Section 11.1

1 FOCUS

Objectives
11.1.1 Identify frames of reference and describe how they are used to measure motion.
11.1.2 Identify appropriate SI units for measuring distances.
11.1.3 Distinguish between distance and displacement.
11.1.4 Calculate displacement using vector addition.

Reading Focus

Build Vocabulary

Vocabulary Knowledge Rating Chart
Before students read the section, have them rate their knowledge of the vocabulary terms for this section in a chart with the following headings: Term, Can Define or Use It, Have Heard or Seen It, Don’t Know. After they have read the section, have them return to the chart and update it to reflect any increase in understanding.

Reading Strategy
a. Answers may vary. Sample answer: Frame of reference may mean the range of distances or area that you are considering in a problem. b. Frame of reference is a system of objects that are not moving with respect to one another. Frames of reference are important because they are needed to accurately describe motion.

2 INSTRUCT

Choosing a Frame of Reference

Use Visuals

Figure 1 Discuss Figure 1 with students after they read the section Choosing a Frame of Reference. Ask, Describe the motion of the girl in the butterfly’s frame of reference. (She would appear to bob up and down, exactly opposite the motion of the butterfly as seen from the girl’s frame of reference.) Describe the motion of the butterfly in the butterfly’s frame of reference. (The butterfly is at rest in the butterfly’s frame of reference.) Which one is “really” moving, the butterfly or the girl? (It depends on the frame of reference.) Visual, Logical

On a spring day a butterfly flutters past. First it flies quickly, then slowly, and then it pauses to drink nectar from a flower. The butterfly’s path involves a great deal of motion. How fast is the butterfly moving? Is it flying toward the flower or away from it? These are the kinds of questions you must answer to describe the butterfly’s motion. To describe motion, you must state the direction the object is moving as well as how fast the object is moving. You must also tell its location at a certain time.

Choosing a Frame of Reference

How fast is the butterfly in Figure 1 moving? Remember that the butterfly is moving on Earth, but Earth itself is moving as it spins on its axis and revolves around the sun. If you consider this motion, the butterfly is moving very, very fast!

To describe motion accurately and completely, a frame of reference is necessary. The necessary ingredient of a description of motion—a frame of reference—is a system of objects that are not moving with respect to one another. The answer to “How fast is the butterfly moving?” depends on which frame of reference you use to measure motion. How do you decide which frame of reference to use when describing the butterfly’s movement?

Figure 1 You must choose a frame of reference to tell how fast the butterfly is moving.

Applying Concepts Identify a good frame of reference to use when describing the butterfly’s motion.

Reading Resources

Print
- Laboratory Manual, Investigation 11A
- Reading and Study Workbook With Math Support, Section 11.1
- Transparencies, Chapter Pretest and Section 11.1

Technology
- Interactive Textbook, Section 11.1
- Presentation Pro CD-ROM, Chapter Pretest and Section 11.1
- Go Online, NSTA SciLinks, Comparing frames of reference
How Fast Are You Moving? How fast are the train passengers in Figure 2 moving? There are many correct answers because their motion is relative. This means it depends on the frame of reference you choose to measure their motion. Relative motion is movement in relation to a frame of reference. For example, as the train moves past a platform, people standing on the platform will see those on the train speeding by. But when the people on the train look at one another, they don’t seem to be moving at all.

Which Frame Should You Choose? When you sit on a train and look out a window, a treetop may help you see how fast you are moving relative to the ground. But suppose you get up and walk toward the rear of the train. Looking at a seat or the floor may tell you how fast you are walking relative to the train. However, it doesn’t tell you how fast you are moving relative to the ground outside. Choosing a meaningful frame of reference allows you to describe motion in a clear and relevant manner.

Measuring Distance

Distance is the length of a path between two points. When an object moves in a straight line, the distance is the length of the line connecting the object’s starting point and its ending point.

It is helpful to express distances in units that are best suited to the motion you are studying. The SI unit for measuring distance is the meter (m). For very large distances, it is more common to make measurements in kilometers (km). One kilometer equals 1000 meters. For instance, it’s easier to say that the Mississippi River has a length of 3780 kilometers than 3,780,000 meters. Distances that are smaller than a meter are measured in centimeters (cm). One centimeter is one hundredth of a meter. You might describe the distance a marble rolls, for example, as 6 centimeters rather than 0.06 meter.

Figure 2 To someone riding on a speeding train, others on the train don’t seem to be moving.
Distance is the length of the displacement.

Evaluating and Revising

1. **Observing** Which is shorter, the distance or the displacement?
2. **Evaluating and Revising** How could you have made the distance shorter?
3. **Inferring** If you keep the Start and End points the same, is it possible to make the displacement shorter? Explain your answer.

### Comparing Distance and Displacement

**Objective**

After completing this activity, students will be able to

- distinguish between distance and displacement.

### Address Misconceptions

This activity helps address the misconception that the distance an object travels and its displacement are the same. Challenge this misconception by discussing the answers to the Analyze and Conclude questions.

### Skills Focus Measuring

**Materials** graph paper, metric ruler  
**Class Time** 15 minutes

**Teaching Tips**

- Make sure that students read the metric side of the ruler if their rulers have both metric and English units.

**Expected Outcome** Students will be able to distinguish between distance, the length traveled between two points, and displacement, the length of the line between two points.

**Analyze and Conclude**

1. Displacement is always shorter than or equal to the distance because it is a straight line between two points, not always the actual path of motion.
2. The distance would be shorter if the path were more direct. The shortest path would be a diagonal line connecting Start and End, and it would be the same length as the displacement.
3. No, the displacement could not be shorter because it will always be the straight-line distance between the Start and End points.

**Visual, Logical**

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### Measuring Displacements

To describe an object’s position relative to a given point, you need to know how far away and in what direction the object is from that point. Displacement provides this information. 

**Distance** is the length of the path between two points. Displacement is the direction from the starting point and the length of a straight line from the starting point to the ending point.

Displacements are sometimes used when giving directions. Telling someone to “Walk 5 blocks” does not ensure they’ll end up in the right place. However, saying “Walk 5 blocks north from the bus stop” will get the person to the right place. Accurate directions give the direction from a starting point as well as the distance.

Think about the motion of a roller coaster car. If you measure the path along which the car has traveled, you are describing distance. The direction from the starting point to the car and the length of the straight line from the starting point to the car describe displacement. After completing one trip around the track, the roller coaster car’s displacement is zero.

### Combining Displacements

Displacement is an example of a vector. A **vector** is a quantity that has magnitude and direction. The magnitude can be size, length, or amount. Arrows on a graph or map are used to represent vectors. The length of the arrow shows the magnitude of the vector. **Vector addition** is the combining of vector magnitudes and directions.

**Add displacements using vector addition.**

#### Displacement Along a Straight Line

When two displacements, represented by two vectors, have the same direction, you can add their magnitudes. In Figure 3A, the magnitudes of the car’s displacements are 4 kilometers and 2 kilometers. The total magnitude of the displacement is 6 kilometers. If two displacements are in opposite directions, the magnitudes subtract from each other, as shown in Figure 3B. Because the car’s displacements (4 kilometers and 2 kilometers) are in opposite directions, the magnitude of the total displacement is 2 kilometers.
Displacement That Isn’t Along a Straight Path

When two or more displacement vectors have different directions, they may be combined by graphing. Figure 4 shows vectors representing the movement of a boy walking from his home to school. He starts by walking 1 block east. Then he turns a corner and walks 1 block north. He turns once again and walks 2 blocks east. For the last part of his trip to school, he walks 3 blocks north. The lengths of the vectors representing this path are 1 block, 1 block, 2 blocks, and 3 blocks.

The boy walked a total distance of 7 blocks. You can determine this distance by adding the magnitudes of each vector along his path. The vector in red is called the resultant vector, which is the vector sum of two or more vectors. In this case, it shows the displacement. The resultant vector points directly from the starting point to the ending point. If you place a sheet of paper on the figure and mark the length of the resultant vector, you see that it equals the length of 5 blocks. Vector addition, then, shows that the boy’s displacement is 5 blocks approximately northeast, while the distance he walked is 7 blocks.

Figure 4 Measuring the resultant vector (the diagonal red line) shows that the displacement from the boy’s home to his school is two blocks less than the distance he actually traveled.

Build Science Skills

Measuring Have students use a map of the city or area to measure the straight-line distance from their homes to the school. They will have to use the scale information on the map to convert from distances on the map to actual distances. Then, have them determine the distances they travel from their home to school by observing the odometer of a car or bus. To get the distances traveled, they should subtract the odometer readings at their start points from the odometer readings when they arrive at the school. Have them compare the distances. In almost every case, the distance traveled should be greater than the straight-line distance on the map. Logical

Assess

Evaluate Understanding

Ask students to write a paragraph describing a situation in which the same motion appears differently from different frames of reference.

Reteach

Use Figure 4 to reteach the difference between displacement and distance traveled.

Writing in Science

Students’ paragraphs should generally describe distances and directions they travel on the way to school. They should understand that displacement is determined by a straight-line distance from home to school. The total distance they travel will almost always be greater than the magnitude of the displacement, unless they travel in a single direction the whole time.

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 11.1.

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Section 11.1 Assessment

Reviewing Concepts

1. What is a frame of reference? How is it used to measure motion?
2. How are distance and displacement similar and different?
3. How are displacements combined?
4. A girl who is watching a plane fly tells her friend that the plane isn’t moving at all. Describe a frame of reference in which the girl’s description would be true.

Critical Thinking

5. Using Analogies Is displacement more like the length of a rope that is pulled tight or the length of a coiled rope? Explain.

7. Problem Solving Should your directions to a friend for traveling from one city to another include displacements or distances? Explain.
8. Inferring The resultant vector of two particular displacement vectors does not equal the sum of the magnitudes of the individual vectors. Describe the directions of the two vectors.

Compare-Contrast Paragraph Write a paragraph describing how the distance you travel from home to school is different from your displacement from home to school. (Hint: Make a simple sketch similar to Figure 4 and refer to it as you write.)

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1. A frame of reference is a set of objects that are not moving with respect to one another. Motion can only be described in comparison to a frame of reference.
2. Distance is the length of an object’s actual path from a starting point to an ending point. Displacement is the length of a straight line from the starting point to the ending point.
3. Displacements are combined using vector addition.
4. If the plane is far away and flying directly toward or away from the girl, the plane would appear not to be moving. Also, the plane would not be moving in the frame of reference of the people on the plane.
5. Displacement is more like the length of a rope that is pulled tight; it measures the shortest distance between two points.
6. It makes sense to measure the height of a building in meters. Kilometers are too large and centimeters are too small.
7. You should use displacements. Displacements tell your friend how far and which direction to go. Distances will only tell how far to go.
8. The vectors are at an angle to each other.
11.2 Speed and Velocity

**Focus**

**Objectives**

11.2.1 Identify appropriate SI units for measuring speed.
11.2.2 Compare and contrast average speed and instantaneous speed.
11.2.3 Interpret distance-time graphs.
11.2.4 Calculate the speed of an object using slopes.
11.2.5 Describe how velocities combine.

**Reading Focus**

**Build Vocabulary**

**Venn Diagram** Have students draw a Venn diagram to show how the key terms of the section are related to each other. Student diagrams should show circles labeled Speed and Direction. The area in which the circles overlap should be labeled Velocity.

**Reading Strategy**

Answers may vary. Sample answers are shown below.

a. Average speed is distance divided by time. b. I could use this to calculate various speeds, like the average speed at which I travel getting to school. c. Instantaneous speed is different from average speed. d. You can’t use a single speedometer reading to determine how long a trip will take. e. Velocity is not the same as speed. f. This could be useful in giving directions or in describing the path that you take on a walk.

**Instruct**

**Speed**

**Build Science Skills**

**Forming Operational Definitions** An operational definition limits the meaning of a term to what is observed or measured in a particular situation. Ask, What is an operational definition of speed for a skater on a circular track? (Sample answer: The amount of time it takes to circle the track one time, the number of times the skater could circle the track one time) What is an operational definition for a person walking down a street? (Sample answer: The number of meters traveled each second) Verbal, Logical

**Section Resources**

**Print**

- Interactive Textbook, Section 11.2
- Presentation Pro CD-ROM, Section 11.2
- Go Online, NSTA SciLinks, Motion; PHSchool.com, Data sharing

**Technology**

- Laboratory Manual, Investigation 11B
- Reading and Study Workbook With Math Support, Section 11.2 and Math Skill: Interpreting a Distance-Time Graph
- Math Skills and Problem Solving Workbook, Section 11.2
- Transparencies, Section 11.2

Look out a window for a few minutes, and you will see things in motion. Some things are moving slowly. Perhaps you see a leaf floating through the air. Other things, such as a car or a bird, are moving fast. The growth rate of trees and grass is so slow that their motion cannot be detected with the unaided eye. The differences among these types of motion can be described in terms of speed.

**Speed**

To describe the speed of a car, you might say it is moving at 45 kilometers per hour. **Speed** is the ratio of the distance an object moves to the amount of time the object moves. The SI unit of speed is meters per second (m/s). However, just as with distances, you need to choose units that make the most sense for the motion you are describing. The in-line skater in Figure 5 may travel 2 meters in one second. The speed would be expressed as 2 m/s. A car might travel 80 kilometers in one hour. Its speed would be expressed as 80 km/h.

Two ways to express the speed of an object are average speed and instantaneous speed. **Average speed** is computed for the entire duration of a trip, and instantaneous speed is measured at a particular instant. In different situations, either one or both of these measurements may be a useful way to describe speed.
Average Speed  Describing the speed of a hiker isn’t as easy as describing constant speed along a straight line. A hiker may travel slowly along rocky areas but then travel quickly when going downhill. Sometimes it is useful to know how fast something moves for an entire trip.  

**Average speed** \( \bar{v} \) is the total distance traveled, \( d \), divided by the time, \( t \), it takes to travel that distance. This can be written as an equation:

\[
\text{Average speed} = \frac{\text{Total distance}}{\text{Total time}}, \text{ or } \bar{v} = \frac{d}{t}
\]

During the time an object is moving, its speed may change, but this equation tells you the average speed over the entire trip.

### Math Skills

**Calculating Average Speed**

While traveling on vacation, you measure the times and distances traveled. You travel 3.5 kilometers in 0.4 hour, followed by 53 kilometers in 0.6 hour. What is your average speed?

1. **Read and Understand**
   - What information are you given?
     - Total Distance \( d = 35 \text{ km} + 53 \text{ km} = 88 \text{ km} \)
     - Total Time \( t = 0.4 \text{ h} + 0.6 \text{ h} = 1.0 \text{ h} \)

2. **Plan and Solve**
   - What unknown are you trying to calculate?
     - Average Speed \( \bar{v} = ? \)
   - What formula contains the given quantities and the unknown?
     - \( \bar{v} = \frac{d}{t} \)
   - Replace each variable with its known value.
     - \( \bar{v} = \frac{88 \text{ km}}{1 \text{ h}} = 88 \text{ km/h} \)

3. **Look Back and Check**
   - Is your answer reasonable?
     - Yes, 88 km/h is a typical highway speed.

### Math Practice

1. A person jogs 4.0 kilometers in 32 minutes, then 2.0 kilometers in 22 minutes, and finally 1.0 kilometer in 16 minutes. What is the jogger’s average speed in kilometers per minute?
2. A train travels 190 kilometers in 3.0 hours, and then 120 kilometers in 2.0 hours. What is its average speed?

### Additional Problems

1. A car travels 85 km from Town A to Town B, then 45 km from Town B to Town C. The total trip took 1.5 hours. What was the average speed of the car? (87 km/h)
2. A bicyclist travels for 1.5 hours at an average speed of 32 km/h. How far does the bicyclist travel in that time? (48 km)

### Use Community Resources

Have students contact their local or state department of transportation to find out about laws or guidelines for the assignment of speed limits. They may ask, “Are there specific maximum speed limits for residential areas?” or “What is the maximum speed limit for highways outside of city limits?” They may also ask the department representative what other factors are used in determining speed limits.

**Interpersonal, Portfolio**

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**Customize for English Language Learners**

**Create a Word Wall**

Students can relate the concepts in this section to the vocabulary words by creating a word wall. Write the words speed, average speed, instantaneous speed, and velocity on the board. Then, as students work through the section, ask them to define each word in their own terms. Discuss their definitions and write acceptable definitions on the board next to each word. Students may also draw a graph or paste a magazine picture next to the corresponding word.

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**Go Online**

For: Links on motion
Visit: www.SciLinks.org
Web Code: ccc-2112

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**Solutions**

1. \( \bar{v} = \frac{4.0 \text{ km} + 2.0 \text{ km} + 1.0 \text{ km}}{(32 \text{ min} + 22 \text{ min} + 16 \text{ min})} = \frac{(7.0 \text{ km})}{(70 \text{ min})} = 0.10 \text{ km/min} \)
2. \( \bar{v} = \frac{190 \text{ km} + 120 \text{ km}}{(3.0 \text{ h} + 2.0 \text{ h})} = \frac{(310 \text{ km})}{5.0 \text{ h}} = 62 \text{ km/h} \)

**Logical**

**For Extra Help**

Remind students that all the values they plug into the equation must have appropriate units. They may have to convert some of the given units. Also remind students that the equation can be rearranged to solve for other variables. Show them how to rearrange to solve for \( d \) or \( t \). Logical

Direct students to the Math Skills in the Skills and Reference Handbook at the end of the student text for additional help.

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**Go Online**

For: Activity on the movement of Earth’s plates
Visit: PHSchool.com
Web Code: ccc-2112

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Instantaneous Speed  Average speed is useful because it lets you know how long a trip will take. Sometimes however, such as when driving on the highway, you need to know how fast you are going at a particular moment. The car’s speedometer gives your instantaneous speed. Instantaneous speed, \( v \), is the rate at which an object is moving at a given moment in time. For example, you could describe the instantaneous speed of the car in Figure 6 as 55 km/h.

What does a car’s speedometer measure?

Graphing Motion

A distance-time graph is a good way to describe motion. Figure 7 shows distance-time graphs for the motion of three cars. Recall that slope is the change in the vertical axis value divided by the change in the horizontal axis value. On these graphs, the slope is the change in the distance divided by the change in time.

