SECTION 2

Constant Speed and Acceleration: Measuring Motion

Section Overview

In this section, students pull tapes through a dot timer to record motion at three different speeds. They then record and compare motion at a constant speed vs. increasing speed and decreasing speed. By analyzing the spacing of dots on different segments of tape, they compare how the distance between the dots changes as the speed increases, decreases, or remains the same when the velocity is constant. The graph students make with tape segments gives them a visual representation of both constant speed and changing speed, which is defined as acceleration. They use their findings in the *Investigate* to distinguish between average speed, instantaneous speed, and acceleration. Students also reflect on how variations in speed and acceleration affect the outcome of an event. Through the *Investigate* and sample problems in the *Physics Talk*, they learn the strategy for calculating acceleration.

Background Information

An object's motion is described by stating the object's initial and subsequent positions, speed, and acceleration. These quantities basically tell how far and how fast the object's motion is changing. An object's speed is determined by dividing the distance it travels by the time required to traverse that distance. In general, the speed of an object changes as it moves. Consequently, it is necessary to distinguish average speed from instantaneous speed. Average speed is found by dividing the total distance traveled by the total time. Instantaneous speed is the speed at a particular instant. A speedometer provides an automobile's instantaneous speed. In theory, the "instant" is an immeasurably short period of time. In practice, an object's instantaneous speed is actually an average speed calculated over a very short time interval. In this section, the motion of a student is recorded with a dot timer. A tape is pulled through a device that marks a dot on the tape every 1/60 of a second. The faster the person moves, the farther apart the dots. Constant speed results in uniformly spaced dots.

Acceleration is the rate at which the speed or direction of motion of an object changes with respect to time. To determine the acceleration of an object due to speed change, it is necessary to measure the speed of the object at the beginning and the end of a time interval. To determine the acceleration due to the changing direction of an object, a different, slightly more complicated procedure is used. In this section, students will be concerned with an object's acceleration in a straight line. By pulling a tape through a dot timer, a student's motion is displayed and analyzed. First the paper tape is marked and labeled in consecutive segments of 6-dot intervals each. These segments are then cut. Six-dot intervals happen in 1/10 of a second. Pasting them in order on a sheet of paper yields a graph of the average velocity of the student during each 1/10 s interval. Acceleration is revealed by the slope of the graph: a positive slope means the student was speeding up; a negative slope, slowing down; and no slope, constant speed.

Crucial Physics

- Constant speed occurs when objects always cover equal distances in equal times.
- Acceleration is the change in velocity of an object per unit time.
- Positive and negative acceleration are determined by both speed and direction.
- Acceleration units are meters/second per second.
- The formula for calculating an objects average speed is distance traveled divided by the elapsed time or $v_{average} = \Delta d / \Delta t$. An object may have an average speed without traveling at constant speed.
- The formula for calculating acceleration is change in speed divided by time interval or $a = \Delta v / \Delta t$.
- Scientists refer to increasing speed when traveling in a straight line in one direction as positive acceleration, and when decreasing speed under the same conditions as negative acceleration.
- The units for acceleration are those for the increase in speed for each second. In the
- metric system this would be m/s/s or m/s^2.

Learning Outcomes	Location in the Section	Evidence of Understanding
Give examples of distance, time, speed, and acceleration.	***Investigate*** Steps 8-11	Students pull the tape at a slow speed and then at a faster speed. They measure the length of each strip as the distance covered in 1/10 of a second. They give examples of this change in speed in an interval of time as an example of acceleration.
Differentiate between instantaneous and average speed.	***Physics Talk***	Students learn the difference between instantaneous and average speed by defining the two and studying sample problems.
Recognize when motion is accelerated.	***Investigate*** Steps 8-11 ***Checking Up*** Questions 1 and 4 ***Physics Talk***	Students see how the length of strips change with a change in speed, how the distance between the dots on the ticker tape changes with a change in speed, and solve a problem to calculate average acceleration.
Calculate average speed and acceleration.	***Physics to Go*** Questions 2-6, 8-9, 11-13	Students solve problems to calculate average speed and acceleration.

CHAPTER 2

Section 2 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Multimedia DVD/CD Set		1 per class
Ruler, metric, 30 cm	1 per group	
Timer, ticker tape, AC	1 per group	
Scissors	1 per group	
Meter stick, wood	1 per group	
Ticker tape, roll	1 per group	
Glue stick	1 per group	

*Additional items needed not supplied

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Multimedia DVD/CD Set		1 per class
Ruler, metric, 30 cm		1 per class
Timer, ticker tape, AC		1 per class
Scissors		1 per class
Meter stick, wood		1 per class
Ticker tape, roll		1 per class
Glue stick		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.

Teacher Preparation

- Familiarize yourself with the operation of the ticker tape timer. Those that operate on AC power are preset to vibrate at 60 cycles/second. If you have any of the older timers that operate on battery or DC power, you will have to check the vibration rate. This can be done either with a calibrated strobe or by pulling a section of tape through the timer for 5 s, and counting the dots.
- Have spare carbon disks on hand for any timer where the disk is becoming worn out. Replace the disk if the spots on the student's tape become faint. It often is worthwhile for the student to mark faint dots with a pen to make them more visible prior to analyzing the tape.

Safety Requirement

- Make sure the area where the students will walk is clear of any obstructions that may cause them to trip. The students should unplug the timers as soon as they are finished taking measurements to prevent overheating, and to save the carbon disk.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Following directions	***Investigate***	**Augmentation** • Ask students to read the entire *Investigate* to get a general idea of what is required to complete 11 steps of directions in a timely manner. • Model how to use a ticker timer. • The information in parentheses in *Investigate* 3, is especially important. Make sure students understand how to count six spaces instead of six dots while looking at the illustration below *Step 3*. • Give students a time limit to complete this section. Set a timer and give time updates every 5-10 minutes. **Accommodation** • Provide a checklist that breaks a step into smaller tasks that can be marked off as students complete each one.
Making sketches	***Investigate*** Steps 6.a), 8.a), and 10.a)	**Augmentation** • Students with graphomotor or visual-motor issues may struggle to sketch accurate graphs. Provide graph paper for sketches. • Tell students that the sketch should display general trends or patterns and does not have to be an exact replica of the original bar graph. • Remind students that they should have three bar graphs in their *Active Physics* logs when they are finished.
Understanding trends to interpret graphs	***Physics Talk*** ***Physics to Go***	**Augmentation** • Ask students to describe in their own words the differences between the bar graphs in this section. How is slow speed different from medium speed on a ticker-tape bar graph? How is positive acceleration different from negative acceleration on a ticker-tape bar graph? • To check for understanding, provide bar graphs without labels. Ask students to label the graphs (slow speed, medium speed, etc.) independently. • Understanding the trends in these graphs will help students answer *Physics to Go*, Questions 4, 7, 10, and 14.
Sequential learning and then using two new formulas at the same time	***Physics Talk***	**Augmentation** • Provide direct instruction for the average speed formula and allow opportunities for guided practice. Then provide direct instruction for the acceleration formula and let students practice problems similar to the sample problems.
Differentiating nuances in new vocabulary	***Physics Words*** ***Physics to Go*** Question 1	**Augmentation** • Students may not notice the subtle differences in the definitions for average versus instantaneous speed and positive versus negative acceleration. Ask students to explain the definitions in their own words. • If students are required to copy definitions, ask them to highlight or underline the differences. • Students can also write the words that are different in positive and negative acceleration definitions in capital letters (INCREASE and DECREASE).
Reading vocabulary	***Physics Essential Questions***	**Augmentation** • When reading the *Why do you believe?* section, explain the meaning of *subatomic particle*. Students may know about protons, neutrons, and electrons but may not know the meaning of subatomic particles.

CHAPTER 2

Learning Issue	Reference	Augmentation and Accommodations
Completing long-term projects	***Reflecting on the Section and the Challenge***	**Augmentation** • Assist students in the creation of a calendar, timeline, or checklist for completing the *Chapter Challenge*. • Check in with students each step of the way to make sure they understand and are completing the smaller tasks required to complete the challenge. **Accommodation** • Allow students to work with a partner who has good time-management skills.
Performing calculations with a formula	***Physics to Go*** Question 2	**Augmentation** • Students learned two formulas in this section. Make sure it is clear that students are supposed to use the average speed formula for these problems. • Require that students show their work when solving problems. This allows the teacher and/or student to check for misunderstandings and mistakes. **Accommodation** • Provide students with a sheet of blank problem-solving boxes.
Solving problems with data from a table	***Physics to Go*** Question 5	**Augmentation** • Students with visual-spatial and attention issues may struggle to accurately track numbers in the table. Ask students to use a ruler, note card, or another straight edge to track the numbers in each row that are needed to do the calculation. **Accommodation** • Provide students with a table that has the first two columns reversed so that "Length of 6-tick segment" is column 1 and "Elapsed time" is column 2. Then students can sequentially enter data into their calculators (distance traveled divided by elapsed time).

