BIG Idea
Motion occurs when an object changes its position.

2.1 Describing Motion
An object’s speed depends on how far an object travels in a unit of time.

2.2 Acceleration
Acceleration describes how the speed of an object is changing.

2.3 Motion and Forces
An object’s motion changes only if the forces acting on the object are unbalanced.

Taking the Plunge
How would you describe a ride on a roller coaster? You might talk about the thrills you experienced on the high-speed turns or on the breath-taking downhill plunges. The high speeds and sudden changes in speed and direction can all help make the ride a memorable experience.

Science Journal
Write a paragraph describing how three different rides in an amusement park cause you to move.
Compare Speeds
A cheetah can run at a speed of almost 120 km/h and is the fastest runner in the world. A horse can reach a speed of 64 km/h; an elephant’s top speed is about 40 km/h; and the fastest snake slithers at a speed of about 3 km/h. The speed of an object is calculated by dividing the distance the object travels by the time it takes it to move that distance. How does your speed compare to the speeds of these animals?

1. Use a meterstick to mark off 10 m.
2. Have your partner use a stopwatch to determine how fast you run 10 m.
3. Divide 10 m by your time in seconds to calculate your speed in m/s.
4. Multiply your answer by 3.6 to determine your speed in km/h.
5. **Think Critically** Write a paragraph in your Science Journal comparing your speed with the maximum speed of a cheetah, horse, elephant, and snake. Could you win a race with any of them?

Identify Questions
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**Motion**
Many things are in motion in your everyday life. Make the following Foldable to help you better understand motion as you read the chapter.

**STEP 1** Fold a sheet of paper in half lengthwise. Make the back edge about 1.25 cm longer than the front edge.

**STEP 2** Fold in half, then fold in half again to make three folds.

**STEP 3** Unfold and cut only the top layer along the three folds to make four tabs.

**STEP 4** Label the tabs.

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Motion

Are distance and time important in describing running events at the track-and-field meets in the Olympics? Would the winners of the 5-km race and the 10-km race complete the run in the same length of time?

Distance and time are important. In order to win a race, you must cover the distance in the shortest amount of time. The time required to run the 10-km race should be longer than the time needed to complete the 5-km race because the first distance is longer. How would you describe the motion of the runners in the two races?

Motion and Position

You don’t always need to see something move to know that motion has taken place. For example, suppose you look out a window and see a mail truck stopped next to a mailbox. One minute later, you look out again and see the same truck stopped farther down the street. Although you didn’t see the truck move, you know it moved because its position relative to the mailbox changed.

A reference point is needed to determine the position of an object. In Figure 1, the reference point might be a tree or a mailbox. Motion occurs when an object changes its position relative to a reference point. The motion of an object depends on the reference point that is chosen. For example, the motion of the mail truck in Figure 1 would be different if the reference point were a car moving along the street, instead of a mailbox.
Frame of Reference After a reference point is chosen, a frame of reference can be created. A frame of reference is a coordinate system in which the position of the objects is measured. The x-axis and y-axis of the reference frame are drawn so that they intersect the reference point.

Distance In track-and-field events, have you ever run a 50-m dash? A distance of 50 m was marked on the track or athletic field to show you how far to run. An important part of describing the motion of an object is to describe how far it has moved, which is distance. The SI unit of length or distance is the meter (m). Longer distances are measured in kilometers (km). One kilometer is equal to 1,000 m. Shorter distances are measured in centimeters (cm). One meter is equal to 100 centimeters.

Displacement Suppose a runner jogs to the 50-m mark and then turns around and runs back to the 20-m mark, as shown in Figure 2. The runner travels 50 m in the original direction (north) plus 30 m in the opposite direction (south), so the total distance she ran is 80 m. How far is she from the starting line? The answer is 20 m. Sometimes you may want to know not only your distance but also your direction from a reference point, such as from the starting point. Displacement is the distance and direction of an object’s change in position from the starting point. The runner’s displacement in Figure 2 is 20 m north.

The length of the runner’s displacement and the distance traveled would be the same if the runner’s motion was in a single direction. If the runner ran from the starting point to the finish line in a straight line, then the distance traveled would be 50 m and the displacement would be 50 m north.

How do distance and displacement differ?

Speed Think back to the example of the mail truck’s motion in Figure 1. You could describe the movement by the distance traveled and by the displacement from the starting point. You also might want to describe how fast it is moving. To do this, you need to know how far it travels in a given amount of time. Speed is the distance an object travels per unit of time.
Calculating Speed  Any change over time is called a rate. If you think of distance as the change in position, then speed is the rate at which distance is traveled or the rate of change in position. Speed can be calculated from this equation:

\[
\text{speed (in meters/second)} = \frac{\text{distance (in meters)}}{\text{time (in seconds)}}
\]

\[
\text{s} = \frac{d}{t}
\]

In SI units, distance is measured in meters and time is measured in seconds, so the SI unit for speed is meters per second (m/s). Sometimes it is more convenient to express speed in other units, such as kilometers per hour (km/h). Table 1 shows some convenient units for certain types of motion.

### Table 1

<table>
<thead>
<tr>
<th>Speed Equation</th>
<th>distance (in meters)</th>
<th>time (in seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>speed (in meters/second) = ( \frac{d}{t} )</td>
<td>units of</td>
<td>units of</td>
</tr>
<tr>
<td>s = ( \frac{d}{t} )</td>
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### Solve for Speed

A car traveling at a constant speed covers a distance of 750 m in 25 s. What is the car’s speed?