The fastest speed a line on a distance-time graph is speed. In Figure 7A, the car travels 500.0 meters in 20.0 seconds, or 25.0 meters per second. In Figure 7B, another car travels 250.0 meters in 20.0 seconds at a constant speed. The slope of the line is 250.0 meters divided by 20.0 seconds, or 12.5 meters per second. Notice that the line for the car traveling at a higher speed is steeper. A steeper slope on a distance-time graph indicates a higher speed.

Figure 7C shows the motion of a car that is not traveling at a constant speed. This car travels 200.0 meters in the first 8.0 seconds. Then it stops for 4.0 seconds, as indicated by the horizontal part of the line. Next the car travels 300.0 meters in 8.0 seconds. The times when the car is gradually increasing or decreasing its speed are shown by the curved parts of the line. The slope of the straight portions of the line represent periods of constant speed. Note that the car’s speed is 25 meters per second during the first part of its trip and 38 meters per second during the last part of its trip.
Interpreting Diagrams  What is the purpose of the worm gears?

Coil spring  This spring holds the pointer at zero when the car and the magnet are at rest.

Pointer  The pointer is attached to the drag cup. The faster the magnet spins, the greater the angle the drag cup turns. The higher speed is shown by the pointer.

Measurement  For each full turn of the worm gear the odometer moves up one digit, indicating that the car has traveled one tenth of a mile.

Worm gears  The worm gears reduce the cable’s rotational speed and move the odometer dials.

Drum  The drum turns from its resting position through an angle that increases with the magnet’s spin rate.

Magnet  The magnet is attached to the shaft. As the shaft spins the magnet, a magnetic field exerts force on the drag cup.

Digital Odometer  Some cars have a magnetic sensor that detects turns of the transmission shaft. The signal is transmitted to a computer, which calculates and displays the car’s distance traveled.

Cable  A cable linked to the transmission rotates at a rate directly proportional to the road speed.

Worm gears convert the rotation of the cable into a much slower rotation that turns the odometer. The worm gears also change the direction of rotation so the shafts can be positioned to align with the odometer.

For Enrichment

Have students use a library or the Internet to research how speeds are measured on ships, airplanes, or spacecraft. Have them write a paragraph explaining their findings.

Verbal, Portfolio

Answer to . . .

Figure 7  The slope of the line would increase.

Instantaneous speed
To determine how long it will be before the cheetah reaches the antelope, you need to know the cheetah's velocity, not just its speed. The speed and direction in which an object is moving are called velocity. To determine how long it will be before the cheetah reaches the antelope, you need to know the cheetah's velocity, not just its speed. **Velocity** is a description of both speed and direction of motion. Velocity is a vector.

Figure 8 shows a cheetah in motion. If you have ever seen a video of a cheetah chasing its prey, you know that a cheetah can change speed and direction very quickly. To represent the cheetah's motion, you could use velocity vectors. You would need vectors of varying lengths, each vector corresponding to the cheetah's velocity at a particular instant. A longer vector would represent a faster speed, and a shorter one would show a slower speed. The vectors would also point in different directions to represent the cheetah's direction at any moment.

A change in velocity can be the result of a change in speed, a change in direction, or both. The sailboat in Figure 9 moves in a straight line (constant direction) at a constant speed. The sailboat can be described as moving with uniform motion, which is another way of saying it has constant velocity. The sailboat may change its velocity simply by speeding up or slowing down. However, the sailboat's velocity also changes if it changes its direction. It may continue to move at a constant speed, but the change of direction is a change in velocity.

**Velocity**

The cheetah is the fastest land animal in the world. Suppose a cheetah, running at 90 kilometers per hour, is 30 meters from an antelope that is standing still. How long will it be before the cheetah reaches the antelope? Do you have enough information to answer the question? The answer is no. Sometimes knowing only the speed of an object isn't enough. You also need to know the direction of the object's motion. Together, the speed and direction in which an object is moving are called velocity. To determine how long it will be before the cheetah reaches the antelope, you need to know the cheetah's velocity, not just its speed. **Velocity** is a description of both speed and direction of motion. Velocity is a vector.

Students may think that an object's speed and its velocity are the same thing. On the board, draw a picture of an oval racetrack. Have students imagine a racecar traveling at a constant speed of 120 km/h around the track. Point to a place on the track where the car would be moving to the right. Ask students, What is the speed of the racecar at this point? (120 km/h) In what direction is the racecar traveling at this point? (To the right) What is the velocity of the racecar at this point? (120 km/h to the right) Now point to a point on the track where the car would be moving to the left. Ask students, What is the speed of the racecar at this point? (120 km/h) In what direction is the racecar traveling at this point? (To the left) What is the velocity of the racecar at this point? (120 km/h to the left) The speeds are the same at each point, but the velocities are different because the racecar is traveling in different directions. **Verbal, Visual**

**Address Misconceptions**

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**Address Misconceptions**

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Combining Velocities

Sometimes the motion of an object involves more than one velocity.

Two or more velocities add by vector addition. The velocity of the river relative to the riverbank (X) and the velocity of the boat relative to the river (Y) in Figure 10A combine. They yield the velocity of the boat relative to the riverbank (Z). This velocity is 17 kilometers per hour downstream.

In Figure 10B, the relative velocities of the current (X) and the boat (Y) are at right angles to each other. Adding these velocity vectors yields a resultant velocity of the boat relative to the riverbank of 13 km/h (Z).

Note that this velocity is at an angle to the riverbank.

Section 11.2 Assessment

Reviewing Concepts
1. What does velocity describe?
2. What shows the speed on a distance-time graph?
3. What is the difference between average speed and instantaneous speed?
4. How can two or more velocities be combined?

Critical Thinking
5. Applying Concepts Does a car’s speedometer show instantaneous speed, average speed, or velocity? Explain.
6. Designing Experiments Describe an experiment you could perform to determine the average speed of a toy car rolling down an incline.

7. Applying Concepts Explain why the slope on a distance-time graph is speed. (Hint: Use the definition of speed on page 332 and the graphs in Figure 7.)

8. An Olympic swimmer swims 50.0 meters in 23.1 seconds. What is his average speed?
9. A plane’s average speed between two cities is 600 km/h. If the trip takes 2.5 hours, how far does the plane fly? (Hint: Use the average speed formula in the form d = rt.)

Combining Velocities

Use Visuals

Figure 10 Vector addition is used when motion involves more than one velocity. The velocity of the boat in the reference frame of the riverbank (17 km/h) is a combination of the relative velocities of the boat and the river. B You can determine the resultant velocity of the boat relative to the riverbank (13 km/h) by measuring from the tail of one vector to the head of the other.

Motion 337
Navigation at Sea

Background

Before the invention of the compass, the most reliable source of information for navigators was the stars. Celestial navigation was useful not only at sea, but also in open deserts where there were few landmarks. The simplest examples of celestial navigation are the sighting of north using Polaris, the pole star, and crude approximations of east and west using sunrise and sunset. Early navigators at sea also often simply followed coastlines or tracked well-known ocean currents to keep from losing their way. The Polynesians were masters of navigation in the open sea, traveling long distances to pinpoint tiny islands in the South Pacific. The Polynesians are believed to have used the migratory paths of birds and the directions of waves as navigational clues.

For centuries, crossing the oceans was extremely perilous. There are few landmarks at sea to guide the sailor, and methods of measuring direction, speed, and distance were crude and often inaccurate.

The invention of the magnetic compass brought major advancement in navigation in the early 1100s. Although the compass allowed a sailor to maintain an accurate course, it did nothing to tell him where he actually was. For this, a frame of reference was needed, and the one adopted was the system of latitude and longitude. This system measures location in degrees north or south of the equator, and degrees east or west of Greenwich, England. Using a device called a sextant, latitude in the northern hemisphere was relatively easy to determine. Finding longitude was more difficult. The solution was to combine celestial observation and the use of a highly accurate sea-going clock that kept track of the time at a fixed location on Earth.

**Sextant**

This instrument was once an essential aid to navigation. With it, a sailor could accurately measure the angles of celestial bodies above the horizon. To take a reading, the observer looks through the telescope and moves the sextant's arm until an image of a star or the sun lines up with the horizon. The angle is then read off the scale.
Finding location

Regular calculations of latitude and longitude have been the cornerstone of ocean navigation for about 300 years. A sextant and an accurate sea-going clock were needed to calculate both.

Determining latitude
To determine latitude is to find out how far north or south you are from the equator. In the northern hemisphere, latitude is measured with reference to Polaris. Using a sextant, you measure the angle of Polaris above the horizon, and this gives you your latitude, expressed in degrees. If Polaris is directly overhead, you must be at the North Pole (90° north latitude); if it is on the horizon, you must be at the equator (0°).

Determining longitude
To determine longitude is to find out how far east or west you are from Greenwich, England. To do this, while you are still in your home port, you set your sea-going clock for noon when the sun is at its highest point. Then, while you are at sea, you check the clock again when the sun is at its highest point. If the clock says 3 P.M., then you must have traveled 3 hours west of the port. Since the sun moves 15° per hour, 3 hours corresponds to 45° west.