Strategies for Students With Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Vocabulary comprehension	***Investigate***	Before beginning this *Investigate*, have each group discuss the word "constant" as used in "constant speed" and "constant acceleration" and share its interpretation with the class. Be sure all students have an appropriate understanding of the word in the context of physics. The word "trend" is used in *Investigate* Step 8.c). Be sure students understand this word in context as well. Try using "pattern" instead.
Comprehension	***Investigate*** Step 1.a)	To help students reinforce their description of the tape, have them draw in their *Active Physics* log what the tape would look like and add labels for positive acceleration and negative acceleration.
Comprehension	***Physics Talk***	To ensure that students understand the *Units of Acceleration* box, collaborate with their math teachers to determine what level of comprehension students have for exponents.
Comprehension	***What Do You Think Now?***	Have students write the answer in their *Active Physics* log. Invite students to share their responses and explain how their understanding may have changed.
Making connections	***Reflecting on the Section and the Challenge***	Remind students of the voice-over narration they are going to write and perform at the end of the chapter. Have them start thinking of the sporting event they want to cover. Ask some guiding questions: What are the rules of nature that govern your event? What physics principles apply to your event? What physics terms can you use to describe your event? How can you make your voice-over lively and engaging?

NOTES

SECTION 2

Teaching Suggestions and Sample Answers

What Do You See?

This illustration brings an array of colorful images together, which deftly connect with the topic of *Section 2*. Consider using an overhead to highlight different aspects of two contrasting visuals. Ask students to note their similarities and differences. Have students recall prior learning to gauge how their understanding of the physics of motion is progressing. You could also touch on the humorous element in the illustration to initiate a lively discussion. Students will invariably respond to the image of the boy running with a bouquet of roses in his hand. The two visuals present ample opportunity to develop ideas and lead students to think about the concepts that students will be investigating in this section. You might want to post an enlarged version of this illustration on the wall of your classroom, so that students can note how their initial perception of the illustration continues to evolve with their investigations and subsequent interpretation of physics concepts.

What Do You Think?

Encourage students to answer the *What Do You Think?* questions and emphasize that all answers will be accepted. You might want to clarify to them at this stage that your prime concern is to prepare the class for physics concepts that will appear later in the section. Stress that the purpose of these questions is to guide your students' understanding. Each question relates to a topic that will be investigated and analyzed in detail.

What Do You Think?

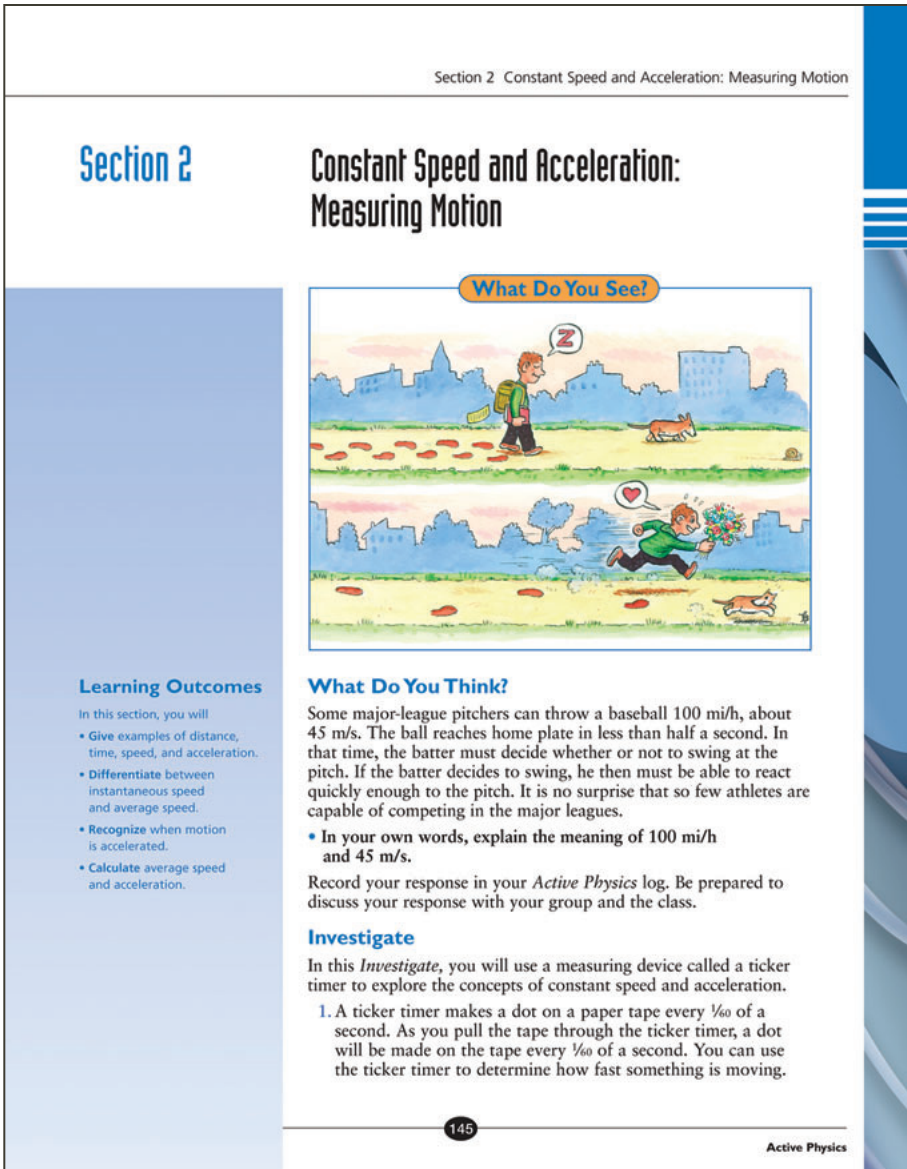
A Physicist's Response

A fastball thrown at 100 mph translates to a speed of 147 ft/s. When objects move at speeds such as this, short time intervals can mean an object travels a significant distance. For a batter who is 1/100 of a second off will miss the ball by 1.47 ft or 18 in.

Students' Prior Conceptions

As they work through *Section 2*, students can root out preconceptions on steady motion, non-steady motion, speed, velocity, and acceleration, either speeding up or slowing down. The preconceptions are as follows:

1. **The location of an object can be described by stating its distance from a given point (ignoring direction).** Students will confront the difference between the total distance an object travels with the displacement of an object relative to a specific point of reference or origin. Students must consider both the distance and the direction from the reference point when describing the location of objects. The concept of magnitude of measurement is distinguishable from magnitude with direction.
2. **The terms *distance* and *displacement* are synonymous and may be used interchangeably.** Thus, the distance an object travels and its displacement are always the same. Student confusion between distance and displacement relates directly to the previous preconception that deals with how the motion of the object changes, and in which direction the change occurs.
3. **Velocity is another word for speed. An object's speed and velocity are always the same.** Teachers need to encourage students to recognize that moving forward, away from the origin with a given speed, differs from starting in front of the origin and moving toward it with the same speed. The direction of the motion, away from the origin (positive velocity) or toward the origin



Section 2 Constant Speed and Acceleration: Measuring Motion

Section 2

Constant Speed and Acceleration: Measuring Motion

What Do You See?

Learning Outcomes

In this section, you will

- **Give** examples of distance, time, speed, and acceleration.
- **Differentiate** between instantaneous speed and average speed.
- **Recognize** when motion is accelerated.
- **Calculate** average speed and acceleration.

What Do You Think?

Some major-league pitchers can throw a baseball 100 mi/h, about 45 m/s. The ball reaches home plate in less than half a second. In that time, the batter must decide whether or not to swing at the pitch. If the batter decides to swing, he then must be able to react quickly enough to the pitch. It is no surprise that so few athletes are capable of competing in the major leagues.

- **In your own words, explain the meaning of 100 mi/h and 45 m/s.**

Record your response in your *Active Physics* log. Be prepared to discuss your response with your group and the class.

Investigate

In this *Investigate*, you will use a measuring device called a ticker timer to explore the concepts of constant speed and acceleration.

1. A ticker timer makes a dot on a paper tape every 1/60 of a second. As you pull the tape through the ticker timer, a dot will be made on the tape every 1/60 of a second. You can use the ticker timer to determine how fast something is moving.

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Investigate

1.

Student predictions.

CHAPTER 2

(negative velocity) is vital to student understanding of velocity and to how velocity is interpreted from a graph of displacement vs. time.

4. **Students confuse acceleration with speed; acceleration means that an object is speeding up.** Encourage students to measure the motions of objects so that it is evident that a change in velocity within a given time period is an acceleration. This change in velocity can be positive or negative, leading to a positive acceleration with motion that may either speed up or slow down or a negative acceleration with motion that also may either speed up or slow down. A positive acceleration does not always occur in the same direction as an object is moving.

5. **If an object has a speed of zero, even instantaneously, it has no acceleration.** Because acceleration is the change in velocity, an object can have an instantaneous speed of zero and still be acted upon by a force that gives it acceleration. The correlation between acceleration and force occurs in subsequent activities.

1.a)

At constant speed the dots should be equally spaced.

1.b)

At a faster constant speed, the dots should be equally spaced but further apart.

1.c)

At a slower constant speed, the dots should be equally spaced but closer together.

1.d)

When walking at a constant speed, then faster and faster, the dots at first should be equally spaced and then get progressively farther apart.

2.

Make sure that students have begun to pull the tape at a constant speed before they actually start the timer.