1. This is what you know:
   - distance: \( d = 750 \text{ m} \)
   - time: \( t = 25 \text{ s} \)

2. This is what you need to find:
   - speed: \( s \)

3. Use this formula:
   \[ s = \frac{d}{t} \]

4. Substitute:
   The values of \( d \) and \( t \) into the formula and divide.

\[
\frac{750}{25} = 30
\]

5. Determine the units:
   \[
   \text{units of } s = \frac{\text{units of } d}{\text{units of } t} = \frac{\text{m}}{\text{s}} = \text{m/s}
   \]

Answer: The car’s speed is 30 m/s.

### Practice Problems

1. A passenger elevator travels from the first floor to the 60th floor, a distance of 210 m, in 35 s. What is the elevator’s speed?
2. A motorcycle is moving at a constant speed of 40 km/h. How long does it take the motorcycle to travel a distance of 10 km?
3. How far does a car travel in 0.75 h if it is moving at a constant speed of 88 km/h?
4. Challenge A long-distance runner is running at a constant speed of 5 m/s. How far does the runner travel in 10 minutes?
Motion with Constant Speed  Suppose you are in a car traveling on a nearly empty freeway. You look at the speedometer and see that the car’s speed hardly changes. If the car neither slows down nor speeds up, the car is traveling at a constant speed. If you are traveling at a constant speed, you can measure your speed over any distance interval.

Changing Speed  Usually speed is not constant. Think about riding a bicycle for a distance of 5 km, as in Figure 3. As you start out, your speed increases from 0 km/h to 20 km/h. You slow down to 10 km/h as you pedal up a steep hill and speed up to 30 km/h going down the other side of the hill. You stop for a red light, speed up again, and move at a constant speed for a while. Finally, you slow down and then stop. Checking your watch, you find that the trip took 15 min. How would you express your speed on such a trip? Would you use your fastest speed, your slowest speed, or some speed between the two?

| Table 1  Examples of Units of Speed |
|--------------------------|-------------------------------------|
| Unit of Speed | Examples of Uses                  | Approximate Speed |
| km/s           | rocket escaping Earth’s atmosphere | 11.2 km/s          |
| km/h           | car traveling at highway speed     | 100 km/h           |
| cm/yr          | geological plate movements         | 2 cm/yr – 17 cm/yr |

Figure 3  The graph shows how the speed of a cyclist changes during a trip. Explain how you describe the speed of an object when the speed is changing.
Average Speed

Average speed describes speed of motion when speed is changing. **Average speed** is the total distance traveled divided by the total time of travel. It can be calculated using the relationships among speed, distance, and time. For the bicycle trip just described, the total distance traveled was 5 km and the total time was 1/4 h, or 0.25 h. The average speed was:

\[ s = \frac{d}{t} = \frac{5 \text{ km}}{0.25 \text{ h}} = 20 \text{ km/h} \]

Instantaneous Speed

Suppose you watch a car’s speedometer, like the one in Figure 4, go from 0 km/h to 60 km/h. A speedometer shows how fast a car is going at one point in time or at one instant. The speed shown on a speedometer is the instantaneous speed. **Instantaneous speed** is the speed at a given point in time.

Changing Instantaneous Speed

When something is speeding up or slowing down, its instantaneous speed is changing. The speed is different at every point in time. If an object is moving with constant speed, the instantaneous speed doesn’t change. The speed is the same at every point in time.

Graphing Motion

The motion of an object over a period of time can be shown on a distance-time graph. Time is plotted along the horizontal axis of the graph and the distance traveled is plotted along the vertical axis of the graph. If the object moves with constant speed, the increase in distance over equal time intervals is the same. As a result, the line representing the object’s motion is a straight line.

For example, the graph shown in Figure 5 represents the motion of three swimmers during a 30-min workout. The straight red line represents the motion of Mary, who swam with a constant speed of 80 m/min over the 30-min workout. The straight blue line represents the motion of Kathy, who swam with a constant speed of 60 m/min during the workout.

The graph shows that the line representing the motion of the faster swimmer is steeper. The steepness of a line on a graph is the slope of the line. The slope of a line on a distance-time graph equals the speed. A horizontal line on a distance-time graph has zero slope, and represents an object at rest. Because Mary has a larger speed than Kathy, the line representing her motion has a larger slope.

**Figure 4** The speed shown on the speedometer gives the instantaneous speed—the speed at one instant in time.

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**Mini Lab**

**Describing the Motion of a Car**

**Procedure**

1. Mark your starting point on the floor with tape.
2. At the starting line, give your toy car a gentle push forward. At the same time, start your stopwatch.
3. Stop timing when the car comes to a complete stop. Mark the spot on the floor at the front of the car with a pencil. Record the time for the entire trip.
4. Use a meterstick to measure the distance to the nearest tenth of a centimeter and convert it to meters.

**Analysis**
Calculate the speed. How would the speed differ if you repeated your experiment in exactly the same way but the car traveled in the opposite direction?

**Reading Check**

What are two examples of motion in which the instantaneous speed changes?
**Changing Speed** The green line represents the motion of Julie, who did not swim at a constant speed. She covered 400 m at a constant speed during the first 10 min, rested for the next 10 min, and then covered 800 m during the final 10 min. During the first 10 min, her speed was less than Mary’s or Kathy’s, so her line has a smaller slope. During the middle period her speed is zero, so her line over this interval is horizontal and has zero slope. During the last time interval she swam as fast as Mary, so that part of her line has the same slope.

