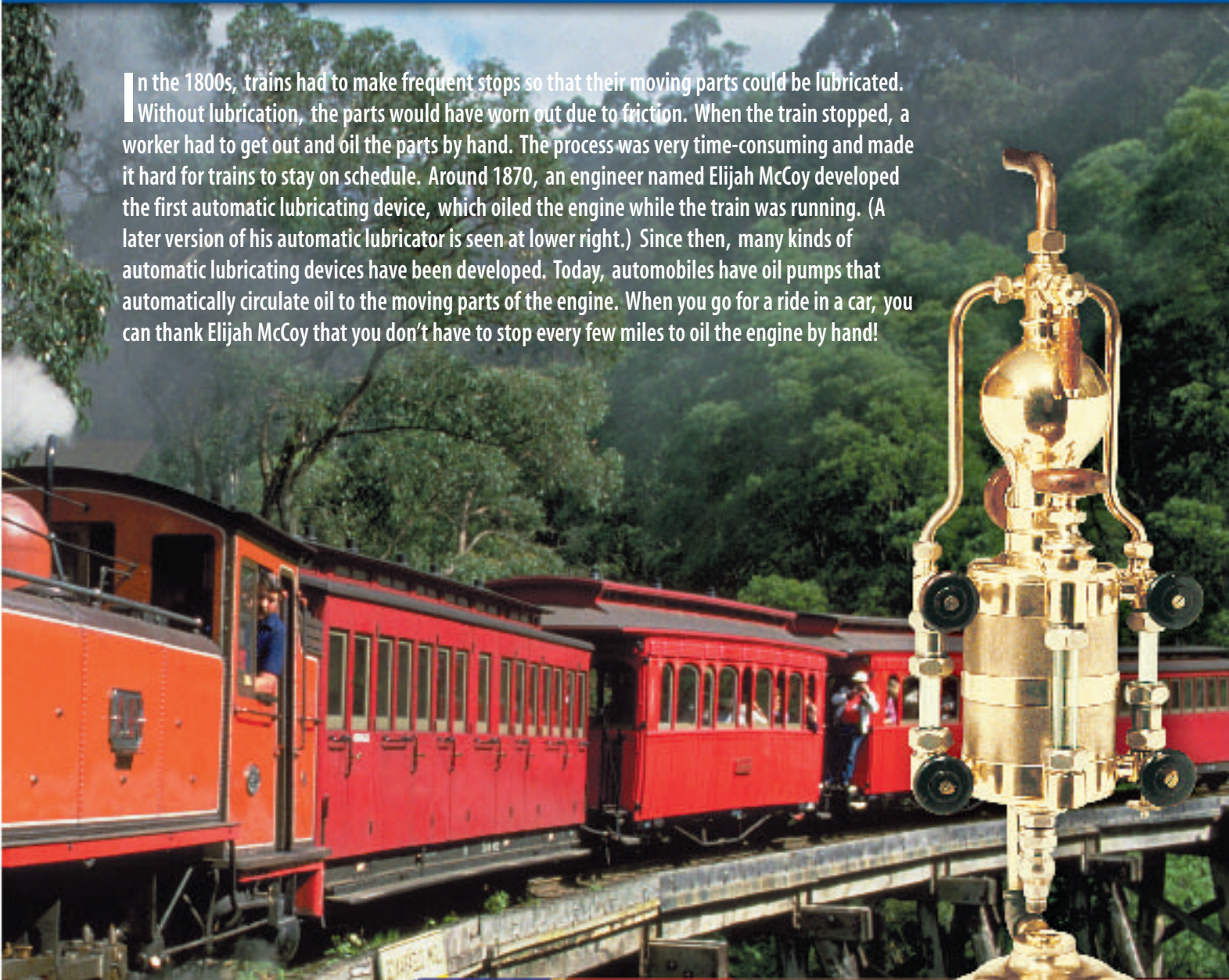


**How Are  
Train Schedules  
& Oil Pumps  
Connected?**



In the 1800s, trains had to make frequent stops so that their moving parts could be lubricated. Without lubrication, the parts would have worn out due to friction. When the train stopped, a worker had to get out and oil the parts by hand. The process was very time-consuming and made it hard for trains to stay on schedule. Around 1870, an engineer named Elijah McCoy developed the first automatic lubricating device, which oiled the engine while the train was running. (A later version of his automatic lubricator is seen at lower right.) Since then, many kinds of automatic lubricating devices have been developed. Today, automobiles have oil pumps that automatically circulate oil to the moving parts of the engine. When you go for a ride in a car, you can thank Elijah McCoy that you don't have to stop every few miles to oil the engine by hand!



## unit projects

Visit [red.msscience.com/unit\\_project](http://red.msscience.com/unit_project) to find project ideas and resources. Projects include:

- **Career** As a class, design a chart of the many fields of engineering and how they relate to conserving and protecting the environment.
- **Technology** Design and construct miniature models of energy-producing devices. Explain how your model works.
- **Model** Analyze locations for a future city. Consider what characteristics will make the best location and make a model of a portion of your design.



**Mag Lev Trains: Floating Locomotives** encourages understanding of magnets and their application in the transportation field.

Design a mag lev train and present it to the class.



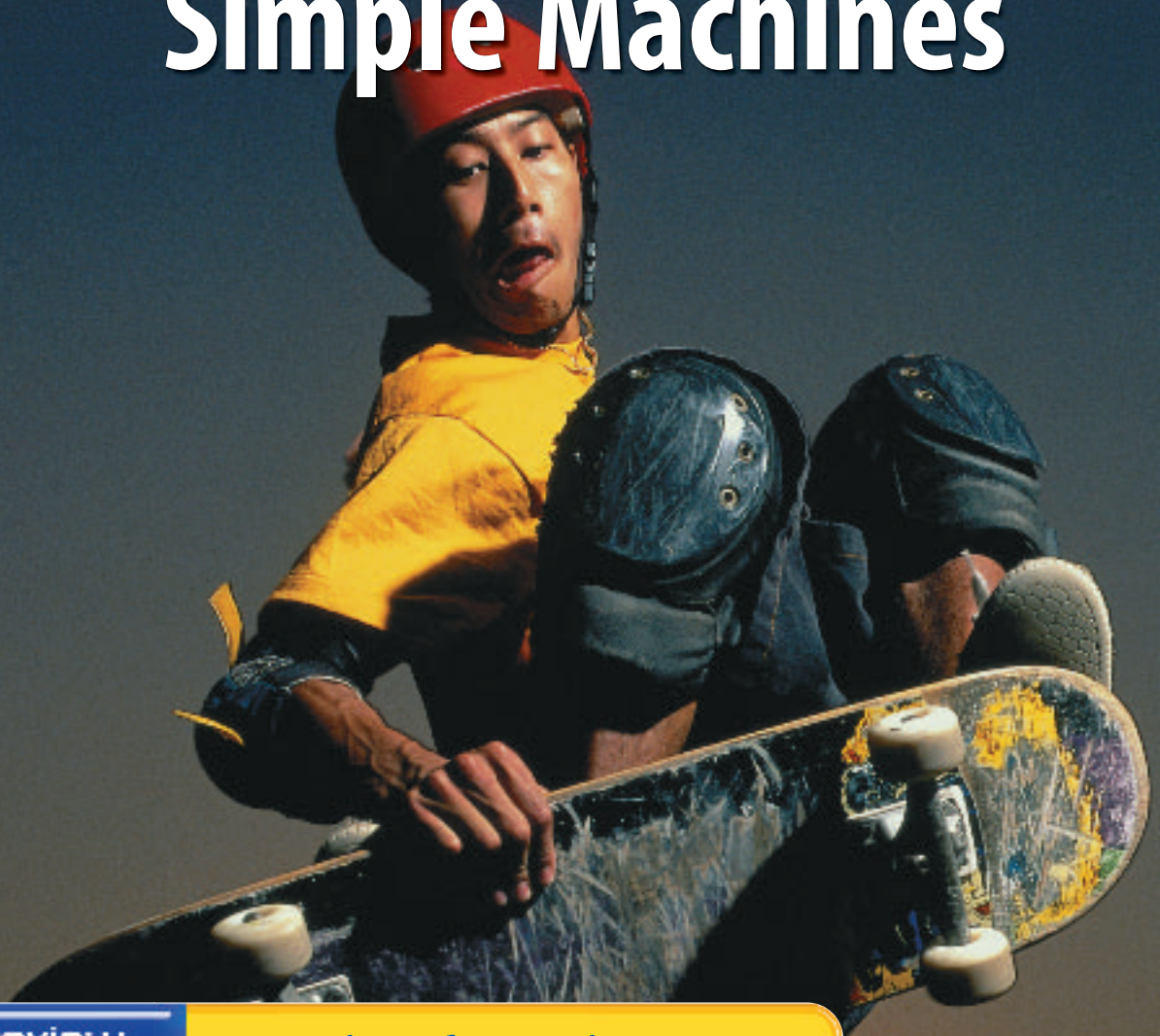


Español

chapter

5

# Motion, Forces, and Simple Machines



## chapter preview

### sections

- 1 Motion
- 2 Newton's Laws of Motion
- 3 Work and Simple Machines

*Lab Motion*

*Lab Methods of Travel*



*Virtual Lab How is momentum conserved in a vehicle collision?*

## Catching Some Air

This skateboarder pauses briefly in the air as he changes direction and begins his descent. How does his motion change as he reaches the bottom of the halfpipe and starts up the other side? In this chapter, you'll learn how forces affect motion.

**Science Journal** Write a paragraph comparing the motion of a ball and a paper airplane being thrown high in the air and returning to the ground.

# Start-Up Activities



## Model Halfpipe Motion

Skateboarders who can ride halfpipes make it look easy. They race down one side and up the other. They rise above the ledge and appear to float as they spin and return. They practice these tricks many times until they get them right. In this chapter, you'll learn how this complicated motion can be explained by forces such as gravity.

1. Use heavy paper or cardboard between two stacks of books to make a U-shaped ramp to model a halfpipe like the one in the picture. A marble will model the skateboard.
2. Release the marble from a point near the bottom of the curve. Observe the motion. How high does it go? When is its speed greatest?
3. Release the marble from a point near the top of the curve. Observe the motion. Compare this to the marble's motion in step 2.
4. **Think Critically** How did the different starting points affect how high the marble rolled up the other side?

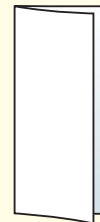


Preview this chapter's content and activities at [red.msscience.com](http://red.msscience.com)

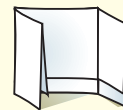
## FOLDABLES™ Study Organizer

**Describing and Explaining Motion** Make the following Foldable to help you understand motion, forces, and simple machines.

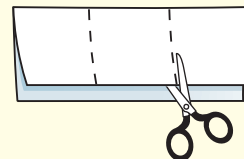
- STEP 1** **Fold** a vertical sheet of paper from side to side. Make the front edge about 1 cm shorter than the back edge.



- STEP 2** **Turn** lengthwise and **fold** into thirds.



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



- STEP 4** **Label** each tab.



**Identify Questions** Before you read the chapter, write what you already know about motion, forces, and simple machines under the left tab of your Foldable, and write questions about what you'd like to know under the center tab. After you read the chapter, list what you learned under the right tab.

# Motion

## as you read

### What You'll Learn

- **Define** speed and acceleration.
- **Relate** acceleration to change in speed.
- **Calculate** distance, speed, and acceleration.

### Why It's Important

Motion can be described using distance, time, speed, and acceleration.

### Review Vocabulary

**meter:** SI unit of distance, abbreviated "m," equal to approximately 39.37 in

### New Vocabulary

- average speed
- instantaneous speed
- velocity
- acceleration



## Speed

Imagine you're a snowboarder speeding down the side of a halfpipe. Your heart pounds as you move faster. As you reach the bottom, you are going fast, and you feel excitement and maybe even fear. You flow through the change in direction as you start up the other side. Your speed decreases as you move higher up the slope. When you reach the top, you are at a near standstill. If you think fast, you can grab hold of the ledge and take a break. Otherwise, you change direction and back down you go, speeding up again as you make your way along the U-shaped ramp.

To understand how to describe even complicated motion like this, think about the simpler movement of the bicycle in **Figure 1**. To describe how fast the bicycle is traveling, you have to know two things about its motion. One is the distance it has traveled, or how far it has gone. The other is how much time it took to travel that distance.

**Average Speed** A bike rider can speed up and slow down several times in a certain time period. One way to describe the bike rider's motion over this time period is to give the average speed. To calculate **average speed**, divide the distance traveled by the time it takes to travel that distance.

### Speed Equation

$$\text{average speed (in m/s)} = \frac{\text{distance traveled (in m)}}{\text{time (in s)}}$$

$$s = \frac{d}{t}$$

Because average speed is calculated by dividing distance by time, its units always will be a distance unit divided by a time unit. For example, the average speed of a bicycle is usually given in meters per second. The speed of a car usually has units of kilometers per hour instead.

**Figure 1** To find the biker's average speed, divide the distance traveled down the hill by the time taken to cover that distance.

**Infer** what would happen to the average speed if the hill were steeper.



## Applying Math Solve a Simple Equation

**BICYCLE SPEED** Riding your bike, it takes you 30 min to get to your friend's house, which is 9 km away. What is your average speed?

### Solution

- 1** *This is what you know:*
  - distance:  $d = 9$  km
  - time:  $t = 30$  min = 0.5 h
- 2** *This is what you need to find:* speed:  $s = ?$  m/s
- 3** *This is the procedure you need to use:* Substitute the known values for distance and time into the speed equation and calculate the speed:
 
$$s = \frac{d}{t}, \frac{9 \text{ km}}{0.5 \text{ h}} = 18 \text{ km/h}$$
- 4** *Check your answer:* Multiply your answer by the time. You should calculate the distance that was given.

### Practice Problems

1. If an airplane travels 1,350 km in 3 h, what is its average speed?
2. Determine the average speed, in km/h, of a runner who finishes a 5-km race in 18 min.



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**Instantaneous Speed** Average speed is useful if you don't care about the details of the motion. For example, suppose you went on a long road trip and traveled 640 km in 8 h. Your average speed was 80 km/h, even though you might have been stuck in a traffic jam for some of the time.

When your motion is speeding up and slowing down, it might be useful to know how fast you are going at a certain time. For example, suppose the speed limit on a part of the above trip was 50 km/h. Does your average speed of 80 km/h mean you were speeding during that part of the trip?

To keep from exceeding the speed limit, the driver would need to know the **instantaneous speed**—the speed of an object at any instant of time. When you ride in a car, the instantaneous speed is given by the speedometer, as shown in **Figure 2**. How does your instantaneous speed change as you coast on a bicycle down one hill and then up another one?



**Figure 2** The odometer in a car measures the distance traveled. The speedometer measures instantaneous speed.

**Describe** how you could use an odometer to measure average speed.



**Reading Check**

How is instantaneous speed different from average speed?



## INTEGRATE Earth Science

### Movement of Earth's Crust

The outer part of Earth is the crust. Earth's crust is broken into huge pieces called plates that move slowly. Research how fast plates can move. In your Science Journal, make a table showing the speeds of some plates.

**Constant Speed** Sometimes an object is moving such that its instantaneous speed doesn't change. When the instantaneous speed doesn't change, an object is moving with constant speed. Then the average speed and the instantaneous speed are the same.

**Calculating Distance** If an object is moving with constant speed, then the distance it travels over any period of time can be calculated using the equation for average speed. When both sides of this equation are multiplied by the time, you have the following new equation.

#### Distance Equation

$$\text{distance traveled (in m)} = \text{average speed (in m/s)} \times \text{time (in s)}$$
$$d = st$$

Notice that the units of time in the speed,  $s$ , and in the time,  $t$ , have to be the same. Otherwise, these units of time won't cancel.

## Applying Math

## Solve a Simple Equation

**FAMILY TRIP DISTANCE** It takes your family 2 h to drive to an amusement park at an average speed of 73 km/h. How far away is the amusement park?

### Solution

- This is what you know:*
  - speed:  $s = 73$  km/h
  - time:  $t = 2$  h
- This is what you need to know:* distance:  $d = ?$  m
- This is the procedure you need to use:* Substitute the known values for speed and time into the distance equation and calculate the distance:  
 $d = st = (73 \text{ km/h})(2 \text{ h}) = 146 \text{ km}$
- Check your answer:* Divide your answer by the time. You should get the speed that was given.

## Practice Problems

- You and your friends walk at an average speed of 5 km/h on a nature hike. After 6 h, you reach the ranger station. How far did you hike?
- An airplane flying from Boston to San Francisco traveled at an average speed of 830 km/h for 6 h. What distance did it fly?



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math\\_practice](http://red.msscience.com/math_practice)

## Velocity

Suppose you are walking at a constant speed on a street, headed north. You turn when you reach an intersection and start walking at the same speed, but you now are headed east, as shown in **Figure 3**. Your motion has changed, even though your speed has remained constant. To completely describe your movement, you would have to tell not only how fast you were moving, but also your direction. The **velocity** of an object is the speed of the object and its direction of motion.

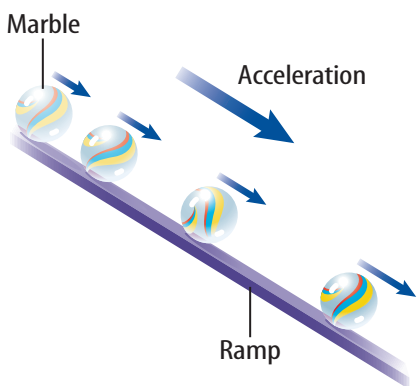
Velocity changes when the speed changes, the direction of motion changes, or both change. When you turned the corner at the intersection, your direction of motion changed, even though your speed remained constant. Therefore, your velocity changed.

## Acceleration

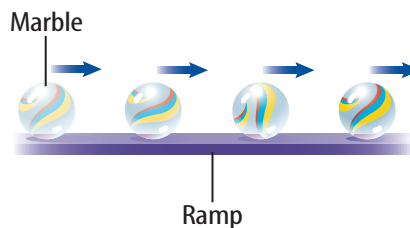
At the top of a skateboard halfpipe, you are at rest. Your speed is zero. When you start down, you smoothly speed up, going faster and faster. If the angle of the halfpipe were steeper, you would speed up at an even greater rate.

How could you describe how your speed is changing? If you changed direction, how could you describe how your velocity was changing? Just as speed describes how the distance traveled changes with time, acceleration describes how the velocity changes with time. **Acceleration** is the change in velocity divided by the time needed for the change to occur. **Figure 4** shows some examples of acceleration when the speed changes but the direction of motion stays the same.

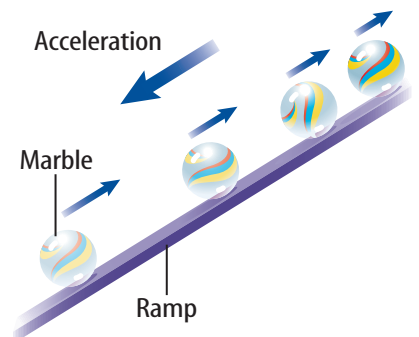
**Reading Check** *The motion of an object can change in what two ways when it accelerates?*



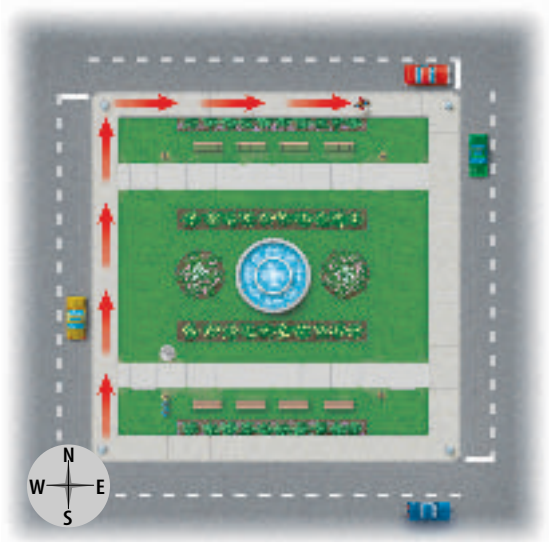
A marble rolling in a straight line down a hill speeds up. Its motion and acceleration are in the same direction.



This marble is rolling in a straight line on a level surface with constant velocity. Its acceleration is zero.



A marble rolling in a straight line up a hill slows down. Its motion and acceleration are in opposite directions.



**Figure 3** If you are walking north at a constant speed and then turn east, continuing at the same speed, you have changed your velocity.

**Identify** another way to change your velocity.

**Figure 4** If the speed but not direction of an object is changing, the object is accelerating. The direction of the acceleration depends on whether the object is speeding up or slowing down.





**Calculating Acceleration** If an object changes speed but not direction then its acceleration can be calculated from the following formula.

### Acceleration Equation

$$\text{acceleration (in m/s}^2\text{)} = \frac{\text{final speed (in m/s)} - \text{initial speed (in m/s)}}{t}$$

$$a = \frac{(s_f - s_i)}{t}$$

The SI units for acceleration are  $\text{m/s}^2$ , which means meters/(seconds  $\times$  seconds). The units  $\text{m/s}^2$  are the result when the units  $\text{m/s}$  are divided by the unit  $\text{s}$ .

## Applying Math

### