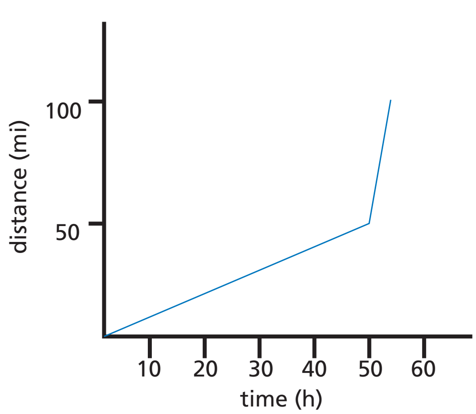
The average speed of the entire trip is the total distance covered divided by the total time taken.

$$v_{av} = \frac{\Delta d}{\Delta t} = \frac{80.0 \text{ mi}}{3.0 \text{ h}} = 27 \text{ mi/h}$$

Does this answer make sense? Why should the average speed be 27 mi/h instead of 30 mi/h?

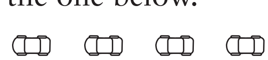
To better understand this situation, look at a more extreme case. Imagine an automobile that travels 100 mi. The first 50 mi, the automobile travels at 1 mi/h. The first 50 mi will take 50 h (more than two days of driving). During the last 50 mi, the automobile travels at 50 mi/h. The last half of the trip only requires 1 h. The average speed would not be 25.5 mi/h (the average of 1 mi/h and 50 mi/h). The average would be very close to 1 mi/h because this driver drove at only 1 mi/h for many hours and only got a chance to drive at 50 mi/h for 1 h. Average speed is about distance and time.

1. Draw a distance versus time graph for both situations described above (the 80 mi trip and the 100 mi trip).
2. Draw a strobe sketch for both situations described above (the 80 mi trip and the 100 mi trip).
3. Suppose someone travels 50 mi at 50 mi/h, then travels 50 mi at 25 mi/h, then travels 50 mi at 10 mi/h.
   a) Estimate their average speed.
   b) Calculate the average speed. How close was it to your estimate?
4. If you travel the first half of a trip at 20 mi/h, how fast must you travel the second half of the trip so that your average speed will be 40 mi/h?

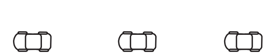


2.

Students' "strobe" picture for the 80-mi trip should look similar to the one below.



20 mi/h
(first half of trip)



40 mi/h
(second half of trip)

For the 100-mi trip, the first part of the trip should show images of a car almost overlapping. The second part of the trip should show images of a car separated 50 times the distance between images in the first part.

3.a)

Students' estimates may vary from an average of the two speeds to many different values.

3.b)

The average speed is the total distance, 150 mi, divided by the total time of 8 h, which gives a speed of 18.75 mi/h.

4.

To get the time traveled for the first half of the trip,
$t = \left(\frac{1}{2}d\right)/\left(20 \text{ mi/h}\right) = d/\left(40 \text{ mi/h}\right)$.

For the second half of the trip, $t = \left(\frac{1}{2}d\right)/v = d/2v$, where v is the unknown velocity. For the entire trip, the average speed must be 40 mi/h.

Using $v = d/t$ gives 40 mi/h = total distance/total time
$d/d\left(1/40 \text{ mi/h} + \frac{1}{2}v\right)$
After cancelling, "d" yields
$40 \text{ mi/h} = 1/1\left(40 + \frac{1}{2}v\right) =$
$1/\left(2a/80v + 40/80v\right)$.

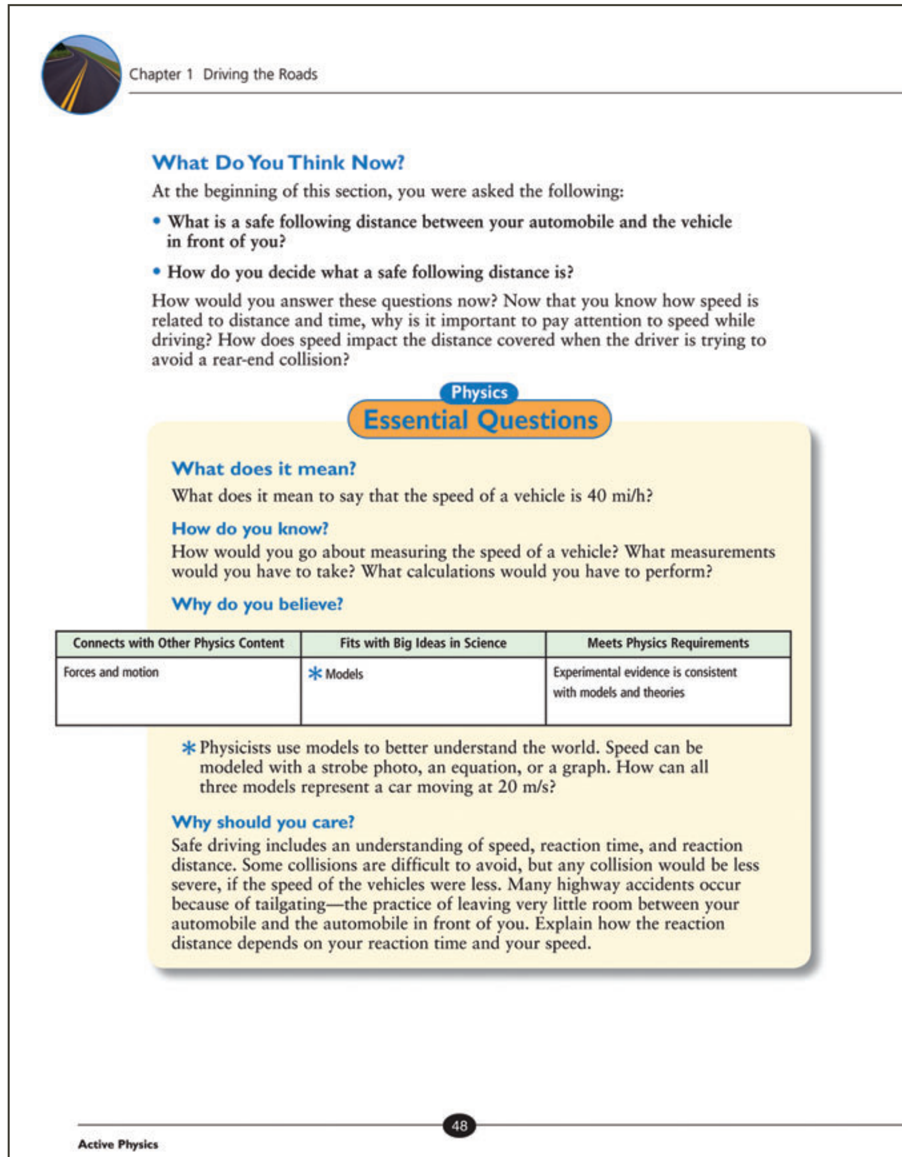
Solving for v proves impossible because it cancels out of the equation. What has occurred here is that if one travels ½ the trip at half speed, you have already used up the total time needed for the total trip to average 40 mi/h. In other words, this is a trick question with no real answer for the students.

What Do You Think Now?

Students should reflect on their earlier answers to the *What Do You Think?* questions and revise them in light of what they know now about average speed. You might want to provide them with *A Physicist's Response* to give them a better understanding of a safe distance that should be maintained between two automobiles. Students' answers will vary. They should be able to discuss strategies for safe driving.

Reflecting on the Section and the Challenge

Now that students have learned that a driver can change the velocity of an automobile by changing its speed or direction of motion, they can use this information to design their *Chapter Challenge*. Knowing how to follow at a safe distance would help students in making a sound argument against tailgating, and by similar reasoning, against speeding.



Chapter 1 Driving the Roads

What Do You Think Now?

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

- **What is a safe following distance between your automobile and the vehicle in front of you?**
- **How do you decide what a safe following distance is?**

How would you answer these questions now? Now that you know how speed is related to distance and time, why is it important to pay attention to speed while driving? How does speed impact the distance covered when the driver is trying to avoid a rear-end collision?