**Plotting a Distance-Time Graph** On a distance-time graph, the distance is plotted on the vertical axis and the time on the horizontal axis. Each axis must have a scale that covers the range of numbers to be plotted. In Figure 5 the distance scale must range from 0 to 2,400 m and the time scale must range from 0 to 30 min. Then, each axis can be divided into equal time intervals to represent the data. Once the scales for each axis are in place, the data points can be plotted. After plotting the data points, draw a line connecting the points.

**Graphing Motion**

- Mary swam at a constant speed of 80 m/min. Her speed was the fastest, so this line has the steepest slope.
- At first Julie swam with a speed of 40 m/min. The slope of this line is less than Kathy’s line.
- Kathy swam with a constant speed of 60 m/min. The slope of this line is less than the slope of Mary’s line.
- Here Julie’s speed was 80 m/min. The slope of this line is the same as Mary’s line.
- Here Julie’s speed was 0 m/min. The slope of this line is 0 m/min.

**Figure 5** The slope of a line on a distance-time graph gives the speed of an object in motion. **Identify the part of the graph that shows one of the swimmers resting for 10 min.**
The speed of a storm is not enough information to plot the path. The direction the storm is moving must be known, too.

**Figure 6** The speed of a storm is not enough information to plot the path. The direction the storm is moving must be known, too.

You turn on the radio and hear the tail end of a news story about a hurricane, like the one in **Figure 6**, that is approaching land. The storm, traveling at a speed of 20 km/h, is located 100 km east of your location. Should you be worried?

Unfortunately, you don’t have enough information to answer that question. Knowing only the speed of the storm isn’t much help. Speed describes only how fast something is moving. To decide whether you need to move to a safer area, you also need to know the direction that the storm is moving. In other words, you need to know the velocity of the storm. **Velocity** includes the speed of an object and the direction of its motion.

Escalators like the one shown in **Figure 7** are found in shopping malls and airports. The two sets of passengers pictured are moving at constant speed, but in opposite directions. The speeds of the passengers are the same, but their velocities are different because the passengers are moving in different directions.

Because velocity depends on direction as well as speed, the velocity of an object can change even if the speed of the object remains constant. For example, look at **Figure 7**. The race car has a constant speed and is going around an oval track. Even though the speed remains constant, the velocity changes because the direction of the car’s motion is changing constantly.

**Reading Check** How are velocity and speed different?

The speed of this car might be constant, but its velocity is not constant because the direction of motion is always changing.

**Figure 7** For an object to have constant velocity, speed and direction must not be changing.

The people on these two escalators have the same speed. However, their velocities are different because they are traveling in opposite directions.
Motion of Earth’s Crust

Can you think of something that is moving so slowly you cannot detect its motion, yet you can see evidence of its motion over long periods of time? As you look around the surface of Earth from year to year, the basic structure of the planet seems the same. Mountains, plains, lakes, and oceans seem to remain unchanged over hundreds of years. Yet if you examined geological evidence of what Earth’s surface looked like over the past 250 million years, you would see that large changes have occurred. Figure 8 shows how, according to the theory of plate tectonics, the positions of landmasses have changed during this time. Changes in the landscape occur constantly as continents drift slowly over Earth’s surface. However, these changes are so gradual that you do not notice them.

About 250 million years ago, the continents formed a supercontinent called Pangaea.

Figure 8  Geological evidence suggests that Earth’s continents have moved slowly over time.

Pangaea began to separate into smaller pieces and by 66 million years ago, the continents looked like the figure above. The continents are still moving today.
Moving Continents  How can continents move around on the surface of Earth? Earth is made of layers, as shown in Figure 9. The outer layer is the crust, and the layer just below the crust is called the upper mantle. Together the crust and the top part of the upper mantle are called the lithosphere. The lithosphere is broken into huge sections called plates that slide slowly on the puttylike layers just below. If you compare Earth to an egg, these plates are about as thick as the eggshell. These moving plates cause geological changes such as the formation of mountain ranges, earthquakes, and volcanic eruptions.

The movement of the plates also is changing the size of the oceans and the shapes of the continents. The Pacific Ocean is getting smaller while the Atlantic Ocean is getting larger. The movement of the plates also changes the shape of the continents as they collide and spread apart.

Plates move so slowly that their speeds are given in units of centimeters per year. In California, two plates slide past each other along the San Andreas Fault with an average relative speed of about 1 cm per year. The Australian Plate’s movement is one of the fastest, pushing Australia north at an average speed of about 17 cm per year.
SECTION 2 Acceleration

Acceleration, Speed, and Velocity

You’re sitting in a car at a stoplight when the light turns green. The driver steps on the gas pedal and the car starts moving faster and faster. Just as speed is the rate of change of position, acceleration is the rate of change of velocity. When the velocity of an object changes, the object is accelerating.

Remember that velocity includes the speed and direction of an object. Therefore, a change in velocity can be either a change in how fast something is moving or a change in the direction it is moving. Acceleration occurs when an object changes its speed, its direction, or both.

Speeding Up and Slowing Down When you think of acceleration, you probably think of something speeding up. However, an object that is slowing down also is accelerating.

Imagine a car traveling through a city. If the speed is increasing, the car has positive acceleration. When the car slows down its speed is decreasing and the car has negative acceleration. In both cases the car is accelerating because its speed is changing.