Build Science Skills

Observing Have students go out on a clear night and locate Polaris, the pole star. Students may do this on their own, or you may have a class field trip. If you go as a group, also take a few pairs of binoculars and a telescope, if available. With a basic pair of binoculars, students can see many more stars, as well as many interesting celestial sights such as star clusters, the moons of Jupiter, and craters on Earth’s moon. Teach students how to use the two stars at the end of the Big Dipper to locate Polaris. Then, follow the line from these two stars “up” away from the dipper (in the direction of the opening in the dipper; the actual direction will depend on the position of the dipper). The first bright star in the line is Polaris.

Have students use a protractor and a ruler or other straight object to estimate Polaris’ angle of elevation above the horizon. This angle should be equal to the latitude at which you are observing. Have students compare their estimates to the actual latitude.

Visual, Group, Portfolio
**Build Science Skills**

**Measuring**

**Purpose** After doing this activity, students will be able to use a handheld GPS receiver to find coordinates, mark waypoints, and navigate to a location.

**Materials** handheld GPS receivers, 1 per group

**Advance Prep** Clear data from all the GPS receivers. Set all receivers so they are using the same units for coordinates. If you are unfamiliar with operating a GPS receiver, review the manual and practice marking a few waypoints (waypoints are locations that you store in the memory of a GPS unit). Find several locations on the school grounds and write down the GPS coordinates for those locations (students will return to those locations in the activity).

**Class Time** 30 minutes

**Procedure**

1. Start by showing the class the basics of operating the GPS receiver. You may do this outdoors, or if you are in the classroom, put the receiver in simulator mode. Show students how to tell how strong the signals are, how to read the coordinates of their location, and how to mark a waypoint.
2. Start all groups at a single point. Have them acquire the coordinates at that location and mark a waypoint. Assign each group a different location and give them the coordinates (but do not tell them where the location is). Then, have them use the receivers to find their assigned locations. You may have them use the navigation feature of the receiver to find the location, or they may just use the coordinates. Have them mark a waypoint when they reach the location.
3. After they have found their location, have the group return and describe the location to you. Verify that it is close to the location that you intended. Check each group’s receiver to see if their marked waypoints have the correct coordinates.

**Modern navigation**

Today’s sea navigators are fortunate by comparison with their predecessors. Instead of having to make complex calculations involving times and sextant angles, they can buy a global positioning system receiver. This modern receiver not only provides quick and accurate readings of latitude and longitude, but it also displays the ship’s position on a digital chart.

**Global Positioning System (GPS)**

A GPS receiver calculates its distance from a minimum of three satellites by analysing the different travel times of their signals. The distance from each satellite gives a range of possibilities for the receiver’s location. To find its exact position, a microchip in the on-board receiver calculates where the signals intersect.

**GPS satellite** Each satellite emits precisely timed radio signals.

**GPS receiver** On-board

**Master control** Located in Colorado, the master control communicates with all the satellites.

**Satellite network** The global network consists of 24 satellites in six different circular orbits around Earth.

**Range of positions** Each satellite transmits a range of possible positions for the ship (shown here by colored circles).
GPS receiver
Today, receivers are made in a range of sizes down to handheld models. They usually give a position accurate to 100 meters, but enhanced units are accurate within 10 meters.

Nautical dividers
Dividers are used for making chart measurements.

Using radar
A radar set displays nearby land, boats, and other surface objects. It is useful for both navigation and collision avoidance, especially in foggy conditions.

Expected Outcome
Students may have trouble finding the locations at first. The GPS receivers may have varying degrees of accuracy, depending on the receiver and the outside conditions. Also, students may be confused if the axes of the coordinates do not align with the boundaries of the area. However, students should get used to operating the receiver and following the coordinates. Note that due to inaccuracies in GPS data and to differences in individual receivers, the locations that students find might not align perfectly with the locations that you found initially.

Kinesthetic, Group, Logical

Going Further
Students’ paragraphs should describe how early navigators measured the speed of a ship by throwing a log or wooden panel overboard. The log or panel was tied with a rope that had knots tied at regular intervals. The speed of the ship (relative to the water) could be measured by counting the number of knots that passed over the edge of the ship in a certain time interval. Knots are still used as units of speed in navigation, although they are measured with more precise instruments. 1 knot = 1 nautical mile per hour = 6076 feet per hour = 1.15 mph.

Verbal

Discovery School

Video Field Trip
Charting New Ground

After students have viewed the Video Field Trip, ask them the following questions: What was the shape of Earth according to the ancient Greeks? What Earth dimension did they calculate using this shape? (They knew Earth was a sphere, and calculated its circumference.) What does latitude measure? Longitude? (Latitude measures how far north or south a location is. Longitude measures how far east or west a location is.) What did navigators notice about how high the sun rose at noon in northern regions? How could this be used to determine the position of their ships? (Navigators noticed that in northern regions the sun remained low in the sky even in the middle of the summer. The height of the sun at noon told navigators how far north they were. Some students may note that when the sun is low in the sky at noon in the Southern Hemisphere, this would indicate how far south you are.) How did navigators know how far west they were from their homeport in the 1700s? (The ship’s clock would be set at the same time as the clock in the navigator’s homeport. As the ship traveled west, the sun was lower in the sky when the clock read noon.) List two modern technologies that are now used in making maps. (Student answers may include aerial photography, satellites, and computers.)
11.3 Acceleration

Key Concepts
- How are changes in velocity described?
- How can you calculate acceleration?
- How does a speed-time graph indicate acceleration?
- What is instantaneous acceleration?

Vocabulary
- acceleration
- free fall
- constant acceleration
- linear graph
- nonlinear graph

Reading Strategy
Summarizing: Read the section on acceleration. Then copy and complete the concept map below to organize what you know about acceleration.

A basketball constantly changes velocity during a game. The player in Figure 11 dribbles the ball down the court, and the ball speeds up as it falls and slows down as it rises. As she passes the ball, it flies through the air and suddenly stops when a teammate catches it. The velocity of the ball increases again as it is thrown toward the basket.

But the rate at which velocity changes is also important. Imagine a basketball player running down the court and slowly coming to a stop. Now imagine the player running down the court and stopping suddenly. If the player stops slowly, his or her velocity changes slowly. If the player stops suddenly, his or her velocity changes quickly. The ball handler’s teammates must position themselves to assist the drive or to take a pass. Opposing team members want to prevent the ball handler from reaching the basket. Each player must anticipate the ball handler’s motion.

A basketball constantly changes velocity as it rises and falls.

Reading Focus

1. Identify changes in motion that produce acceleration.
2. Describe examples of constant acceleration.
3. Calculate the acceleration of an object.
4. Interpret speed-time and distance-time graphs.
5. Classify acceleration as positive or negative.
6. Describe instantaneous acceleration.

Build Vocabulary

Word Forms: Point out other forms of the terms or parts of the terms. For example, in this section explain that linear contains the word line and means, “in a straight line,” or more generally, “having to do with lines.” Then have students predict what nonlinear might mean. (It means not in a straight line or having to do with lines that are not straight.)

Reading Strategy:
- Speed (or direction)
- Direction (or speed)
- $\text{m/s}^2$

What Is Acceleration?

Use Visuals

Figure 11 Use the example of a bouncing basketball to introduce acceleration. Ask, As the ball falls from the girl’s hand, how does its speed change? (Its speed increases.) What happens to the speed of the ball as the ball rises from the ground back to her hand? (The speed decreases.) At what points does the ball have zero velocity? (When it touches the girl’s hand and when it touches the floor) How does the velocity of the ball change when it bounces on the floor? (The speed quickly drops to zero, then quickly increases again. The ball also changes direction.)

Visual, Logical

Section Resources

Print
- Reading and Study Workbook With Math Support, Section 11.3
- Math Skills and Problem Solving Workbook, Section 11.3
- Transparencies, Section 11.3

Technology
- Interactive Textbook, Section 11.3
- Presentation Pro CD-ROM, Section 11.3
- Go Online, NSTA SciLinks, Acceleration
**Changes in Speed** We often use the word acceleration to describe situations in which the speed of an object is increasing. A television newscaster describing the liftoff of a rocket-launched space shuttle, for example, might exclaim, "That shuttle is really accelerating!" We understand that the newscaster is describing the spacecraft’s quickly increasing speed as it clears its launch pad and rises through the atmosphere. Scientifically, however, acceleration applies to any change in an object’s velocity. This change may be either an increase or a decrease in speed. Acceleration can be caused by positive (increasing) change in speed or by negative (decreasing) change in speed.

For example, suppose that you are sitting on a bus waiting at a stoplight. The light turns green and the bus moves forward. You feel the acceleration as you are pushed back against your seat. The acceleration is the result of an increase in the speed of the bus. As the bus moves down the street at a constant speed, its acceleration is zero. You no longer feel pushed toward your seat. When the bus approaches another stoplight, it begins to slow down. Again, its speed is changing, so the bus is accelerating. You feel pulled away from your seat. Acceleration results from increases or decreases in speed. As the bus slows to a stop, it experiences negative acceleration, also known as deceleration. Deceleration is an acceleration that slows an object’s speed.

An example of acceleration due to change in speed is free fall, the movement of an object toward Earth solely because of gravity. Recall that the unit for velocity is meters per second. The unit for acceleration, then, is meters per second per second. This unit is typically written as meters per second squared (m/s²). Objects falling near Earth’s surface accelerate downward at a rate of 9.8 m/s². Each second an object is in free fall, its velocity increases downward by 9.8 meters per second. Imagine the stone in Figure 12 falling from the mouth of the well. After 1 second, the stone will be falling at about 9.8 m/s. After 2 seconds, the stone will be going faster by 9.8 m/s. Its speed will now be downward at 19.6 m/s. The change in the stone’s speed is 9.8 m/s², the acceleration due to gravity.

![Figure 12](image.png)

**Figure 12** The velocity of an object in free fall increases 9.8 m/s each second.

**Build Reading Literacy**

**Outline** Refer to page 156D in Chapter 6, which provides the guidelines for an outline.

Have students create an outline of Section 11.3 (pp. 342–348). Outlines should follow the head structure used in the section. Major headings are shown in green, and subheadings are shown in blue. Ask students, **Based on your outline, what are two types of changes associated with acceleration? (Changes in speed and changes in direction)** Name two types of graphs that can be used to represent acceleration. **(Speed-time graphs and distance-time graphs)**

**Verbal, Logical**

**Address Misconceptions**

Students may think that if an object is accelerating then the object is speeding up. Explain to students that this is true in common, everyday usage. But in scientific terms, acceleration refers to any change in velocity. Velocity is a vector including both speed and direction, so acceleration can be speeding up, slowing down, or even just changing direction.

**Verbal**

**Use Visu als**

**Figure 12** Have students examine Figure 12. Ask, **How much time passes between each image of the falling rock? (1 s)** How does the distance traveled change between successive time intervals? **(The distance traveled increases.)** How does the average speed change between successive time intervals? **(The average speed increases.)**

**Visual, Logical**

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**Customize for Inclusion Students**

**Visually Impaired**

Students who are visually impaired may grasp the concept of acceleration by considering the following scenario. When traveling in a closed car with your eyes closed, it is hard to tell how far you have traveled or how fast you are going. But you can feel accelerations. Ask, **How do you know when you are speeding up or slowing down? (When speeding up, it feels as if you are pressed against the back of the seat. When you are slowing down, it feels as if you are pulled forward against the seat belt.)**

**How can you tell if you are changing direction? (You can feel yourself pulled to one side, away from the direction the car is turning.)**

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**Motion 343**
Acceleration isn’t always the result of changes in speed. You can accelerate even if your speed is constant. You experience this type of acceleration if you ride a bicycle around a curve. Although you may have a constant speed, your change in direction means you are accelerating. You also may have experienced this type of acceleration if you have ridden on a carousel like the one in Figure 13. A horse on the carousel is traveling at a constant speed, but it is accelerating because its direction is constantly changing.

Changes in Direction Acceleration isn’t always the result of changes in speed. You can accelerate even if your speed is constant. You experience this type of acceleration if you ride a bicycle around a curve. Although you may have a constant speed, your change in direction means you are accelerating. You also may have experienced this type of acceleration if you have ridden on a carousel like the one in Figure 13. A horse on the carousel is traveling at a constant speed, but it is accelerating because its direction is constantly changing.

Changes in Speed and Direction Sometimes motion is characterized by changes in both speed and direction at the same time. You experience this type of motion if you ride on a roller coaster like the one in Figure 14. The roller coaster ride starts out slowly as the cars travel up the steeply inclined rails. The cars reach the top of the incline. Suddenly they plummet toward the ground and then whip around a curve. You are thrown backward, forward, and sideways as your velocity increases, decreases, and changes direction. Your acceleration is constantly changing because of changes in the speed and direction of the cars of the roller coaster.

Similarly, passengers in a car moving at a posted speed limit along a winding road experience rapidly changing acceleration. The car may enter a long curve at the same time that it slows to maintain a safe interval behind another car. The car is accelerating both because it is changing direction and because its speed is decreasing.

Figure 13 When you ride on a carousel, you accelerate because of the changing direction.

Figure 14 A roller coaster produces acceleration due to changes in both speed and direction. Applying Concepts Describe the acceleration occurring at this instant on the roller coaster ride.

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Figure 13 When you ride on a carousel, you accelerate because of the changing direction.

Figure 14 A roller coaster produces acceleration due to changes in both speed and direction. Applying Concepts Describe the acceleration occurring at this instant on the roller coaster ride.
Constant Acceleration
The velocity of an object moving in a straight line changes at a constant rate when the object is experiencing constant acceleration. Constant acceleration is a steady change in velocity. That is, the velocity of the object changes by the same amount each second. An example of constant acceleration is illustrated by the jet airplane shown in Figure 15. The airplane’s acceleration may be constant during a portion of its takeoff.

Calculating Acceleration
Acceleration is the rate at which velocity changes. You calculate acceleration for straight-line motion by dividing the change in velocity by the total time.

\[
\text{Acceleration} = \frac{\Delta \text{velocity}}{\Delta \text{time}} = \frac{v_f - v_i}{t}
\]

Notice in this formula that velocity is in the numerator and time is in the denominator. If the velocity increases, the numerator is positive and thus the acceleration is also positive. For example, if you are coasting downhill on a bicycle, your velocity increases and your acceleration is positive. If the velocity decreases, then the numerator is negative and the acceleration is also negative. For example, if you continue coasting after you reach the bottom of the hill, your velocity decreases and your acceleration is negative.

Remember that acceleration and velocity are both vector quantities. Thus, if an object moving at constant speed changes its direction of travel, there is still acceleration. In other words, the acceleration can change even if the velocity is constant. Think about a car moving at a constant speed as it rounds a curve. Because its direction is changing, the car is accelerating.

To determine a change in velocity, subtract one velocity vector from another. If the motion is in a straight line, however, the velocity can be treated as speed. You can then find acceleration from the change in speed divided by the time.

Calculating
Once students have learned the equation for acceleration, return to Figure 12 on p. 343. Apply the equation for acceleration to calculate the magnitude of the stone’s acceleration in the first time interval:

\[
a = \frac{v_f - v_i}{t} = \frac{(9.8 \text{ m/s} - 0 \text{ m/s})}{1 \text{ s}} = 9.8 \text{ m/s}^2
\]

Then, have the students use the equation to calculate the acceleration of the stone for other time intervals. They should find that for every time interval, the magnitude of the acceleration is 9.8 m/s².

Logical
Download a worksheet on acceleration for students to complete, and find additional teacher support from NSTA SciLinks.
Calculating Acceleration

A ball rolls down a ramp, starting from rest. After 2 seconds, its velocity is 6 meters per second. What is the acceleration of the ball?

1. Read and Understand
What information are you given?
- Time = 2 s
- Starting velocity = 0 m/s
- Ending velocity = 6 m/s

2. Plan and Solve
What unknown are you trying to calculate?
- Acceleration = ?

What formula contains the given quantities and the unknown?

\[
\text{Acceleration} = \frac{(v_f - v_i)}{t}
\]

Replace each variable with its known value.

\[
\text{Acceleration} = \frac{(6 \text{ m/s} - 0 \text{ m/s})}{2 \text{ s}}
\]

= 3 m/s² down the ramp

3. Look Back and Check
Is your answer reasonable?
- Objects in free fall accelerate at a rate of 9.8 m/s².
- The ramp is not very steep. An acceleration of 3 m/s² seems reasonable.

Graphs of Accelerated Motion

You can use a graph to calculate acceleration. For example, consider a downhill skier who is moving in a straight line. After traveling down the hill for 1 second, the skier’s speed is 4 meters per second. In the next second the speed increases by an additional 4 meters per second, so the skier’s acceleration is 4 m/s². Figure 16 is a graph of the skier’s speed.

The slope of a speed-time graph is acceleration. This slope is change in speed divided by change in time.
**Speed-Time Graphs** The skier’s speed increased at a constant rate because the skier was moving down the hill with constant acceleration. Constant acceleration is represented on a speed–time graph by a straight line. The graph in Figure 16 is an example of a linear graph, in which the displayed data form straight-line parts. The slope of the line is the acceleration.

Constant negative acceleration decreases speed. A speed-time graph of the motion of a bicycle slowing to a stop is shown in Figure 17. The horizontal line segment represents constant speed. The line segment sloping downward represents the bicycle slowing down. The change in speed is negative, so the slope of the line is negative.

**Figure 16** The slope of a speed–time graph indicates acceleration. A positive slope shows that the skier’s acceleration is positive.

**Figure 17** The horizontal part of the graph shows a biker’s constant speed. The part of the graph with negative slope shows negative acceleration as the mountain biker slows to a stop.

---

**Graphs of Accelerated Motion**

**Build Math Skills**

**Finding Slope on a Graph** Remind students that the slope of a line on a graph is found by dividing the difference of two points on the vertical axis by the corresponding points on the horizontal axis. The two points used to find the slope should be chosen as far apart on the line as possible.

Have students calculate the slope of the line on the graph in Figure 16. Tell them also to include the units in their calculation. (4 m/s²) Now have them calculate the slope of the line between 10 and 20 seconds on the graph in Figure 17. (0.5 m/s²)

**Logical**

Direct students to the Math Skills in the Skills and Reference Handbook at the end of the student text for additional help.

**Use Visuals**

**Figure 17** Ask students the following questions about the speed-time graph in Figure 17. What are the units on the vertical axis? (m/s) What are the units on the horizontal axis? (s) What would be the units of the slope of a line on this graph? (m/s/s, or m/s²) Remind students that the line represents the motion of a mountain biker in the photograph. Ask students, Is the bike moving at time zero? (Yes) How fast is it moving at that time? (5 m/s) What happens to the bike after 10 seconds? (It starts to slow down.) How would you describe the acceleration of the bike from that point on? (The acceleration is constant and negative.)

**Visual, Logical**
Section 11.3 (continued)

Instantaneous Acceleration

Integrate Math L2

Differential calculus is the branch of mathematics that physicists use when considering instantaneous quantities, such as instantaneous speed or instantaneous acceleration. When you use calculus to determine acceleration, you can take the difference in velocities over smaller and smaller time intervals until the time interval becomes, in effect, infinitely small. The slope of a curved line is equal to the slope of a line drawn tangent to a point on the plotted curve. Graphically, this is like finding the slope of a line connecting two points on a speed-time graph, but then moving the points closer and closer together until you have the slope of a line tangent to the curve at a single point on the graph. In this case, the slope of the line represents the instantaneous acceleration at that point.

Logical, Visual

3 ASSESS

Evaluate Understanding L2

Ask students to sketch a speed-time graph of a car starting from rest, accelerating up to the speed limit, maintaining that speed, then slowing again to a stop.

Retreat L1

Use the graphs on page 347 to retreat the concepts in the section. Ask students to identify which kind of acceleration cannot be shown on the graphs. (A change in direction)

Math Practice L2

Solutions

8. $a = \frac{(v_f - v_i)}{t} = \frac{(25\ m/s - 0\ m/s)}{(30.0\ s)} = 0.83\ m/s^2$
9. $a = \frac{(v_f - v_i)}{t} = \frac{(30.0\ m/s - 25\ m/s)}{(10.0\ s)} = 0.50\ m/s^2$

Try This. If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 11.3.

Section 11.3 Assessment

Reviewing Concepts

1. Describe three types of changes in velocity.
2. What is the equation for acceleration?
3. What shows acceleration on a speed-time graph?
4. Define instantaneous acceleration.

Critical Thinking

5. Comparing and Contrasting How are deceleration and acceleration related?
6. Applying Concepts Two trains leave a station at the same time. Train A travels at a constant speed of 16 m/s. Train B starts at 8.0 m/s but accelerates constantly at 1.0 m/s$^2$. After 10.0 seconds, which train has the greater speed?

7. Inferring Suppose you plot the distance traveled by an object at various times and you discover that the graph is not a straight line. What does this indicate about the object’s acceleration?

8. A train moves from rest to a speed of 25 m/s in 10.0 seconds. What is the magnitude of its acceleration?

9. A car traveling at a speed of 25 m/s increases its speed to 30.0 m/s in 10.0 seconds. What is the magnitude of its acceleration?

Section 11.3 Assessment

1. Changes in velocity can be described as changes in speed, changes in direction, or changes in both (or, an increase in speed, a decrease in speed, or a change in direction).
2. $a = \frac{(v_f - v_i)}{t}$
3. The slope of the line on a speed-time graph gives the acceleration.

4. Instantaneous acceleration is how fast the velocity is changing at a specific instant.

5. Deceleration is a special case of acceleration in which the speed of an object is decreasing.

6. Train B ($v = v_0 + at = 8.0\ m/s + (1.0\ m/s^2)(10.0\ s) = 8.0\ m/s + 10.0\ m/s = 18\ m/s$)
7. The graph indicates that the object is accelerating.
The time-lapse photo shows how the position of a gymnast changes from moment to moment.

Chapter 11

Motion

How do science concepts apply to your world? Here are some questions you’ll be able to answer after you read this chapter.

■ How can two people look at the same object, and only one of them see the object as moving? (Section 11.1)
■ One person says that your school is 5 blocks from the library, and another person says the two buildings are 7 blocks apart. How can both people be right? (Section 11.1)
■ What does a car’s speedometer measure? (Section 11.2)
■ How do ships stay on course? (page 338)
■ When you drop a stone off a cliff, how fast does the stone fall? (Section 11.3)
■ How can something that is slowing down be accelerating? (Section 11.3)

Chapter Pretest

1. How many meters are in 28 km? (28,000 m)
2. Convert 35 km/h to a speed in m/s. (9.7 m/s)
3. Rearrange the following equation to solve for d: \( v = \frac{d}{t} \). (d = vt)
4. Rearrange the following equation to solve for \( a \): \( a = \frac{(v_f - v_i)}{t} \). (\( v_f - at + v_i \))
5. What are the SI units for distance and time? (Meters and seconds)
6. Which of the following describes the slope of a line? (d)
   a. rise \times run
   b. run/rise
   c. run − rise
   d. rise/run
7. If a graph uses units of meters on the vertical axis and units of seconds on the horizontal axis, what would be the units of the slope of a line on the graph? (m/s)
8. Which of the following is true about a curved line on a graph? (b)
   a. The slope is the same at every point.
   b. The slope of the line may be different at every point.
   c. The line has no slope.
   d. The slope of the line is zero.
Chapter Preview

11.1 Distance and Displacement
11.2 Speed and Velocity
11.3 Acceleration

ENGAGE/EXPLORE

How Does a Ramp Affect a Rolling Marble?

Purpose
In this activity, students will begin to describe how the steepness of a ramp affects the motion of a rolling marble.

Skills Focus Measuring, Predicting

Prep Time 10 minutes

Materials 1-m long wooden board at least 10 cm wide, 6 identical textbooks, stopwatch, marble

Class Time 20 minutes

Safety Students must wear safety goggles. Ensure that the boards are smooth to prevent splinters.

Teaching Tips
- The boards should not be curved or warped so that the marbles do not roll off the sides of the ramps.

Expected Outcome Students will observe that the marble takes longer to descend when the steepness of the ramp is reduced.

Predicting Students may correctly predict that a height of three books would approximately double the time the marble takes to reach the bottom of the ramp.

Think About It
1. The time needed would be very long because the speed of the marble would be almost zero.
2. When the ramp is vertical, the marble is in free fall and the time required reaches a finite minimum value.

Kinesthetic, Group

Encourage students to view the Video Field Trip “Charting New Ground.”
Investigating the Velocity of a Sinking Marble

In this lab, you will graph the motion of a marble falling through shampoo.

**Problem** What does a distance-time graph look like for a marble falling through shampoo?

**Materials**
- clear shampoo
- 100-mL graduated cylinder
- 2 small marbles
- forceps
- masking tape
- long glass stirring rod
- dropper pipet
- graph paper

**Skills** Measuring, Observing, Using Tables and Graphs

**Procedure**

1. On a separate sheet of paper, make a copy of the data table shown.

<table>
<thead>
<tr>
<th>Distance (mm)</th>
<th>First Marble Time (s)</th>
<th>Second Marble Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Wrap a small amount of masking tape around the tips of the forceps. This will allow you to grip the marble with them.

3. Measure the distance between the 10-mL graduations on the 100-mL graduated cylinder. Record the new distance in the first row of your data table.

4. Multiply this distance by 2 and write the result in the second row. For the third row, multiply the distance by 3. Continue until you have written distances in 10 rows.

5. Slowly pour 100 mL of clear shampoo into the 100-mL graduated cylinder.

6. Be ready to observe the marble as it falls through the shampoo. Grasp the marble with the forceps and hold the marble just above the shampoo-filled graduated cylinder.

7. Say “Go!” as you drop the marble into the shampoo. At the same time, your partner should start the stopwatch.

8. Each time the lower edge of the marble reaches a 10-mL mark on the cylinder, say “Now.” Your partner should note and record the time on the stopwatch.

9. Continue calling out “Now” each time the marble reaches a 10-mL mark until it comes to rest on the bottom of the cylinder. Say “Stop!”

10. Use the 10-mL graduated cylinder to add about 8 mL of water to the 100-mL graduated cylinder. Use the glass stirring rod to mix the water and shampoo gently but thoroughly.

11. With the dropper pipet, remove enough liquid from the graduated cylinder to decrease the volume to 100 mL.

12. Repeat Steps 6 through 9 using another marble.

13. Wash all supplies as instructed by your teacher.

**Analyze and Conclude**

1. The graph should be a nearly straight line for both marbles. The graph for the second marble will be steeper.

2. At first, the marbles fell at a nearly constant velocity, which is shown as a straight line on the distance-time graph. The second marble fell faster than the first marble. As the marbles approached the bottom of the cylinder, the viscosity of the shampoo caused them to slow down.

3. Answers will depend on the viscosity of the shampoo. In most cases, the marble did not accelerate because of the resistance from the viscous shampoo.

4. The speeds will depend on the type of shampoo used. Typical speeds are 2.5 mm/s and 6.0 mm/s for marbles falling in shampoo and diluted shampoo, respectively.

**Logical, Kinesthetic**

**Teaching Tips**
- Tell students to pour the shampoo into the graduated cylinder so that as little as possible sticks to the side.
- Have students wear safety goggles to ensure shampoo does not enter their eyes.

**Expected Outcome**
- The marble falls more quickly through diluted shampoo than through undiluted shampoo.

**Sample Data**

![Velocity Graph](Velocity.jpg)

**Go Online**

For: Data sharing  
Visit: PHSchool.com  
Web Code: ccd2110

Students should see that the marbles have a nearly constant speed until they near the bottom of the graduated cylinder, where they begin to slow, but students’ results will depend on their own data and the data on the site.
### Planning Guide

**SECTION OBJECTIVES**

<table>
<thead>
<tr>
<th>11.1 Distance and Displacement, pp. 328–331</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1, A-2, B-4</td>
</tr>
<tr>
<td>11.1.1 Identify frames of reference and describe how they are used to measure motion.</td>
</tr>
<tr>
<td>11.1.2 Identify appropriate SI units for measuring distances.</td>
</tr>
<tr>
<td>11.1.3 Distinguish between distance and displacement.</td>
</tr>
<tr>
<td>11.1.4 Calculate displacement using vector addition.</td>
</tr>
<tr>
<td>11.2 Speed and Velocity, pp. 332–337</td>
</tr>
<tr>
<td>A-1, B-4, E-2, F-1, G-1, G-3</td>
</tr>
<tr>
<td>11.2.1 Identify appropriate SI units for measuring speed.</td>
</tr>
<tr>
<td>11.2.2 Compare and contrast average speed and instantaneous speed.</td>
</tr>
<tr>
<td>11.2.3 Interpret distance-time graphs.</td>
</tr>
<tr>
<td>11.2.4 Calculate the speed of an object using slopes.</td>
</tr>
<tr>
<td>11.2.5 Describe how velocities combine.</td>
</tr>
<tr>
<td>11.3 Acceleration, pp. 342–348</td>
</tr>
<tr>
<td>A-1, A-2, B-4, D-1</td>
</tr>
<tr>
<td>11.3.1 Identify changes in motion that produce acceleration.</td>
</tr>
<tr>
<td>11.3.2 Describe examples of constant acceleration.</td>
</tr>
<tr>
<td>11.3.3 Calculate the acceleration of an object.</td>
</tr>
<tr>
<td>11.3.4 Interpret speed-time and distance-time graphs.</td>
</tr>
<tr>
<td>11.3.5 Classify acceleration as positive or negative.</td>
</tr>
<tr>
<td>11.3.6 Describe instantaneous acceleration.</td>
</tr>
</tbody>
</table>

**STANDARDS**

<table>
<thead>
<tr>
<th>NATIONAL</th>
<th>STATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1, B-4, E-2, F-1, G-1, G-3</td>
<td></td>
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<tr>
<td>A-1, A-2, B-4, E-2, F-1, G-1, G-3</td>
<td></td>
</tr>
<tr>
<td>A-1, A-2, B-4, D-1</td>
<td></td>
</tr>
</tbody>
</table>

**ACTIVITIES and LABS**

| SE | Exploration Lab: Investigating the Velocity of a Sinking Marble, p. 349 |
| TE | Teacher Demo: Ticker Tape Car, p. 334 |
| LM | Investigation 11A: Measuring Distance and Displacement |
| SE | Inquiry Activity: How Does a Ramp Affect a Rolling Marble? p. 327 |
| SE | Quick Lab: Comparing Distance and Displacement, p. 330 |
| TE | Teacher Demo: Frames of Reference, p. 329 |
| LM | Investigation 11B: Investigating Free Fall |
| TE | Teacher Demo: Pendulum Accelerometer, p. 344 |

326A Chapter 11
Materials for Activities and Labs

Quantities for each group

STUDENT EDITION

Inquiry Activity, p. 327
1-m long wooden board at least 10 cm wide, 6 identical textbooks, stopwatch, marble

Quick Lab, p. 330
graph paper, metric ruler

Exploration Lab, p. 349
clear shampoo, 100-mL graduated cylinder, 2 small marbles, stopwatch, forceps, masking tape, metric ruler, 10-mL graduated cylinder, long glass stirring rod, dropper pipet, graph paper

TEACHER’S EDITION

Teacher Demo, p. 329
tennis ball

Teacher Demo, p. 334
toy car, ticker tape, ticker timer (acceleration timer), masking tape

Build Science Skills, p. 340
handheld GPS receivers, 1 per group

Teacher Demo, p. 344
short pendulum (25 cm), turntable, lab stand, tape

Chapter Assessment

CHAPTER ASSESSMENT

SE Chapter Assessment, pp. 351–352

CUT Chapter 11 Test A, B

CTB Chapter 11

IT Chapter 11

PHSchool.com GO

Web Code: cca-2110

STANDARDIZED TEST PREP

SE Chapter 11, p. 353

TP Diagnose and Prescribe

Interactive Textbook with assessment at PHSchool.com
Distance and Displacement 11.1

For one-dimensional motion, the position of an object can be defined by a function \( x(t) \). Displacement over a time interval can then be defined as \( \Delta x = x_2 - x_1 \). In more than one dimension, the displacement can be defined by a single vector function:

\[
s(t) = x(t)i + y(t)j + \ldots
\]

In this equation, \( s(t) \) is the displacement as a function of time, \( i \) and \( j \) are unit vectors in the horizontal and vertical directions, respectively, and \( x(t) \) and \( y(t) \) are positions along the horizontal axis and vertical axis as functions of time.

Distance is how far an object travels on a path. Displacement is the straight-line distance from the start point to the end point.

Speed and Velocity 11.2

Velocity is defined as the rate of change of displacement. This can be expressed by the following differential equation:

\[
v(t) = \frac{dx(t)}{dt}
\]

Taking the derivative of displacement as shown above gives the instantaneous velocity at a point. The magnitude of this vector is the instantaneous speed.

Students may use the equation \( \bar{v} = \frac{d}{t} \) to calculate average speed over a time interval, where \( \bar{v} \) is the average speed, \( d \) is the distance traveled during a time interval, and \( t \) is the time interval.

From the Author

Michael Wysession
Washington University

Big Ideas

Most of physics, and all of science, is concerned with motions. Before students can learn about the how (forces) and why (energy) of motions, they need to be able to describe them.

Space and Time

In our local region of the universe, space has three spatial dimensions. Space is closely related to time, which is often considered to be a fourth dimension. In fact, large distances are measured in light-years, which are units of time.

Einstein demonstrated that all motions are relative, so a frame of reference within the three-dimensional space must be chosen. Distances, directions, and displacements are always measured relative to a frame of reference. Displacement is the combination of distance and direction.

Because it is important to describe motion over time, rates such as speed and velocity are often used. Velocity is the combination of speed and direction, analogous to the relation between displacement and distance. Acceleration is another common way to describe motion. Acceleration is the rate at which motion changes. Displacement, velocity, and acceleration are the most common examples of vectors.

Forces and Motion

The motions of objects change when forces act upon them. Students need to be able to calculate these motions, and to be able to graph them. When there are no accelerations (no net forces), velocities are constant. These constant velocities plot as straight lines on a speed-time graph. When there are net forces, non-zero accelerations result in non-linear curves on a speed-time graph.

Matter and Energy

Objects that appear to be motionless contain atoms that are continuously in motion—vibrating and colliding. Even pure electromagnetic energy such as light is in motion. Many of the following physics chapters explore the relations between matter and energy. In all cases, understanding and measuring how this matter and energy moves is a fundamental part of understanding the laws of the universe.

Address Misconceptions

The location of an object can be described by stating its distance from a given point, ignoring direction. To describe position fully, you must specify both distance and direction. For a strategy to overcome this misconception, see Address Misconceptions on page 330.

An object’s speed is the same as its velocity. Velocity is a vector quantity that describes both speed and the direction of motion. For a strategy to overcome this misconception, see Address Misconceptions on page 336.
Acceleration 11.3

Acceleration is defined as the rate of change of velocity. This can be expressed by the following differential equation:

\[ a(t) = \frac{dv(t)}{dt} \]

Acceleration, like velocity and displacement, is a vector quantity having both magnitude and direction. Acceleration can be a change in speed, a change in direction, or both.

Taking the derivative of velocity as shown above gives the instantaneous acceleration at a point. For motion along a straight line, students may use the following equation

\[ a = \frac{v_f - v_i}{t} \]

to calculate average acceleration, where \( a \) is the average acceleration, \( v_f \) is the final speed, \( v_i \) is the initial speed, and \( t \) is the time interval. Note that if velocity of an object moving in the positive direction decreases during the time interval, \( v_f < v_i \), and the average acceleration is negative.

Graphing Motion 11.2 and 11.3

Speed in one-dimensional motion can be shown on a graph of distance versus time, as shown in Figure A below. Constant speed appears on the graph as a straight line with finite, nonzero slope. The greater the absolute value of the slope, the greater the speed. A horizontal line represents zero velocity.