Physics **Essential Questions**

What does it mean?

What does it mean to say that the speed of a vehicle is 40 mi/h?

How do you know?

How would you go about measuring the speed of a vehicle? What measurements would you have to take? What calculations would you have to perform?

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. Speed can be modeled with a strobe photo, an equation, or a graph. How can all three models represent a car moving at 20 m/s?

Why should you care?

Safe driving includes an understanding of speed, reaction time, and reaction distance. Some collisions are difficult to avoid, but any collision would be less severe, if the speed of the vehicles were less. Many highway accidents occur because of tailgating—the practice of leaving very little room between your automobile and the automobile in front of you. Explain how the reaction distance depends on your reaction time and your speed.

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Physics Essential Questions

What does it mean?

A speed of 40 mi/h means that the automobile can travel 40 miles in 1 hour. These units can be changed so that you can also find the distance that can be traveled in 1 minute or 1 second.

How do you know?

To measure the speed of a vehicle, you would measure the time it takes for the vehicle to travel a specific distance. You would need a meter stick to measure the distance and a stopwatch to measure the time. The speed of the vehicle would be the distance traveled divided by the time, $v = d/t$.

Why do you believe?

The strobe photo shows the distance the automobile travels every second. The equation allows you to calculate the distance the automobile travels every second. The graph shows the position of the automobile at every time and the steepness of the slope represents the velocity.

Section 3 Average Speed: Following Distance and Models of Motion

Reflecting on the Section and the Challenge

When you drive an automobile, you are controlling its velocity. You change the automobile's velocity by changing its speed (stepping on the gas pedal or brake pedal), and/or by changing its direction of motion (by turning the steering wheel). As you drive, you are continuously monitoring the automobile's velocity (speed and direction). You adjust both speed and direction as necessary.

Based on all the information you have just read, you now have ways to symbolically represent motion. You can use a strobe sketch or a distance–time graph. Also, you can calculate the reaction distance by knowing the speed of the automobile and the driver's reaction time.

You should be able to make a good argument against tailgating as a result of learning about reaction distance as part of the *Chapter Challenge*. Tailgating is when a driver leaves little space between his or her automobile and the automobile in front. You also should be able to make a good argument against excessive speed in any driving situation, especially when approaching an intersection or places where there may be pedestrians.

Physics to Go

1. Describe the motion of each automobile below. The diagrams of strobe photos were taken every 3 s (seconds).

a) 

b) 

2. Sketch diagrams of strobe photos of the following:
   a) An automobile starting from rest and reaching a final constant speed.
   b) An automobile traveling at a constant speed then coming to a stop.
3. A race car driver travels at 350 ft/s (that's almost 250 mph) for 20 s. How far has the driver traveled during this time?
4. A salesperson drives the 215 mi from New York City to Washington, DC, in 4.5 h.
   a) What was her average speed?
   b) Do you know how fast she was going when she passed through Baltimore? Explain your answer.
5. If you planned to bike to a park that was five miles away, what average speed would you have to maintain to arrive in about 15 min? (Hint: To compute your speed in miles per hour, consider this: What fraction of an hour is 15 min?)

Why should you care?

The reaction distance is the distance you travel before you brake and while you brake. During the reaction time of deciding to step on the brakes of your automobile, your automobile continues to travel at a constant speed. The longer the reaction time, the further you go. After you move your foot to the brake, an additional distance is traveled as the brakes are applied. This additional distance will also be greater for a greater speed.

Physics to Go

1.a)

The automobile is moving at a constant speed with evenly spaced images every 3 s.

1.b)

Speeds up, and then slows again.

2.a)

Answers will vary, but there should be a measurable increase in the distance of the first few automobiles, and then the same distance while the automobile travels at a constant speed.

2.b)

The automobile moves at a constant speed then slows down. Students' sketches should look similar to the diagram below.

3.

Using the formula $v = d/t$, $d = vt =$ $350 \text{ ft/s} \times 20 \text{ s} = 7000 \text{ ft}$.

4.a)

$v = d/t = 215 \text{ m}/4.5 \text{ h} \approx$ 48 mi/h.

Her average speed was about 48 mi/h.

4.b)

This question cannot be answered with the data provided. One can only assume that she was probably going 48 mi/h.

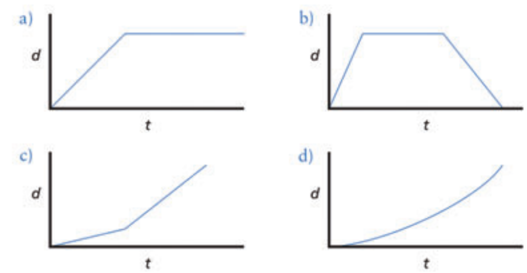
5.

$$v = d/t = \frac{5 \text{ mi}}{0.25 \text{ h}} = 20 \text{ mi/h}.$$

You would need to maintain an average speed of 20 mi/h.

CHAPTER 1

6. For each graph below, describe the motion of the automobile. The vertical axes are labeled with the distance the automobile traveled, denoted *d*.



7. Use your average reaction time from *Section 1* to answer the following:
   a) How far does your automobile travel in meters during your reaction time if you are moving at 55 mi/h (25 m/s)?
   b) How far does your automobile travel during your reaction time if you are moving at 35 mi/h (16 m/s)? How does the distance compare with the distance at 55 mi/h?
   c) Suppose you are very tired and your reaction time is doubled. How far would you travel at 55 mi/h during your reaction time?
8. According to traffic experts, the following distance between your automobile and the vehicle in front of you should be three seconds. As the vehicle in front of you passes a fixed point, say to yourself "one thousand one, one thousand two, one thousand three." Your automobile should not reach that point before you complete the phrase.
   a) A second is a unit of time. How can traffic experts be sure this is a safe following distance?
   b) Will three seconds following "distance" be equally as safe on an interstate highway as on a rural road? Explain your answer.
9. A sneeze requires you to close your eyes for one third of a second.
   a) If you are driving at 70 mi/h (100 ft/s), how far will you travel with your eyes closed during a sneeze?
   b) Is this longer than the length of your classroom?

6.a)

The automobile first travels with constant speed away from the origin, then it is at rest.

6.b)

The automobile travels at a high constant speed away from the origin for the first part of the trip, is at rest for the middle part, then travels at a lower constant speed back to the origin.

6.c)

The automobile travels at a low constant speed away from the origin for the first part of the trip, then travels at a higher constant speed away from the origin for the second part of the trip where the slope changes.

6.d)

The automobile is traveling with increasing speed (possibly constant acceleration) away from the origin.

7.a)

At 55 mi/h, the automobile is moving at about 25 m/s; therefore, the distance, $d = vt = 25 \text{ m/s} \times$ reaction time (reaction times will vary according to student). For example, for a reaction time of 0.16 s, $d = vt = 25 \text{ m/s} \times 0.16 \text{ s} = 4 \text{ m}$.

7.b)