Acceleration also has direction, just as velocity does. If the acceleration is in the same direction as the velocity, as in Figure 10, the speed increases and the acceleration is positive. If the speed decreases, the acceleration is in the opposite direction from the velocity, and the acceleration is negative for the car shown in Figure 10.
Changing Direction  A change in velocity can be either a change in how fast something is moving or a change in the direction of movement. Any time a moving object changes direction, its velocity changes and it is accelerating. Think about a horse on a carousel. Although the horse’s speed remains constant, the horse is accelerating because it is changing direction constantly as it travels in a circular path, as shown in Figure 11. In the same way, Earth is accelerating constantly as it orbits the Sun in a nearly circular path.

Graphs of speed versus time can provide information about accelerated motion. The shape of the plotted curve shows when an object is speeding up or slowing down. Figure 12 shows how motion graphs are constructed.

Calculating Acceleration

Acceleration is the rate of change in velocity. To calculate the acceleration of an object, the change in velocity is divided by the length of the time interval over which the change occurred.

To calculate the change in velocity, subtract the initial velocity—the velocity at the beginning of the time interval—from the final velocity—the velocity at the end of the time interval. Let \( v_i \) stand for the initial velocity and \( v_f \) stand for the final velocity. Then the change in velocity is:

\[
\text{change in velocity} = \text{final velocity} - \text{initial velocity} = v_f - v_i
\]

Using this expression for the change in velocity, the acceleration can be calculated from the following equation:

\[
\text{acceleration (in meters/second}^2\text{)} = \frac{\text{change in velocity (in meters/second)}}{\text{time (in seconds)}}
\]

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

Recall that velocity includes both speed and direction. However, if the direction of motion doesn’t change and the object moves in a straight line, the change in velocity can be calculated from the change in speed. The change in velocity then is the final speed minus the initial speed.

The unit for acceleration is a unit for velocity divided by a unit for time. In SI units, velocity has units of m/s, and time has units of s, so acceleration has units of m/s².

Aircraft Carriers  An aircraft carrier provides a landing strip for airplanes to land and take off at sea. The carrier must be equipped to provide enough negative acceleration to stop a moving plane. The carrier also must be equipped to quickly accelerate planes to allow them to take off on a short runway. In 1911, American pilot Eugene Ely landed on a specially equipped deck on the battleship Pennsylvania. The experiment was successful, and today aircraft carriers are an important part of navies worldwide.

Figure 11  The speed of the horses in this carousel is constant, but the horses are accelerating because their direction is changing constantly.
Acceleration can be positive, negative, or zero depending on whether an object is speeding up, slowing down, or moving at a constant speed. If the speed of an object is plotted on a graph, with time along the horizontal axis, the slope of the line is related to the acceleration.

A The car in the photograph on the right is maintaining a constant speed of about 90 km/h. Because the speed is constant, the car’s acceleration is zero. A graph of the car’s speed with time is a horizontal line.

B The green graph shows how the speed of a bouncing ball changes with time as it falls from the top of a bounce. The ball speeds up as gravity pulls the ball downward, so the acceleration is positive. For positive acceleration, the plotted line slopes upward to the right.

C The blue graph shows the change with time in the speed of a ball after it hits the ground and bounces upward. The climbing ball slows as gravity pulls it downward, so the acceleration is negative. For negative acceleration, the plotted line slopes downward to the right.
Calculating Positive Acceleration  How is the acceleration for an object that is speeding up different from that of an object that is slowing down? Suppose the jet airliner in Figure 13 starts at rest at the end of a runway and reaches a speed of 80 m/s in 20 s. The airliner is traveling in a single direction down the runway, so its change in velocity can be calculated from its change in speed. Because it started from rest, its initial speed was zero. Its acceleration can be calculated as follows:

$$a = \frac{(v_f - v_i)}{t} = \frac{(80 \text{ m/s} - 0 \text{ m/s})}{20 \text{ s}} = 4 \text{ m/s}^2$$

The airliner is speeding up, so the final speed is greater than the initial speed and the acceleration is positive.

Calculating Negative Acceleration  Now imagine that the skateboarder in Figure 13 is moving in a straight line at a constant speed of 3 m/s and comes to a stop in 2 s. The final speed is zero and the initial speed was 3 m/s. The skateboarder’s acceleration is calculated as follows:

$$a = \frac{(v_f - v_i)}{t} = \frac{(0 \text{ m/s} - 3 \text{ m/s})}{2 \text{ s}} = -1.5 \text{ m/s}^2$$

The skateboarder is slowing down, so the final speed is less than the initial speed and the acceleration is negative. The acceleration always will be positive if an object is speeding up and negative if the object is slowing down.

Figure 13  A speed-time graph tells you if acceleration is positive or negative.
Amusement Park Acceleration

Riding roller coasters in amusement parks can give you the feeling of danger, but these rides are designed to be safe. Engineers use the laws of physics to design amusement park rides that are thrilling, but harmless. Roller coasters are constructed of steel or wood. Because wood is not as rigid as steel, wooden roller coasters do not have hills that are as high and steep as some steel roller coasters have. As a result, the highest speeds and accelerations usually are produced on steel roller coasters.

Steel roller coasters can offer multiple steep drops and inversion loops, which give the rider large accelerations. As the rider moves down a steep hill or an inversion loop, he or she will accelerate toward the ground due to gravity. When riders go around a sharp turn, they also are accelerated. This acceleration makes them feel as if a force is pushing them toward the side of the car. Figure 14 shows one of the fastest roller coasters in the United States.

What happens when riders on a roller coaster go around a sharp turn?

Figure 14 This roller coaster can reach a speed of about 200 km/h in 4 s.

Summary

**Acceleration, Speed, and Velocity**

- Acceleration is the rate of change of velocity.
- A change in velocity occurs when the speed of an object changes, or its direction of motion changes, or both occur.
- The speed of an object increases if the acceleration is in the same direction as the velocity.
- The speed of an object decreases if the acceleration and the velocity of the object are in opposite directions.

**Calculating Acceleration**

- Acceleration can be calculated by dividing the change in velocity by the time according to the following equation:
  \[ a = \frac{v_f - v_i}{t} \]
- The SI unit for acceleration is m/s².
- If an object is moving in a straight line, the change in velocity equals the final speed minus the initial speed.

Self Check

1. **Describe** three ways to change the velocity of a moving car.
2. **Determine** the change in velocity of a car that starts at rest and has a final velocity of 20 m/s north.
3. **Explain** why streets and highways have speed limits rather than velocity limits.
4. **Describe** the motion of an object that has an acceleration of 0 m/s².
5. **Think Critically** Suppose a car is accelerating so that its speed is increasing. Describe the plotted line on a distance-time graph of the motion of the car.

6. **Calculate Time** A ball is dropped from a cliff and has an acceleration of 9.8 m/s². How long will it take the ball to reach a speed of 24.5 m/s?
7. **Calculate Speed** A sprinter leaves the starting blocks with an acceleration of 4.5 m/s². What is the sprinter’s speed 2 s later?

**Applying Math**

ScienceOnline

gpscience.com/self_check_quiz
What is force?

Passing a basketball to a team member or kicking a soccer ball into the goal are examples of applying force to an object. A force is a push or pull. In both examples, the applied force changes the movement of the ball. Sometimes it is obvious that a force has been applied. But other forces aren’t as noticeable. For instance, are you conscious of the force the floor exerts on your feet? Can you feel the force of the atmosphere pushing against your body or gravity pulling on your body? Think about all the forces you exert in a day. Every push, pull, stretch, or bend results in a force being applied to an object.

Changing Motion What happens to the motion of an object when you exert a force on it? A force can cause the motion of an object to change. Think of hitting a ball with a racket, as in Figure 15. The racket strikes the ball with a force that causes the ball to stop and then move in the opposite direction. If you have played billiards, you know that you can force a ball at rest to roll into a pocket by striking it with another ball. The force of the moving ball causes the ball at rest to move in the direction of the force. In these cases, the velocities of the ball and the billiard ball were changed by a force.
Balanced Forces

Force does not always change velocity. In Figure 16A, two students are pushing on opposite sides of a box. Both students are pushing with an equal force but in opposite directions. When two or more forces act on an object at the same time, the forces combine to form the net force. The net force on the box in Figure 16A is zero because the two forces cancel each other. Forces on an object that are equal in size and opposite in direction are called balanced forces.

Unbalanced Forces

Another example of how forces combine is shown in Figure 16B. When two students are pushing with unequal forces in opposite directions, a net force occurs in the direction of the larger force. In other words, the student who pushes with a greater force will cause the box to move in the direction of the force. The net force that moves the box will be the difference between the two forces because they are in opposite directions. They are considered to be unbalanced forces.

In Figure 16C, the students are pushing on the box in the same direction. These forces are combined, or added together, because they are exerted on the box in the same direction. The net force that acts on this box is found by adding the two forces together.

Give another example of an unbalanced force.
Inertia and Mass

The dirt bike in Figure 17 is sliding on the track. This sliding bike demonstrates the property of inertia. **Inertia** (ih NUR shuh) is the tendency of an object to resist any change in its motion. If an object is moving, it will have uniform motion. It will keep moving at the same speed and in the same direction unless an unbalanced force acts on it. The velocity of the object remains constant unless a force changes it. If an object is at rest, it tends to remain at rest. Its velocity is zero unless a force makes it move.

Does a bowling ball have the same inertia as a table-tennis ball? Why is there a difference? You couldn’t change the motion of a bowling ball much by swatting it with a table-tennis paddle. However, you easily could change the motion of the table-tennis ball. A greater force would be needed to change the motion of the bowling ball because it has greater inertia. Why is this? Recall that mass is the amount of matter in an object, and a bowling ball has more mass than a table-tennis ball does. The inertia of an object is related to its mass. The greater the mass of an object is, the greater its inertia.

**Newton’s Laws of Motion** Forces change the motion of an object in specific ways. The British scientist Sir Isaac Newton (1642–1727) was able to state rules that describe the effects of forces on the motion of objects. These rules are known as Newton’s laws of motion. They apply to the motion of all objects you encounter every day such as cars and bicycles, as well as the motion of planets around the Sun.
Newton’s First Law of Motion  Newton’s first law of motion states that an object moving at a constant velocity keeps moving at that velocity unless an unbalanced net force acts on it. If an object is at rest, it stays at rest unless an unbalanced net force acts on it. Does this sound familiar? It is the same as the earlier discussion of inertia. This law is sometimes called the law of inertia. You probably have seen and felt this law at work without even knowing it. Figure 18 shows a billiard ball striking the other balls in the opening shot. What are the forces involved when the cue ball strikes the other balls? Are the forces balanced or unbalanced? How does this demonstrate the law of inertia?

What happens in a crash?