3.

Students will draw a line through the tape at every sixth dot.

4.

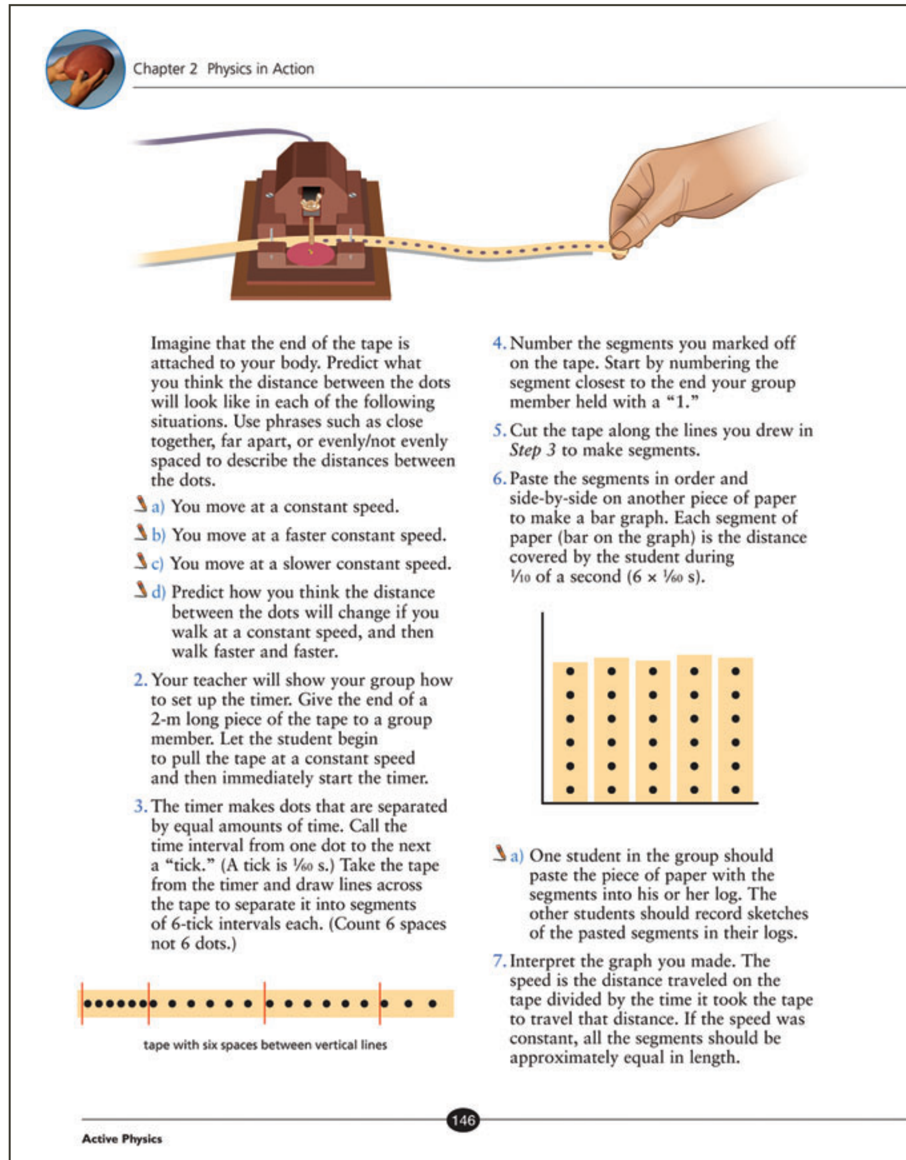
Students will number the tape sections.

5.

Students will cut the tape into sections.

6.

Students must be certain to line all the paper strips up along the x-axis. Other students in the group should make sketches of the taped graph in their own logs.



Chapter 2 Physics in Action

Imagine that the end of the tape is attached to your body. Predict what you think the distance between the dots will look like in each of the following situations. Use phrases such as close together, far apart, or evenly/not evenly spaced to describe the distances between the dots.

a) You move at a constant speed.

b) You move at a faster constant speed.

c) You move at a slower constant speed.

d) Predict how you think the distance between the dots will change if you walk at a constant speed, and then walk faster and faster.

2. Your teacher will show your group how to set up the timer. Give the end of a 2-m long piece of the tape to a group member. Let the student begin to pull the tape at a constant speed and then immediately start the timer.

3. The timer makes dots that are separated by equal amounts of time. Call the time interval from one dot to the next a "tick." (A tick is $\frac{1}{60}$ s.) Take the tape from the timer and draw lines across the tape to separate it into segments of 6-tick intervals each. (Count 6 spaces not 6 dots.)

tape with six spaces between vertical lines

4. Number the segments you marked off on the tape. Start by numbering the segment closest to the end your group member held with a "1."

5. Cut the tape along the lines you drew in *Step 3* to make segments.

6. Paste the segments in order and side-by-side on another piece of paper to make a bar graph. Each segment of paper (bar on the graph) is the distance covered by the student during $\frac{1}{10}$ of a second ($6 \times \frac{1}{60}$ s).

a) One student in the group should paste the piece of paper with the segments into his or her log. The other students should record sketches of the pasted segments in their logs.

7. Interpret the graph you made. The speed is the distance traveled on the tape divided by the time it took the tape to travel that distance. If the speed was constant, all the segments should be approximately equal in length.

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a) Explain why you would expect all the segments to be about equal in length if the speed was constant.

b) Was the speed constant? How could you tell? If the speed was not constant, try again.

8. Use a new 2-m long section of tape. This time, ask the student pulling the tape to start at a slow speed and gradually increase his or her speed. Recall from the previous section, that a change in speed over a given time is called acceleration. Again, mark the tape into segments of 6-tick intervals and number the segments. Cut the segments apart and paste them in order, side-by-side, on a second sheet of paper. The length of each segment (bar on the graph) is the distance covered by the student during $^1/_{10}$ of a second.

a) One student in the group should paste the piece of paper with the segments into his or her log. The other students should record sketches of the pasted segments in their logs.

b) What does the length of the paper segments (bars on the graph) tell you about the student's speed during each time interval?

c) Is there a trend in the lengths of the paper segments of your graph?

9. Remember that the student pulling the tape started at slow speed (short strip) and then gradually speeded up (increasing the length of subsequent strips). The difference in the length of each successive strip measures the change in the student's speed during that $^1/_{10}$ of a second. A change in speed is called *acceleration*. Acceleration measures how much an object's speed changes in a given time interval.

a) In your log, measure the acceleration for each time interval on your graph by measuring the difference in length of each strip compared to the previous strip. Do not worry about exact time intervals yet. Use the differences in strip lengths to represent acceleration.

b) Did the student pulling the tape move with a constant acceleration? Was the change in the length of the strips constant?

10. Use another new section of tape. This time, ask the student pulling the tape to start moving at high speed and steadily slow down. Again, mark and cut the tape into 6-tick segments and make a paper-tape bar graph.

a) One student in the group should paste the piece of paper with the segments into his or her log. The other students should record sketches of the pasted segments in their logs.

b) How do you expect the pattern on the graph when decreasing speed to be different from the pattern on the graph when increasing speed?

c) Measure the acceleration for each $^1/_{10}$ of a second (equal to 6 ticks) by using the difference in strip lengths to represent the change in speed. Did the student travel with a constant acceleration?

11. Compare the graphs for increasing and decreasing speed. Physicists often consider the acceleration with increasing speed positive and the acceleration with decreasing speed negative.

a) Describe the tape of a person who speeds up and then slows down using this +/- acceleration convention.

7.a)

Constant speed means covering equal distances in equal times. Because all of the strips are

at a time interval of 6 "ticks" (equal times), the strips should all be equal distances for constant speed.

7.b)

If all the strips are approximately the same lengths, the speed is constant. Natural variation in walking will result in some differences.

8.a)

Students should first pull the tape at a slow speed, then gradually increase the speed.

8.b)

The length of each strip increases for the same amount of time by 6 "ticks," which means that the speed increases as the length of each strip increases.

8.c)

Each paper segment is longer than the previous one.

9.a)

Student measure acceleration by measuring the difference in the length of each strip.

9.b)

If the change in length of the strips from one section to the next was always the same (which would be very difficult to do), the acceleration would be constant.

10.a)

Students pull the tape at high speed and steadily slow down. The tape is then cut into 6-tick segments and made into a paper-tape graph.

10.b)

For decreasing speed, each tape strip of 6 "ticks" should be shorter than the previous one.

10.c)

Student calculation using the tape strips.

11.a)

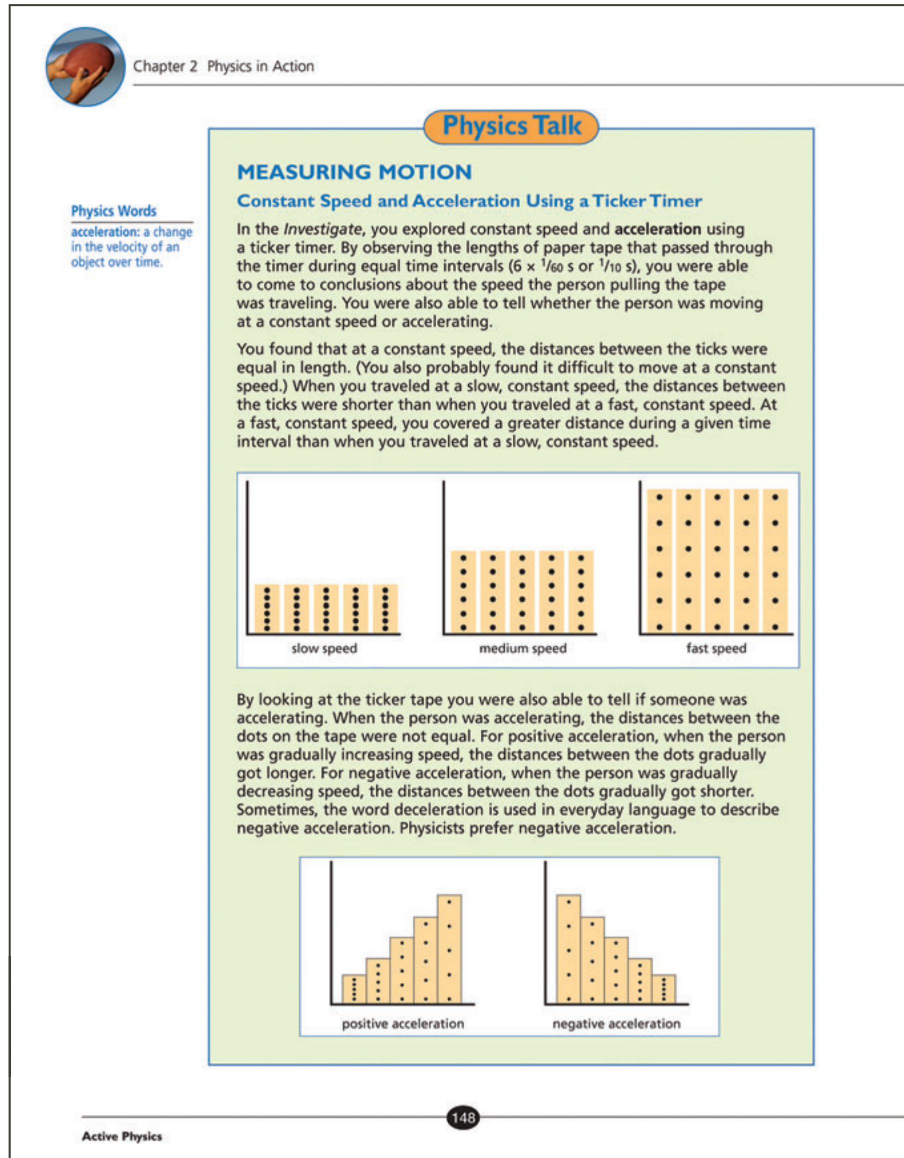
When the person is increasing speed it would be a positive acceleration, and when decreasing speed the acceleration would be negative.

Physics Talk

This *Physics Talk* explores the concepts of speed and acceleration by making a significant connection between the students' experiment in the *Investigate* and the changes in speed and acceleration. Ask students how they could tell from the ticker tape whether a person was traveling at constant speed or accelerating. Have them indicate positive and negative acceleration on the ticker tapes and write down the definitions of these terms. Students should understand the difference between average and instantaneous speed. Discuss the concepts of acceleration and deceleration. Do the sample problems on the board and invite students to ask questions on how to calculate average speed and acceleration. Reemphasize the units for each quantity.

2-2a Blackline Master

2-2b Blackline Master


Chapter 2 Physics in Action

Physics Talk

MEASURING MOTION

Constant Speed and Acceleration Using a Ticker Timer

Physics Words

acceleration: a change in the velocity of an object over time.

In the *Investigate*, you explored constant speed and **acceleration** using a ticker timer. By observing the lengths of paper tape that passed through the timer during equal time intervals (6 × 1/60 s or 1/10 s), you were able to come to conclusions about the speed the person pulling the tape was traveling. You were also able to tell whether the person was moving at a constant speed or accelerating.

You found that at a constant speed, the distances between the ticks were equal in length. (You also probably found it difficult to move at a constant speed.) When you traveled at a slow, constant speed, the distances between the ticks were shorter than when you traveled at a fast, constant speed. At a fast, constant speed, you covered a greater distance during a given time interval than when you traveled at a slow, constant speed.

By looking at the ticker tape you were also able to tell if someone was accelerating. When the person was accelerating, the distances between the dots on the tape were not equal. For positive acceleration, when the person was gradually increasing speed, the distances between the dots gradually got longer. For negative acceleration, when the person was gradually decreasing speed, the distances between the dots gradually got shorter. Sometimes, the word deceleration is used in everyday language to describe negative acceleration. Physicists prefer negative acceleration.

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Active Physics

Section 2 Constant Speed and Acceleration: Measuring Motion

Calculating Speed

One way to measure motion is to calculate speed. Speed is a ratio of distance traveled to time taken. The unit for speed is always written as a distance per unit of time. **Average speed** is the distance traveled divided by the time taken to travel that distance.

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

This can be written using symbols.

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

where v_{av} is average speed,

Δd is change in distance or total distance,

Δt is change in time or time elapsed.

The Greek letter *delta*, "Δ," is often used in science to mean "a change in."

Physics Words

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

instantaneous speed: the speed measured during an instant: the speed as the time interval approaches, but does not become zero.

Sample Problem 1

If you drive 140 km in 2 h (hours), calculate your average speed.

Strategy: You can use the equation for average speed.

Given:

$\Delta d = 140$ km

$\Delta t = 2$ h

Solution:

$$v_{av} = \frac{\Delta d}{\Delta t} = \frac{140 \text{ km}}{2 \text{ h}} = 70 \text{ km/h}$$

Your average speed is 70 km/h.

To travel at the average speed of 70 km/h, you might drive 70 km/h throughout the trip. But common sense tells you that your speed changes during a road trip. Before the vehicle starts moving forward, its speed is 0 km/h. At the end of the trip, you slow the vehicle to 0 km/h. And during the trip you probably slow down and speed up as you drive. The speedometer reading at any moment during the trip is your **instantaneous speed**, which is the speed at that moment.

Chapter 2 Physics in Action

Calculating Acceleration

When an object changes its speed, it is accelerating. Acceleration is the change of the speed divided by time. Acceleration is also a change in the direction of motion, but this will be discussed later.

To calculate acceleration in one direction caused by speeding up or slowing down, you divide the change in speed by the time interval during which the change took place.

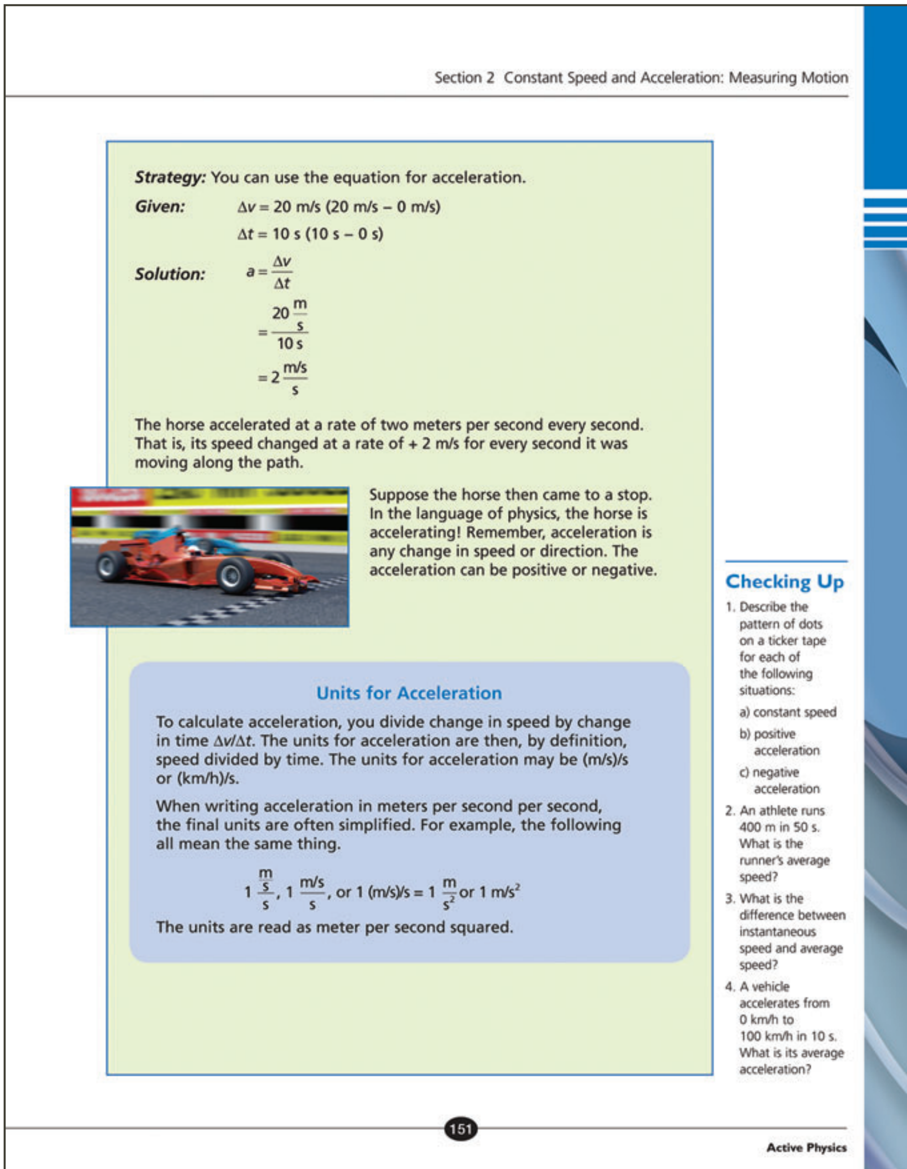
$$\text{Acceleration} = \frac{\text{change in speed}}{\text{time interval}}$$

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

where a is acceleration,
Δv is change in speed,
Δt is change in time or time elapsed.