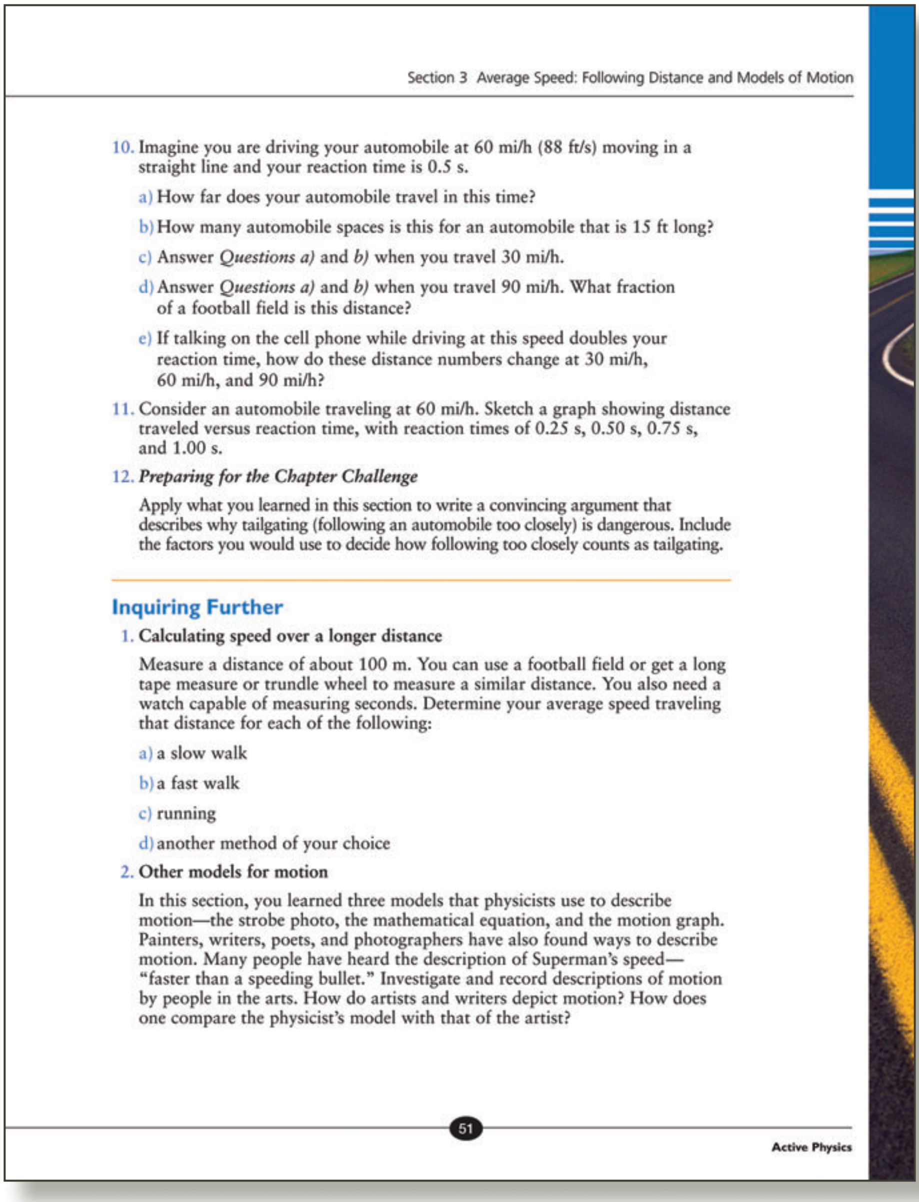
Assume a reaction time of 0.8 s. At 35 mi/h, the car will be moving at about 16 m/s, therefore to find the distance $v = d/t$, then $d = vt$
$d = 16 \text{ m/s} \times 0.8 \text{ s} = 12.8$ or 13 m. A lower speed produces a shorter reaction distance with the same reaction time.

7.c)

You will travel double the distance you calculated for *7.a)*.

8.a)

Because distance traveled is directly proportional to time for constant speed, the three-second rule should work at any speed, and the distance can be described by the travel time. The premise for this rule is that the two automobiles have similar braking ability. The vehicle in front does not "stop on a dime." The three-second distance is not an adequate stopping distance. It is meant to cover the driver's reaction time and the time taken by the lead vehicle to decrease speed before the driver's automobile begins to slow down. Exceptions can be made for poor road, tire, or brake conditions.



Section 3 Average Speed: Following Distance and Models of Motion

10. Imagine you are driving your automobile at 60 mi/h (88 ft/s) moving in a straight line and your reaction time is 0.5 s.

a) How far does your automobile travel in this time?

b) How many automobile spaces is this for an automobile that is 15 ft long?

c) Answer *Questions a)* and *b)* when you travel 30 mi/h.

d) Answer *Questions a)* and *b)* when you travel 90 mi/h. What fraction of a football field is this distance?

e) If talking on the cell phone while driving at this speed doubles your reaction time, how do these distance numbers change at 30 mi/h, 60 mi/h, and 90 mi/h?

11. Consider an automobile traveling at 60 mi/h. Sketch a graph showing distance traveled versus reaction time, with reaction times of 0.25 s, 0.50 s, 0.75 s, and 1.00 s.

12. ***Preparing for the Chapter Challenge***

Apply what you learned in this section to write a convincing argument that describes why tailgating (following an automobile too closely) is dangerous. Include the factors you would use to decide how following too closely counts as tailgating.

Inquiring Further

1. **Calculating speed over a longer distance**

Measure a distance of about 100 m. You can use a football field or get a long tape measure or trundle wheel to measure a similar distance. You also need a watch capable of measuring seconds. Determine your average speed traveling that distance for each of the following:

a) a slow walk

b) a fast walk

c) running

d) another method of your choice

2. **Other models for motion**

In this section, you learned three models that physicists use to describe motion—the strobe photo, the mathematical equation, and the motion graph. Painters, writers, poets, and photographers have also found ways to describe motion. Many people have heard the description of Superman's speed—"faster than a speeding bullet." Investigate and record descriptions of motion by people in the arts. How do artists and writers depict motion? How does one compare the physicist's model with that of the artist?

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8.b)

The three-second following rule should prove equally safe on both rural roads and interstates, since the road conditions will be identical for both automobiles. An automobile may not be able to stop as quickly on a rural road due to poor road surface, but the automobile the driver is following will also need more distance to stop, keeping a safe distance between both the automobiles.

9.a)

Using the equation for speed, $v = d/t$ and solving for d, $d = vt = (100\ \text{ft/s})(0.33\ \text{s}) = 33\ \text{ft}$.

9.b)

33 ft would be approximately the length of a laboratory classroom, but more than a typical classroom.

10.a)

$d = vt = (88\ \text{ft/s})(0.5\ \text{s}) = 44\ \text{ft}$.

10.b)

For an automobile that is 15 ft long, a space of 44 ft is almost three automobile-lengths.

10.c)

At 30 mi/h, the reaction distance is 22 ft, and this is almost 1.5 automobile-lengths.

10.d)

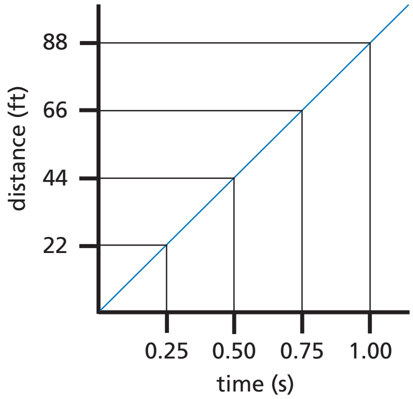
At 90 mi/h, the reaction distance would be 66 ft, or a little more than 4 automobile-lengths. This is almost one-fifth of a football field.

10.e)

When the reaction time is doubled, the distance the automobile travels during that reaction time will also double.

11.

The student graph should be similar to the one below:



CHAPTER 1

12.

Preparing for the Chapter Challenge

Student answers might include some of the following. Tailgating increases the potential hazards of driving. From the time you see the brakes from the lead automobile flash until the time you hit the brake and begin to slow down, your vehicle is still traveling at top speed. If the two vehicles have equal braking ability, there should be a minimum extra distance between the two automobiles equal to the product of your reaction time and the automobile's speed. Because safe driving means minimizing risks, following distances must be commensurate with speed and reaction distance, in addition to road conditions.

The physical condition of the driver might also affect reaction time. The condition of the vehicle in front, which is not under the control of the person tailgating, must be taken into account as an intangible. For instance, the automobile in front might have faulty tail lights, or very good brakes, or the driver in front might be slowing down using the engine (gearing down) rather than the brakes.

Inquiring Further

1. Calculating speed over a longer distance

The results the students obtain for these activities will depend upon their walking speeds.

a) For a slow walk a speed of 2 m/s or less would be normal.

b) A fast walk will be between 3 and 4 m/s.

c) Running speeds of 5–9 m/s would be normal.

d) Some of the methods students might choose could be walking backward, crawling, wheelbarrow race, three-legged race, and so on. Speeds will vary greatly depending upon the choice and the students who are doing the activity.

2. Other models for motion

Artists, writers, and photographers may all depict speed in different ways. An illustrator for a graphic novel will often show speed by putting lines behind the object or person moving, indicating their motion. The longer the lines, the faster the object is traveling. Photographers will often depict motion by panning the camera to blur the background while keeping the moving object in focus during the exposure, or vice versa, blurring the moving object by keeping the camera fixed. A writer has the most options for describing motion. Often, similes (like "faster than a speeding bullet") are used, or descriptive terms such as "rocketing through the night" or "flying down a long hall" also describe motion.

NOTES

SECTION 3 QUIZ

1-3b **Blackline Master**

1. An automobile travels between the 100-m and 250-m markers on a highway in 10 s. The average speed of the automobile during this interval is

   a) 10 m/s. b) 15 m/s.

   c) 25 m/s. d) 40 m/s.

2. A baseball pitcher throws a fastball at 42 m/s. If the batter is 18 m from the pitcher, approximately how much time does it take for the ball to reach the batter?

   a) 1.9 s b) 2.3 s

   c) 0.86 s d) 0.43 s

3. The pattern shown below was left by an automobile as it dripped oil at a constant rate on the road while being driven. During which section of the trip was the car traveling with constant velocity?

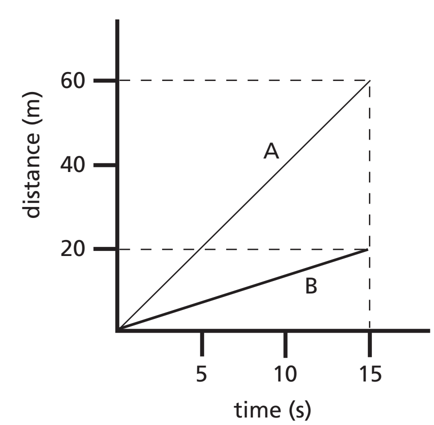
   a) AB b) BC

   c) CD d) DE

4. The graph to the right shows the distance traveled by two objects, A and B. Compared to the speed of object B, the speed of object A is

   a) the same. b) twice as great.

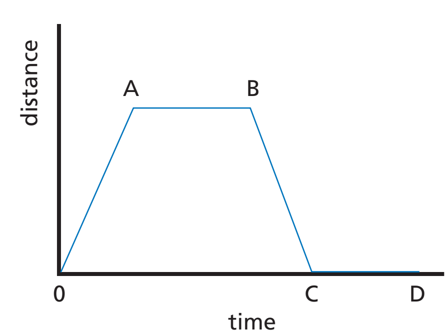
   c) one half as great. d) three times as great.



5. The graph to the right represents the relationship between distance and time for an object in straight-line motion. During which interval was the object at rest?

   a) AB only b) BC only

   c) CD only d) both AB and CD



SECTION 3 QUIZ ANSWERS

1. b) The average speed is the distance traveled/time needed to go that distance. The distance between the markers was 150 m (250 m−100 m), so the speed was 150 m/10 s or 15 m/s. Choices *1.a)* and *1.c)* are wrong because they just use a distance, not the distance traveled, and *1.d)* is wrong because the distances there were added and then divided by the time, rather than subtracted.

2. d) As in the previous question, where the average speed is the distance traveled/time needed to go that distance or $v = d/t$, where $v = 42$ m/s, $d = 18$ m and inserting into the formula gives 42 m/s = 18 m/t. Solving for t gives 0.43 s. If the student mistakenly writes the equation as $v = d \times t$, and then solves, the student will get a wrong answer, 2.3 s. The other answers are double and half the correct value.

3. b) One of the definitions of constant velocity is equal distances in equal times. Because the oil comes out a constant rate, the area where the dots are equally spaced is where the speed will be constant. In section AB, the distance between the dots is increasing, indicating that the car was accelerating, while CD and DE show non-uniform motion with the dots being unevenly spaced.

4. d) The slope of A is three times the slope of B, so the speed must be three times greater. To get the slope, the students can divide the change in the distance by the change in time. Slope A has a change of 60 m in the same time as slope B's change of 20 m.

5. d) During intervals AB and CD, the automobile was at the same distance during the time interval, so its speed must be zero. During interval 0A, the automobile was moving away from the start, and during interval BC, it was moving back toward the starting point.

NOTES