The law of inertia can explain what happens in a car crash. When a car traveling about 50 km/h collides head-on with something solid, the car crumples, slows down, and stops within approximately 0.1 s. Any passenger not wearing a safety belt continues to move forward at the same speed the car was traveling. Within about 0.02 s (1/50 of a second) after the car stops, unbelted passengers slam into the dashboard, steering wheel, windshield, or the backs of the front seats, as in Figure 19. They are traveling at the car’s original speed of 50 km/h—about the same speed they would reach falling from a three-story building.
**Summary**

**What is Force?**
- A force is a push or a pull on an object.
- The net force on an object is the combination of all the forces acting on the object.
- When the forces on an object are balanced, the net force on the object is zero.
- Unbalanced forces cause the motion of objects to change.

**Inertia and Newton’s First Law of Motion**
- The inertia of an object is the tendency of an object to resist a change in motion.
- The larger the mass of an object, the greater its inertia.
- Newton’s first law of motion states that the motion of an object at rest or moving with constant velocity will not change unless an unbalanced net force acts on the object.
- In a car crash, inertia causes an unrestrained passenger to continue moving at the speed of the car before the crash.

**Self Check**
1. Infer whether the inertia of an object changes as the object’s velocity changes.
2. Explain whether or not there must be an unbalanced net force acting on any moving object.
3. Explain Can there be forces acting on an object if the object is at rest?
4. Infer the net force on a refrigerator if you push on the refrigerator and it doesn’t move.
5. Think Critically Describe three situations in which a force changes the velocity of an object.

**Safety Belts**
The crash dummy wearing a safety belt in Figure 20 is attached to the car and slows down as the car slows down. The force needed to slow a person from 50 km/h to zero in 0.1 s is equal to 14 times the force that gravity exerts on the person. The belt loosens a little as it restrains the person, increasing the time it takes to slow the person down. This reduces the force exerted on the person. The safety belt also prevents the person from being thrown out of the car. Car-safety experts say that about half the people who die in car crashes would survive if they wore safety belts. Thousands of others would suffer fewer serious injuries.

Air bags also reduce injuries in car crashes by providing a cushion that reduces the force on the car’s occupants. When impact occurs, a chemical reaction occurs in the air bag that produces nitrogen gas. The air bag expands rapidly and then deflates just as quickly as the nitrogen gas escapes out of tiny holes in the bag. The entire process is completed in about 0.04 s.
If you stand at a stoplight, you will see cars stopping for red lights and then taking off when the light turns green. What makes the cars slow down? What makes them speed up? Can a study of unbalanced forces lead to a better understanding of these everyday activities?

**Real-World Question**
How does an unbalanced force on a book affect its motion?

**Goals**
- **Observe** the effect of force on the acceleration of an object.
- **Interpret** the data collected for each trial.

**Materials**
- tape
- paper clip
- this science book
- triple-beam balance
- 10-N spring scale
- *electronic balance
- large book
- *Alternate materials

**Safety Precautions**
Proper eye protection should be worn at all times while performing this lab.

**Procedure**
1. With a piece of tape, attach the paper clip to your textbook so that the paper clip is just over the edge of the book.
2. Prepare a data table with the following headings: *Force, Mass*.
3. If available, use a large balance to find the mass of this science book.
4. Place the book on the floor or on the surface of a long table. Use the paper clip to hook the spring scale to the book.
5. Pull the book across the floor or table at a slow but constant velocity. While pulling, read the force you are pulling with on the spring scale and record it in your table.
6. Repeat step 5 two more times, once accelerating slowly and once accelerating quickly. Be careful not to pull too hard. Your spring scale will read only up to 10 N.

**Conclude and Apply**
1. **Organize** the pulling forces from greatest to least for each set of trials. Do you see a relationship between force and acceleration? Explain your answer.
2. **Explain** how adding the second book changed the results.

**Communicating Your Data**
Compare your conclusions with those of other students in your class. For more help, refer to the Science Skill Handbook.
Real-World Question

Think about a small ball. How many ways could you exert a force on the ball to make it move? You could throw it, kick it, roll it down a ramp, blow it with a large fan, etc. Do you think the distance and speed of the ball’s motion will be the same for all of these forces? Do you think the acceleration of the ball would be the same for all of these types of forces?

Form a Hypothesis

Based on your reading and observations, state a hypothesis about how a force can be applied that will cause the toy car to go fastest.

Test Your Hypothesis

Make a Plan

1. As a group, agree upon the hypothesis and decide how you will test it. Identify which results will confirm the hypothesis that you have written.

2. List the steps you will need to test your hypothesis. Be sure to include a control run. Be specific. Describe exactly what you will do in each step. List your materials.

3. Prepare a data table in your Science Journal to record your observations.
4. **Read** the entire experiment to make sure all steps are in logical order and will lead to a useful conclusion.

5. **Identify** all constants, variables, and controls of the experiment. Keep in mind that you will need to have measurements at multiple points. These points are needed to graph your results. You should make sure to have several data points taken after you stop applying the force and before the car starts to slow down. It might be useful to have several students taking measurements, making each responsible for one or two points.

**Follow Your Plan**

1. Make sure your teacher approves your plan before you start.
2. Carry out the experiment as planned.
3. While doing the experiment, record your observations and complete the data tables in your Science Journal.

**Analyze Your Data**

1. **Graph** the position of the car versus time for each of the forces you applied. How can you use the graphs to compare the speeds of the toy car?
2. **Calculate** the speed of the toy car over the same time interval for each of the forces that you applied. How do the speeds compare?

**Conclude and Apply**

1. **Evaluate** Did the speed of the toy car vary depending upon the force applied to it?
2. **Determine** For any particular force, did the speed of the toy car change over time? If so, how did the speed change? Describe how you can use your graphs to answer these questions.
3. **Draw Conclusions** Did your results support your hypothesis? Why or why not?

**Compare your data with those of other students. Discuss how the forces you applied might be different from those others applied and how that affected your results.**
We, this people, on a small and lonely planet
Traveling through casual space
Past aloof stars, across the way of indifferent suns
To a destination where all signs tell us
It is possible and imperative that we learn
A brave and startling truth …

When we come to it
Then we will confess that not the Pyramids
With their stones set in mysterious perfection …
Not the Grand Canyon
Kindled into delicious color
By Western sunsets
These are not the only wonders of the world …

When we come to it
We, this people, on this minuscule and kithless \(^1\)
globe …
We this people on this mote \(^2\) of matter

When we come to it
We, this people, on this wayward \(^3\), floating body
Created on this earth, of this earth
Have the power to fashion for this earth
A climate where every man and every woman
Can live freely without sanctimonious piety \(^4\)
Without crippling fear

When we come to it
We must confess that we are the possible
We are the miraculous, the true wonder of the world
That is when, and only when
We come to it.

---

1. What adjectives does the poet use to describe Earth?
2. What does the poet believe are the true wonders of the world?
3. Linking Science and Writing: Write a six-line poem that describes Earth's movement from the point of view of the Moon.

Sometimes a person doesn't need to see movement to know that something has moved. Even though we don't necessarily see Earth's movement, we know Earth moves relative to a reference point such as the Sun. If the Sun is the reference point, Earth moves because the Sun appears to change its position in the sky. The poem describes Earth's movement from a reference point outside of Earth, somewhere in space.

---

1. to be without friends or neighbors
2. small particle
3. wanting one's own way in spite of the advice or wishes of another
4. a self-important show of being religious
Section 1 Describing Motion

1. Motion is a change of position of a body. Distance is the measure of how far an object moved. Displacement is the distance and direction of an object’s change in position from the starting point.

2. A reference point must be specified in order to determine an object’s position.

3. The speed of an object can be calculated from this equation:
   \[ s = \frac{d}{t} \]

4. The slope of a line on a distance-time graph is equal to the speed.

5. Velocity describes the speed and direction of a moving object.

Section 2 Acceleration

1. Acceleration occurs when an object changes speed or changes direction.

2. An object speeds up if its acceleration is in the direction of its motion.

3. An object slows down if its acceleration is opposite to the direction of its motion.

4. Acceleration is the rate of change of velocity, and is calculated from this equation:
   \[ a = \frac{v_f - v_i}{t} \]

Section 3 Motion and Forces

1. A force is a push or a pull.

2. The net force acting on an object is the combination of all the forces acting on the object.

3. The forces on an object are balanced if the net force is zero.

4. Inertia is the resistance of an object to a change in motion.

5. According to Newton’s first law of motion, the motion of an object does not change unless an unbalanced net force acts on the object.
Using Vocabulary

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>acceleration</td>
<td>p.47</td>
</tr>
<tr>
<td>average speed</td>
<td>p.42</td>
</tr>
<tr>
<td>balanced force</td>
<td>p.53</td>
</tr>
<tr>
<td>displacement</td>
<td>p.39</td>
</tr>
<tr>
<td>distance</td>
<td>p.39</td>
</tr>
<tr>
<td>force</td>
<td>p.52</td>
</tr>
<tr>
<td>inertia</td>
<td>p.54</td>
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<tr>
<td>instantaneous speed</td>
<td>p.42</td>
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<tr>
<td>net force</td>
<td>p.53</td>
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<tr>
<td>speed</td>
<td>p.39</td>
</tr>
<tr>
<td>velocity</td>
<td>p.44</td>
</tr>
</tbody>
</table>

Compare and contrast the following pairs of vocabulary words.

1. speed—velocity
2. distance—displacement
3. average speed—instantaneous speed
4. balanced force—net force
5. force—inertia
6. acceleration—velocity
7. velocity—instantaneous speed
8. force—net force
9. force—acceleration

Checking Concepts

Choose the word or phrase that best answers the question.

10. Which of the following do you calculate when you divide the total distance traveled by the total travel time?
   A) average speed
   B) constant speed
   C) variable speed
   D) instantaneous speed

11. Which term below best describes the forces on an object with a net force of zero?
   A) inertia
   B) balanced forces
   C) acceleration
   D) unbalanced forces

12. Which of the following is a proper unit of acceleration?
   A) s/km²
   B) km/h
   C) m/s²
   D) cm/s

13. Which of the following is not used in calculating acceleration?
   A) initial velocity
   B) average speed
   C) time interval
   D) final velocity

14. In which of the following conditions does the car NOT accelerate?
   A) A car moves at 80 km/h on a flat, straight highway.
   B) The car slows from 80 km/h to 35 km/h.
   C) The car turns a corner.
   D) The car speeds up from 35 km/h to 80 km/h.

15. What is the tendency for an object to resist any change in its motion called?
   A) net force
   B) acceleration
   C) balanced force
   D) inertia

16. How can speed be defined?
   A) acceleration/time
   B) change in velocity/time
   C) distance/time
   D) displacement/time

Interpreting Graphics

Use the table below to answer question 17.

<table>
<thead>
<tr>
<th>Distance-Time for Runners</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time (s)</strong></td>
</tr>
<tr>
<td><strong>Sally’s Distance (m)</strong></td>
</tr>
<tr>
<td><strong>Alonzo’s Distance (m)</strong></td>
</tr>
</tbody>
</table>

17. Make a distance-time graph that shows the motion of both runners. What is the average speed of each runner? Which runner stops briefly? Over what time interval do they both have the same speed?
18. Copy and complete this concept map on motion.

19. Evaluate Which of the following represents the greatest speed: 20 m/s, 200 cm/s, or 0.2 km/s?

20. Recognize Cause and Effect Acceleration can occur when a car is moving at constant speed. What must cause this acceleration?

21. Explain why a passenger who is not wearing a safety belt will likely hit the windshield in a head-on collision.

22. Determine If you walked 20 m, took a book from a library table, turned around and walked back to your seat, what are the distance traveled and displacement?

23. Explain When you are describing the rate that a race car goes around a track, should you use the term speed or velocity to describe the motion?

24. Calculate Speed A cyclist must travel 800 km. How many days will the trip take if the cyclist travels 8 h/day at an average speed of 16 km/h?

25. Calculate Acceleration A satellite’s speed is 10,000 m/s. After 1 min, it is 5,000 m/s. What is the satellite’s acceleration?

26. Calculate Displacement A cyclist leaves home and rides due east for a distance of 45 km. She returns home on the same bike path. If the entire trip takes 4 h, what is her average speed? What is her displacement?

27. Calculate Velocity The return trip of the cyclist in question 13 took 30 min longer than her trip east, although her total time was still 4 h. What was her velocity in each direction?

28. Interpret a Graph Use the graph below to answer question 28. Use the graph to determine which runner had the greatest speed.
**Part 1  Multiple Choice**

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

1. Sound travels at a speed of 330 m/s. How long does it take for the sound of thunder to travel 1485 m?
   - A. 45 s
   - B. 4.5 s
   - C. 4,900 s
   - D. 0.22 s

2. The graph shows how a cyclist’s speed changed over distance of 5 km. What is the cyclist’s average speed if the trip took 0.25 h?
   - A. 2 km/h
   - B. 30 km/h
   - C. 20 km/h
   - D. 8 km/h

3. Once the trip was started, how many times did the cyclist stop?
   - A. 0
   - B. 4
   - C. 2
   - D. 5

4. What was the fastest speed the cyclist traveled?
   - A. 20 km/h
   - B. 30 km/h
   - C. 12 km/h
   - D. 10 km/h

5. A skier is going down a hill at a speed of 9 km/s. The hill gets steeper and her speed increases to 18 m/s in 3 s. What is her acceleration?
   - A. 9 m/s²
   - B. 3 m/s²
   - C. 27 m/s²
   - D. 6 m/s²

6. Which of the following best describes an object with constant velocity?
   - A. It is changing direction.
   - B. Its acceleration is increasing.
   - C. Its acceleration is zero.
   - D. Its acceleration is negative.

7. Which of the following is a force?
   - A. friction
   - B. acceleration
   - C. inertia
   - D. velocity

8. What is Daisy’s average speed?
   - A. 0.29 km/min
   - B. 530 km/min
   - C. 2.9 km/min
   - D. 3.4 km/min

9. Which runner has the fastest average speed?
   - A. Daisy
   - B. Jane
   - C. Bill
   - D. Joe

10. The movement of the Australian plate pushes Australia north at an average speed of about 17 cm per year. What will Australia’s displacement be in meters in 1,000 years?
    - A. 170 m north
    - B. 170 m south
    - C. 1,700 m north
    - D. 1,700 m south

---

**Test-Taking Tip**

Read Carefully  Read each question carefully for full understanding.
11. The graph shows the motion of three swimmers during a 30-min workout. Which swimmer had the highest average speed over the 30-min time interval?

12. Did all the swimmers swim at a constant speed? Explain how you know.

13. Why is knowing just the speed at which a hurricane is traveling toward land not enough information to be able to warn people to evacuate?

14. If the speedometer on a car indicates a constant speed, can you be sure the car is not accelerating? Explain.

15. If a car is traveling at a speed of 40 km/h and then comes to a stop in 5 s, what is its acceleration in m/s²?

16. Describe three ways that your acceleration could change as you jog along a path through a park.

17. An object in motion slows down and comes to a stop. Use Newton’s first law of motion to explain why this happens.

18. Give an example of a force applied to an object that does not change the object’s velocity.

19. In an airplane flying at a constant speed, the force exerted by the engine pushing the airplane forward is equal to the opposite force of air resistance. Describe how these forces compare when the plane speeds up and slows down. In which direction is the net force on the airplane in each case?

20. Where would you place the location of a reference point in order to describe the motion of a space probe traveling from Earth to Jupiter? Explain your choice.

21. Use the table below to answer question 21.

<table>
<thead>
<tr>
<th>Car</th>
<th>Mass (kg)</th>
<th>Stopping distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1000</td>
<td>80</td>
</tr>
<tr>
<td>B</td>
<td>1250</td>
<td>100</td>
</tr>
<tr>
<td>C</td>
<td>1500</td>
<td>120</td>
</tr>
<tr>
<td>D</td>
<td>2000</td>
<td>160</td>
</tr>
</tbody>
</table>

21. What is the relationship between a car’s mass and its stopping distance? How can you explain this relationship?

22. Two cars approach each other. How does the speed of one car relative to the other compare with speed of the car relative to the ground?