Acceleration in one-dimensional motion can be shown on a graph of distance versus time, or on a graph of speed versus time, as shown below right in Figure B. On a speed-time graph, constant speed is a horizontal line (with a slope of zero) and constant acceleration is a straight line with a nonzero slope. On a distance-time graph, constant acceleration appears as a curved line.

Build Reading Literacy

Monitor Your Understanding

Self-Questioning and Self-Adjusting While Reading Strategy Help students read and understand difficult technical material. This strategy enables students to focus on their own thought processes as they actively question and apply fix-up strategies to improve comprehension. First, present the three steps in the example below, reviewing the fix-up strategies in Step 2. Then, before students begin, assign a section in Chapter 11, such as Section 11.2, pp. 332–337, for them to read. You might want to model the strategy with a paragraph or two before having students practice it on their own.

Example

1. Self-Question Have students read and think about the paragraphs under each heading, stopping often to ask themselves questions such as, “Do I understand this?” “Is this clear?” and “Does this answer my questions about _____?”

2. Identify Trouble Spots and Apply Fix-Up Strategies
   - Reread/Adjust Reading Pace When students do not understand a paragraph, have them reread it slowly, making sure they understand each sentence before they continue.
   - Clarify When students encounter a difficult paragraph, suggest they state what they do understand, talk through confusing points or steps in a process, or relate new information to concepts and examples that are already familiar to them.
   - Read Ahead/Use Visuals and Captions Show students how to use visuals and captions to help clarify a process or a concept. Suggest that they can also read ahead to see whether a process or concept is discussed further as part of another concept.
   - Use Outside Resources Point out, too, that students should seek assistance from friends, teachers, or other resources. Hearing additional examples or more than one person’s explanation often aids comprehension.

3. Self-Check After students read, have them check their understanding by summarizing or retelling the main idea of a paragraph or section.

See p. 329 for a script on how to use the monitor your understanding strategy with students. For additional Build Reading Literacy strategies, see pp. 336 and 343.
11.1 Distance and Displacement

Key Concepts
- To describe motion accurately and completely, a frame of reference is needed.
- Distance is the length of the path between two points. Displacement is the direction from the starting point and the length of a straight line from the starting point to the ending point.
- Add displacements by using vector addition.

Vocabulary
- frame of reference, p. 328
- relative motion, p. 329
- distance, p. 329
- vector, p. 330
- resultant vector, p. 331

11.2 Speed and Velocity

Key Concepts
- Average speed is computed for the entire duration of a trip, and instantaneous speed is measured at a particular instant.
- The slope of a line on a distance-time graph is speed.
- Velocity is a description of both speed and direction of motion. Velocity is a vector.
- Two or more velocities add by vector addition.

Vocabulary
- speed, p. 332
- average speed, p. 333
- instantaneous speed, p. 334
- velocity, p. 336

11.3 Acceleration

Key Concepts
- Acceleration can be described as changes in speed, changes in direction, or changes in both. Acceleration is a vector.
- You calculate acceleration by dividing the change in velocity by the total time.
- The slope of a speed-time graph is the acceleration.
- Instantaneous acceleration is how fast a velocity is changing at a specific instant.

Vocabulary
- acceleration, p. 342
- free fall, p. 343
- constant acceleration, p. 345
- linear graph, p. 347
- nonlinear graph, p. 348

Thinking Visually

Concept Map Copy the concept map below onto a sheet of paper. Use information from the chapter to complete the concept map.

Motion is described in terms of

- a combination of velocity
- a combination of speed

Acceleration is the change in

- direction
- in speed

Changes in

- direction
- speed

Thinking Visually

a. Velocity
b. Distance
c. Direction
d. Changes in both speed and direction

Chapter Resources

Print
- Chapter and Unit Tests, Chapter 11
- Test Prep Resources, Chapter 11

Technology
- Computer Test Bank, Chapter Test 11
- Interactive Textbook, Chapter 11
- Go Online, PHSchool.com, Chapter 11
1. The rate at which velocity is changing at a given instant is described by
   a. instantaneous acceleration.
   b. average speed.
   c. constant speed.
   d. vector addition.

Understanding Concepts

11. Why is it necessary to choose a single frame of reference when measuring motion?
12. For what kind of distances would you choose to make measurements in millimeters? In kilometers?
13. Light from a star travels to Earth in a straight line at a constant speed of almost 300,000 km/s. What is the acceleration of the light?
14. If two displacement vectors add to yield a total displacement of zero, what do you know about the two displacements?
15. How will the total distance traveled by a car in 2 hours be affected if the average speed is doubled?
16. How do you know that a speedometer tells you the instantaneous speed of a car?
17. On a distance-time graph, what would the curve describing constant speed look like?
18. A spider is crawling on a wall. First it crawls 1 meter up, then 1 meter to the left, and then 1 meter down. What is its total displacement?
19. A jogger travels 8.0 kilometers in 1.25 hours. What is the jogger’s average speed?
20. You see a lightning bolt in the sky. You hear a clap of thunder 3 seconds later. The sound travels at a speed of 330 m/s. How far away was the lightning? (Hint: Assume you see lightning instantly.)
21. If a river current is 8.0 m/s, and a boat is traveling 10.0 m/s upstream, what is the boat’s speed relative to the riverbank?
22. If an object is moving with constant velocity, what do you know about its acceleration?
23. If the plotted points on a speed-time graph do not form a straight line, what do you know about the object’s acceleration?
24. Explain a situation in which you can accelerate even though your speed doesn’t change.
### Critical Thinking

25. The velocities of 2 m/s forward and 2 m/s backwards cancel. An observer standing nearby would see the newspaper drop vertically to the ground.

26. Students’ experiments should include measuring the track and measuring the time for the train to go around the track. They should also mention calculating the speed from these measurements.

27. The raft could be moving with a constant speed because the speed during each measured interval is the same.

28. 1400 m/s

### Math Skills

29. For the first 10 seconds, the person is walking at a constant rate. For the next 10 seconds, the person is standing still.

30. 1.5 m/s

31. 0.75 m/s²

### Concepts in Action

32. The ship’s final velocity is 600 m/s, less than its velocity in problem 28.

33. At each moment, the falling ball has an instantaneous acceleration that is the same as its constant downward acceleration of 9.8 m/s². The ball bouncing on the floor has a changing acceleration each time it hits the ground.

34. 5 km/h

35. Descriptions will vary but should include the up-and-down dribbling motion of the ball, the movement of the player down the court, and the projectile motion of the ball after it is shot toward the basket.

### Performance-Based Assessment

Use the following graph to answer questions 29 and 30.

#### A Record of Typical Motion

<table>
<thead>
<tr>
<th>Time (seconds)</th>
<th>Displacement (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

29. Using Graphs: The graph above shows the motion for a person walking down a street. Describe the history of the motion.

30. Using Graphs: How fast is the person walking during the first 10 seconds?

31. Calculating: A car starts from rest and increases its speed to 15 m/s in 20 seconds. What is the car’s acceleration?
1. A delivery truck driver's round-trip route from the warehouse takes her 3 km east, then 1 km north, then 3 km west, and then 1 km south. Which of the following statements is FALSE?
(A) The displacement of the round trip is zero.
(B) The distance of the round trip is 8 km.
(C) After driving 3 km east, the magnitude of the distance and displacement are the same.
(D) After driving 3 km east and 1 km north, the magnitude of the distance and displacement are the same.
(E) none of the above

2. A runner completes a 10.0-km race in exactly 30 minutes. What is the runner's average speed in km/h? (60 minutes = 1 hour)
(A) 30.0 km/h (B) 20.0 km/h
(C) 15.0 km/h (D) 10.0 km/h
(E) 5.00 km/h

3. Which of the following is NOT a vector quantity?
(A) velocity
(B) displacement
(C) distance
(D) acceleration
(E) none of the above

4. Based on the speed-time graph shown at the left, what is the acceleration during the first 2 seconds?
(A) 1 m/s²
(B) 2 m/s²
(C) 4 m/s²
(D) 5 m/s²
(E) 10 m/s²

5. A race car drives around a circular race track at constant speed. Which of the following statements is TRUE?
(A) A speed-time graph of the car's motion would be a horizontal line.
(B) A distance-time graph of the car's motion would be a straight line with a positive slope.
(C) The velocity of the car is constantly changing.
(D) The car is constantly accelerating.
(E) all of the above

Test-Taking Tip
When answering a question with a graph, keep these tips in mind:
• Read the question thoroughly to identify what the question is asking.
• Study the name of the graph, if applicable. This may help you identify what information is available from the graph.
• Carefully examine the graph and take note of the axes labels.
• Identify the scale of the axes.
• Recall information, equations, definitions, relationships, and so forth that may be required to interpret the graph. For example, the slope of a distance-time graph is the speed of the object.
• Once you have chosen your answer, check it against the graph.

The graph above depicts motion in a straight line. During which time periods does acceleration occur?
(A) 0 ≤ t ≤ 2 s only
(B) 0 ≤ t ≤ 2 s and 6 ≤ t ≤ 8 s only
(C) 2 ≤ t ≤ 8 s only
(D) 0 ≤ t ≤ 2 s, 6 ≤ t ≤ 8 s, and 16 ≤ t ≤ 18 s only
(E) Acceleration occurs during the entire time period shown.

(Answer: D)