Sample Problem 2

A horse is stopped on a straight path. It begins moving forward and reaches a full gallop along the path in 10 s. The horse gallops at a speed of 20 m/s. What was the horse's acceleration?



Strategy: You can use the equation for acceleration.

Given: $\Delta v = 20$ m/s (20 m/s – 0 m/s)

$\Delta t = 10$ s (10 s – 0 s)

Solution:

$$a = \frac{\Delta v}{\Delta t} = \frac{20\ \frac{\text{m}}{\text{s}}}{10\ \text{s}} = 2\ \frac{\text{m/s}}{\text{s}}$$

The horse accelerated at a rate of two meters per second every second. That is, its speed changed at a rate of + 2 m/s for every second it was moving along the path.

Suppose the horse then came to a stop. In the language of physics, the horse is accelerating! Remember, acceleration is any change in speed or direction. The acceleration can be positive or negative.

Units for Acceleration

To calculate acceleration, you divide change in speed by change in time $\Delta v/\Delta t$. The units for acceleration are then, by definition, speed divided by time. The units for acceleration may be (m/s)/s or (km/h)/s.

When writing acceleration in meters per second per second, the final units are often simplified. For example, the following all mean the same thing.

$$1\ \frac{\frac{\text{m}}{\text{s}}}{\text{s}},\ 1\ \frac{\text{m/s}}{\text{s}},\ \text{or } 1\ (\text{m/s})/\text{s} = 1\ \frac{\text{m}}{\text{s}^2} \text{ or } 1\ \text{m/s}^2$$

The units are read as meter per second squared.

Checking Up

1. Describe the pattern of dots on a ticker tape for each of the following situations:
   a) constant speed
   b) positive acceleration
   c) negative acceleration
2. An athlete runs 400 m in 50 s. What is the runner's average speed?
3. What is the difference between instantaneous speed and average speed?
4. A vehicle accelerates from 0 km/h to 100 km/h in 10 s. What is its average acceleration?

Checking Up

1.a)

Constant speed would have a series of dots equally spaced.

1.b)

The series of dots get progressively further apart as speed gradually increases with positive acceleration.

1.c)

The series of dots come closer together as speed gradually decreases with negative acceleration.

2.

An athlete who runs 400 m in 50 s would have an average speed of

$$v_{\text{average}} = \frac{\text{distance}}{\text{time}} = \frac{400\ \text{m}}{50\ \text{s}} = 8\ \text{m/s}.$$

3.

Instantaneous speed is the measured speed at a given instant while average speed is the distance traveled divided by the time taken to travel that distance. The speedometer of a car registers the instantaneous speed of the car.

4.

The acceleration is

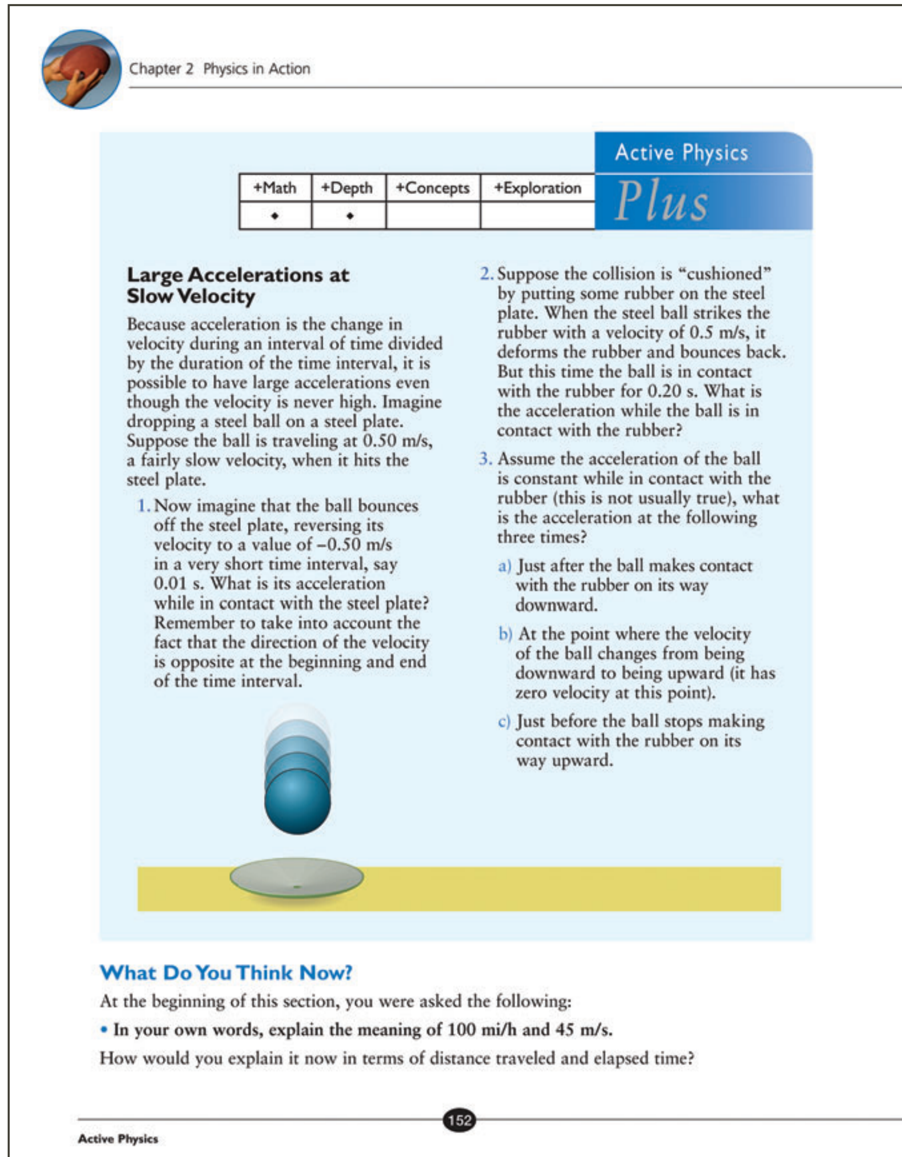
$$a = \frac{\Delta v}{\Delta t} = \frac{100\ \text{km/h}}{10\ \text{s}} = 10\ \frac{\text{km/h}}{\text{s}}, \text{ or}$$

about 2.8 m/s^2.

Active Physics Plus

The purpose of these problems is for students to understand that although there is small change in velocity it is possible to have a large acceleration for a short interval of time. Therefore, a ball traveling at a slow speed after bouncing off a steel plate will accelerate in the opposite direction of its motion.

Consider the downward direction to be negative and the upward direction to be positive, so the steel ball moving downward would have an initial velocity of –0.5 m/s and, after the bounce when it is moving upward, its final velocity will be +0.5 m/s.



Chapter 2 Physics in Action

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
•	•		

Large Accelerations at Slow Velocity

Because acceleration is the change in velocity during an interval of time divided by the duration of the time interval, it is possible to have large accelerations even though the velocity is never high. Imagine dropping a steel ball on a steel plate. Suppose the ball is traveling at 0.50 m/s, a fairly slow velocity, when it hits the steel plate.

1. Now imagine that the ball bounces off the steel plate, reversing its velocity to a value of –0.50 m/s in a very short time interval, say 0.01 s. What is its acceleration while in contact with the steel plate? Remember to take into account the fact that the direction of the velocity is opposite at the beginning and end of the time interval.

2. Suppose the collision is "cushioned" by putting some rubber on the steel plate. When the steel ball strikes the rubber with a velocity of 0.5 m/s, it deforms the rubber and bounces back. But this time the ball is in contact with the rubber for 0.20 s. What is the acceleration while the ball is in contact with the rubber?

3. Assume the acceleration of the ball is constant while in contact with the rubber (this is not usually true), what is the acceleration at the following three times?

   a) Just after the ball makes contact with the rubber on its way downward.

   b) At the point where the velocity of the ball changes from being downward to being upward (it has zero velocity at this point).

   c) Just before the ball stops making contact with the rubber on its way upward.

What Do You Think Now?

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

- **In your own words, explain the meaning of 100 mi/h and 45 m/s.**

How would you explain it now in terms of distance traveled and elapsed time?

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Active Physics

1.

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

$$\frac{+0.5\ \text{m/s} - \left(-0.5\ \text{m/s}\right)}{0.01\ \text{s}} = 100\ \text{m/s}^2$$

upward.

2.

$$\frac{+0.5\ \text{m/s} - \left(-0.5\ \text{m/s}\right)}{0.2\ \text{s}} = 5\ \text{m/s}^2$$

upward.

3.a)

When the object just strikes the rubber, its acceleration is 5 m/s^2 upward.

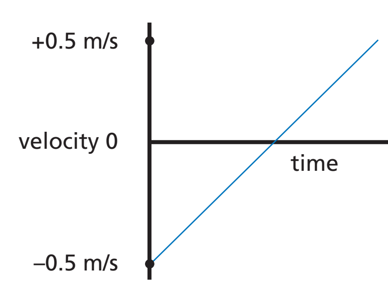
3.b)

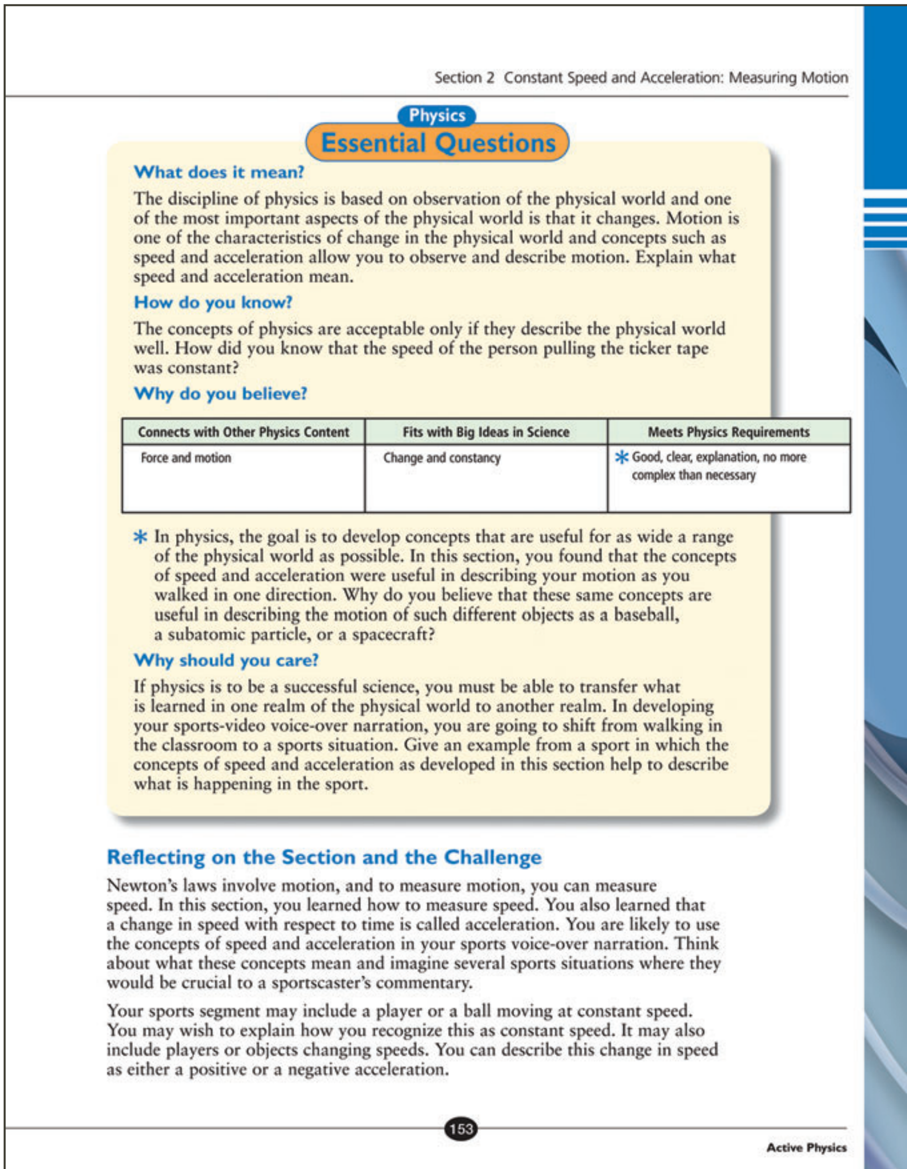
At the lowest point, when it changes direction, its acceleration is still 5 m/s^2 upward.

3.c)

Just before the ball stops making contact with the rubber, its acceleration is 5 m/s^2 upward.

In each case the acceleration is positive and upward. When the ball first strikes the rubber its velocity is negative (downward), but becoming less negative so the change is positive. When the ball momentarily stops at the bottom, its velocity will start to increase upward, so it also has the same acceleration, and also just as it is leaving the rubber. A graph of the ball's velocity would look like the one shown.





Physics
Essential Questions

What does it mean?

The discipline of physics is based on observation of the physical world and one of the most important aspects of the physical world is that it changes. Motion is one of the characteristics of change in the physical world and concepts such as speed and acceleration allow you to observe and describe motion. Explain what speed and acceleration mean.

How do you know?

The concepts of physics are acceptable only if they describe the physical world well. How did you know that the speed of the person pulling the ticker tape was constant?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Force and motion	Change and constancy	* Good, clear, explanation, no more complex than necessary

* In physics, the goal is to develop concepts that are useful for as wide a range of the physical world as possible. In this section, you found that the concepts of speed and acceleration were useful in describing your motion as you walked in one direction. Why do you believe that these same concepts are useful in describing the motion of such different objects as a baseball, a subatomic particle, or a spacecraft?

Why should you care?

If physics is to be a successful science, you must be able to transfer what is learned in one realm of the physical world to another realm. In developing your sports-video voice-over narration, you are going to shift from walking in the classroom to a sports situation. Give an example from a sport in which the concepts of speed and acceleration as developed in this section help to describe what is happening in the sport.

Reflecting on the Section and the Challenge

Newton's laws involve motion, and to measure motion, you can measure speed. In this section, you learned how to measure speed. You also learned that a change in speed with respect to time is called acceleration. You are likely to use the concepts of speed and acceleration in your sports voice-over narration. Think about what these concepts mean and imagine several sports situations where they would be crucial to a sportscaster's commentary.

Your sports segment may include a player or a ball moving at constant speed. You may wish to explain how you recognize this as constant speed. It may also include players or objects changing speeds. You can describe this change in speed as either a positive or a negative acceleration.

What Do You Think Now?

Ask students to revisit their *What Do You Think?* answers. Prompt them to change their answers or add more to what they have written in their logs already. Have a discussion in class to gauge how much students have understood. By now most students should be comfortable answering questions on speed.

Reflecting on the Section and the Challenge

This is the time for students to reflect on the concepts they have explored in this section. Suggest to them that speed, acceleration, and frames of reference are terms that they can incorporate in their voice-over narration for the *Chapter Challenge*. You can have your class brainstorm examples of sports situations where students have an opportunity to discuss their ideas.

Physics Essential Questions

What does it mean?

Speed is a change in distance during an elapsed time. Acceleration is a change in speed during an elapsed time.

How do you know?

Assuming that the dots are created at equal time intervals, we could see that a car was moving at constant speed by measuring whether an equal distance was recorded for each time interval.

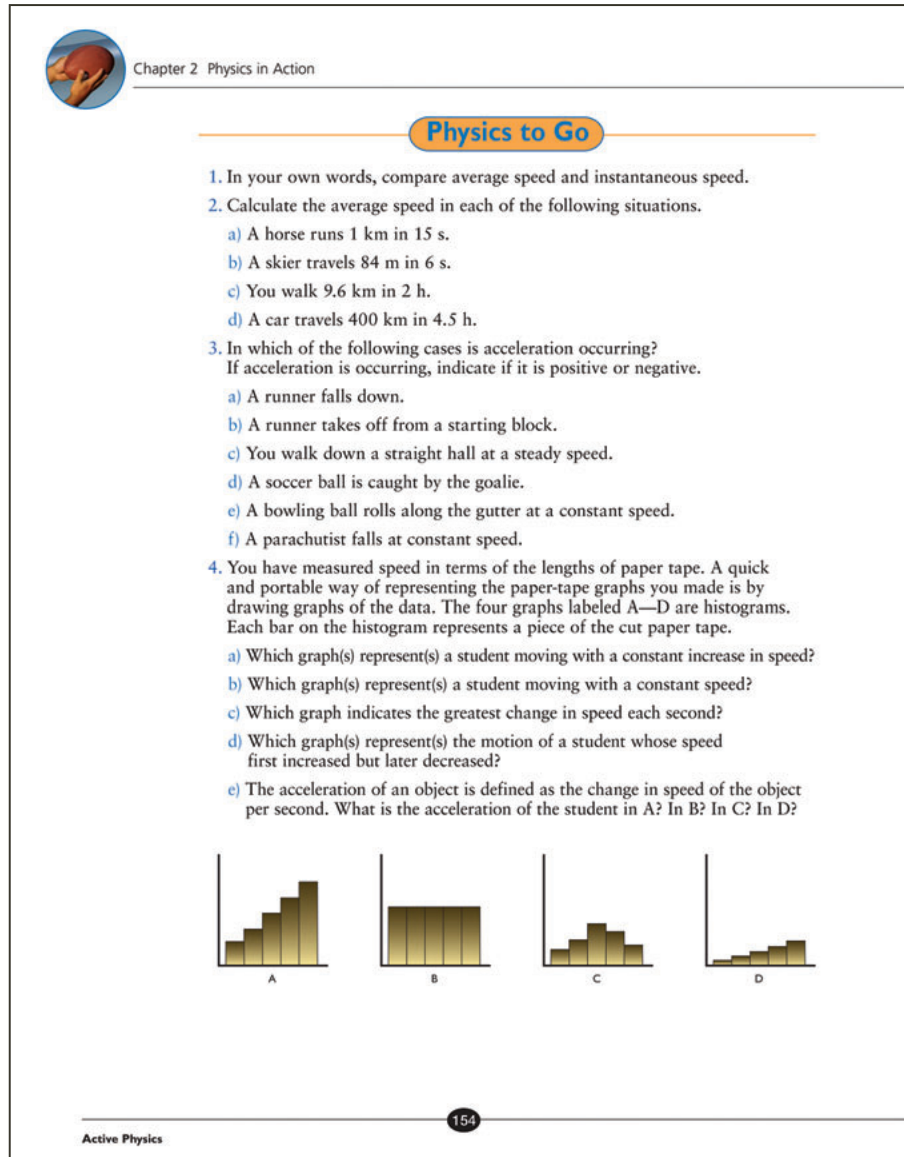
Why do you believe?

Although a baseball, a particle and a spacecraft are all very different objects, the definition of speed as a change in distance during an elapsed time can apply to all of them.

Why should you care?

In the sprint, the runner starts from rest and then accelerates to her top speed. For the rest of the race, she travels at a constant speed

Physics to Go


Chapter 2 Physics in Action

Physics to Go

1. In your own words, compare average speed and instantaneous speed.
2. Calculate the average speed in each of the following situations.
   a) A horse runs 1 km in 15 s.
   b) A skier travels 84 m in 6 s.
   c) You walk 9.6 km in 2 h.
   d) A car travels 400 km in 4.5 h.
3. In which of the following cases is acceleration occurring? If acceleration is occurring, indicate if it is positive or negative.
   a) A runner falls down.
   b) A runner takes off from a starting block.
   c) You walk down a straight hall at a steady speed.
   d) A soccer ball is caught by the goalie.
   e) A bowling ball rolls along the gutter at a constant speed.
   f) A parachutist falls at constant speed.
4. You have measured speed in terms of the lengths of paper tape. A quick and portable way of representing the paper-tape graphs you made is by drawing graphs of the data. The four graphs labeled A—D are histograms. Each bar on the histogram represents a piece of the cut paper tape.
   a) Which graph(s) represent(s) a student moving with a constant increase in speed?
   b) Which graph(s) represent(s) a student moving with a constant speed?
   c) Which graph indicates the greatest change in speed each second?
   d) Which graph(s) represent(s) the motion of a student whose speed first increased but later decreased?
   e) The acceleration of an object is defined as the change in speed of the object per second. What is the acceleration of the student in A? In B? In C? In D?

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Active Physics

1.
Answers will vary and may include everyday experiences, like driving in a car. Average speed can be calculated for a trip; instantaneous speed is shown on the speedometer.

2.a)
0.06 km/s

2.b)
14 m/s

2.c)
4.8 km/h

2.d)
89 km/h

3.a)
Negative acceleration is occurring as the runner falls to the ground and slows down.

3.b)
Positive acceleration is occurring as the runner gains speed.

3.c)
Acceleration is zero for constant speed in a straight line.

3.d)
Negative acceleration is occurring as the goalie slows down the soccer ball.

3.e)
Acceleration is zero for constant speed in a straight line.

3.f)
Acceleration is zero for constant speed in a straight line.

4.a)
Graphs A and D

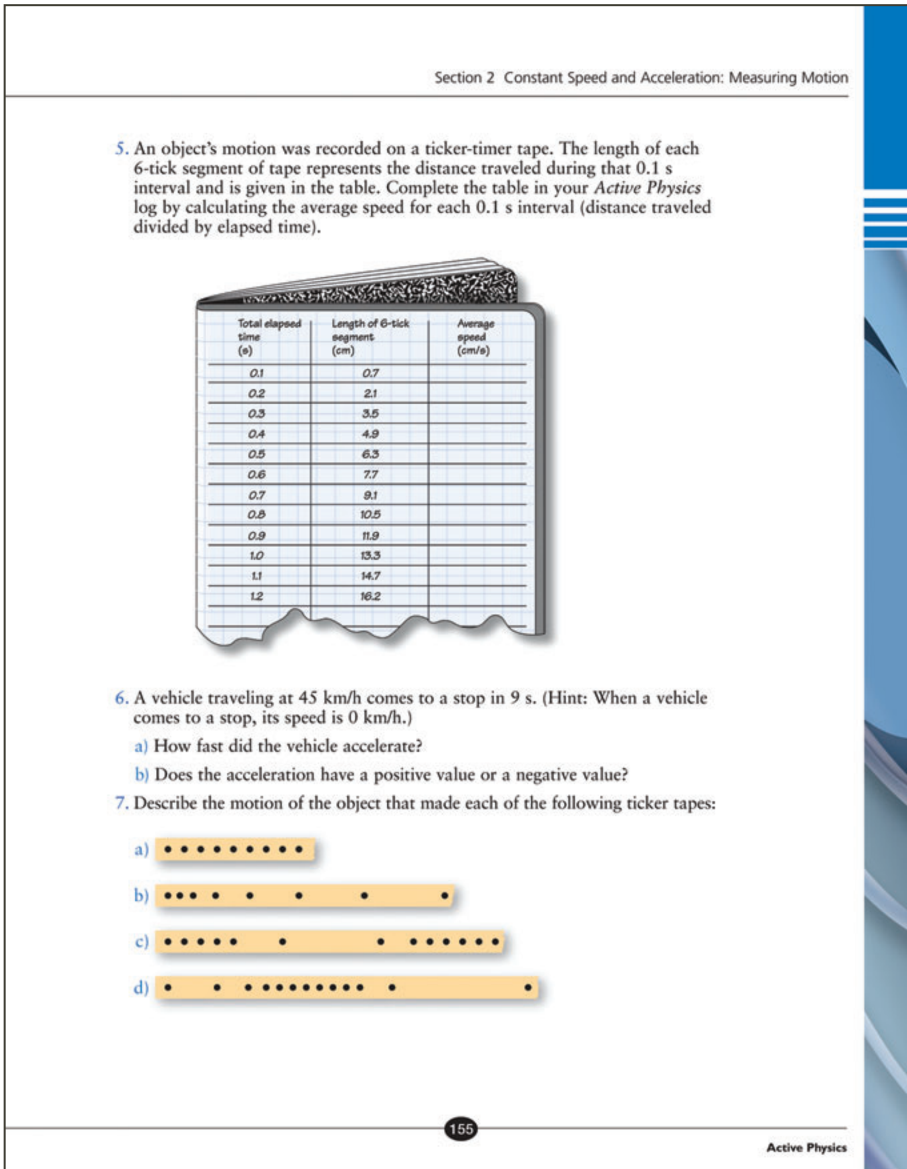
4.b)
Graph B

4.c)
Graph A

4.d)
Graph C

4.e)
Graph A: positive acceleration;
Graph B: zero acceleration;
Graph C: positive, then negative acceleration.

5.
The completed table should appear as follows on the next page:



5. An object's motion was recorded on a ticker-timer tape. The length of each 6-tick segment of tape represents the distance traveled during that 0.1 s interval and is given in the table. Complete the table in your *Active Physics* log by calculating the average speed for each 0.1 s interval (distance traveled divided by elapsed time).

Total elapsed time (s)	Length of 6-tick segment (cm)	Average speed (cm/s)
0.1	0.7	
0.2	2.1	
0.3	3.5	
0.4	4.9	
0.5	6.3	
0.6	7.7	
0.7	9.1	
0.8	10.5	
0.9	11.9	
1.0	13.3	
1.1	14.7	
1.2	16.2	

6. A vehicle traveling at 45 km/h comes to a stop in 9 s. (Hint: When a vehicle comes to a stop, its speed is 0 km/h.)
   a) How fast did the vehicle accelerate?
   b) Does the acceleration have a positive value or a negative value?
7. Describe the motion of the object that made each of the following ticker tapes:
   a)
   b)
   c)
   d)

6.a)

$$a = \frac{\Delta v}{\Delta t} = \frac{-45\ \text{km/h}}{9\ \text{s}} = -5\ \frac{\text{km/h}}{\text{s}}$$

6.b)

The acceleration has a negative acceleration because the speed is decreasing.

7.a)

Constant speed

7.b)

Positive acceleration

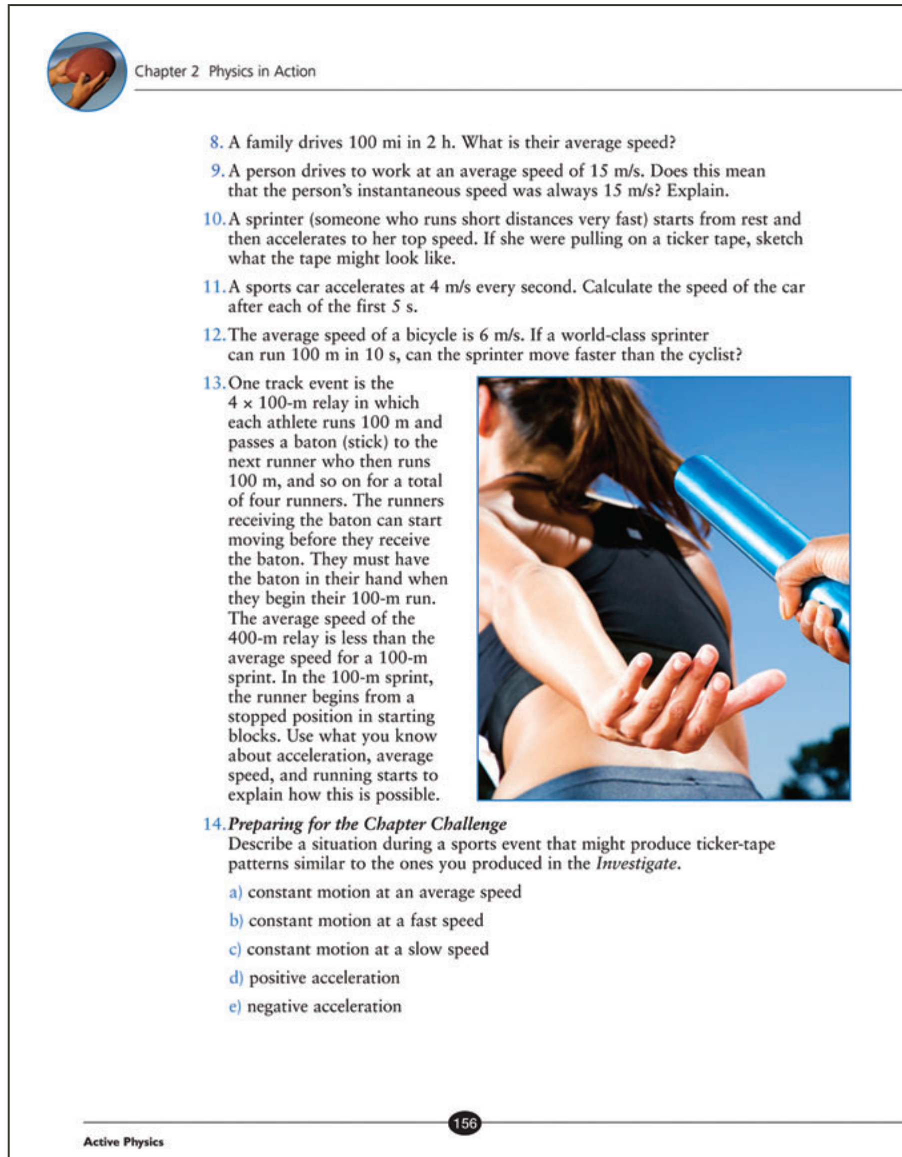
7.c)

Slow constant speed, increasing to faster constant speed, slowing down to slow constant speed

7.d)

Negative acceleration to constant speed to positive acceleration

Elapsed time (s)	Length of 6-tick segment (cm)	Average speed (cm/s)
0.1	0.7	7.0
0.2	2.1	21
0.3	3.5	35
0.4	4.9	49
0.5	6.3	63
0.6	7.7	77
0.7	9.1	91
0.8	10.5	105
0.9	11.9	119
1.0	13.3	133
1.1	14.7	147
1.2	16.2	162



8. A family drives 100 mi in 2 h. What is their average speed?

9. A person drives to work at an average speed of 15 m/s. Does this mean that the person's instantaneous speed was always 15 m/s? Explain.

10. A sprinter (someone who runs short distances very fast) starts from rest and then accelerates to her top speed. If she were pulling on a ticker tape, sketch what the tape might look like.

11. A sports car accelerates at 4 m/s every second. Calculate the speed of the car after each of the first 5 s.

12. The average speed of a bicycle is 6 m/s. If a world-class sprinter can run 100 m in 10 s, can the sprinter move faster than the cyclist?

13. One track event is the 4 × 100-m relay in which each athlete runs 100 m and passes a baton (stick) to the next runner who then runs 100 m, and so on for a total of four runners. The runners receiving the baton can start moving before they receive the baton. They must have the baton in their hand when they begin their 100-m run. The average speed of the 400-m relay is less than the average speed for a 100-m sprint. In the 100-m sprint, the runner begins from a stopped position in starting blocks. Use what you know about acceleration, average speed, and running starts to explain how this is possible.

14. *Preparing for the Chapter Challenge*
Describe a situation during a sports event that might produce ticker-tape patterns similar to the ones you produced in the *Investigate*.

a) constant motion at an average speed

b) constant motion at a fast speed

c) constant motion at a slow speed

d) positive acceleration

e) negative acceleration

8.

50 mi/h

9.

No, this is only the person's average speed, he or she may have gone faster or slower for much of the time, but must have gone 15 mph for at least one instant.

10.

4 m/s, 8 m/s, 12 m/s, 16 m/s, 20 m/s

Yes, a sprinter running 100 m in 10 s has an average speed of 10 m/s, while the bike is only 6 m/s. However, a sprinter can only run this fast for a short time, while the bicycle rider can travel at this speed for many hours.

13.

The runners in the 400-m relay do not have the advantage of being able to accelerate as quickly as the sprinter due to the starting blocks. In addition, the relay runners have to make certain that the baton is passed from runner to runner. Usually this requires the runners to slow down somewhat to insure that the baton is not dropped.

Preparing for the Chapter Challenge

14.a)

A long-distance or marathon runner would have constant average velocity, as would be an ice skater in a long race.

14.b)

A football player running for a touchdown or a soccer player racing downfield

14.c)

A race walker traveling at a constant low speed, or a basketball player "walking" the ball up the court

14.d)

A sprinter starting out, or a football player running forward immediately after the ball is snapped, would have positive acceleration.

14.e)

A diver entering the water, or a race-car driver at the end of the race, would have negative acceleration.

SECTION 2 QUIZ

2-2c Blackline Master

1. What is the average velocity of an automobile that travels a distance of 30 km in 0.5 h?

   a) 15 km/h   b) 45 km/h

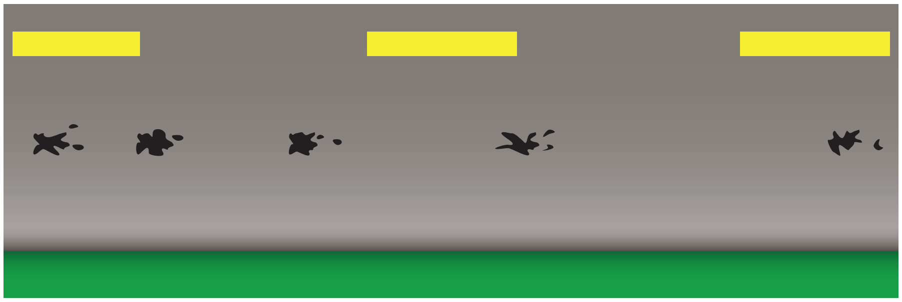
   c) 60 km/h   d) 75 km/h

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

   a) 1.9 s   b) 0.86 s

   c) 2.3 s   d) 0.43 s

3. An automobile that is dripping oil leaves a track on the road shown below. The automobile is moving from left to right. According to the oil drops on the pavement, the automobile was traveling



   a) with constant speed.   b) with positive acceleration.

   c) with negative acceleration.   d) with negative acceleration, then constant speed.

4. An automobile accelerates at 5 m/s^2. How much time is required for the automobile to reach a speed of 30 m/s?

   a) 0.17 s   b) 5 s

   c) 150 s   d) 6 s

5. A vehicle travels between the 100 m and 250 m highway markers in 10 s. During this time, the vehicle's average speed is

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

   c) 25 m/s.   d) 35 m/s.

SECTION 2 QUIZ ANSWERS

1. c) The average speed is given by $v_{average}$ = distance/time = 30 km/0.5 h = 60 km/h. All other answers would be due to mistakes in math.

2. d) The average speed is given by $v_{average}$ = distance/time. Since time is the unknown, we can solve for time as time = distance/$v_{average}$ = (18 m)/(42 m/s) = 0.43 s. Other answers would reflect misapplication of the formula.

3. b) The oil pattern shows the drops are moving successively farther apart indicating positive acceleration since the vehicle started from the left. Negative acceleration would show the drops getting closer together, and for constant velocity the drops would have been equally spaced.

4. d) Using the formula $a = \Delta v/\Delta t$ gives $5\ m/s^2 = (30 m/s)/t$. Solving for t gives $t = 6$ s. Other answers would reflect incorrect use of the formula.

5. b) The average speed is given by $v_{average}$ = distance/time. The distance traveled is the difference between 250 m and 100 m, which is equal to 150 m. If the students used any other distance from the question, they would have reached one of the incorrect answers.

NOTES

NOTES

CHAPTER 2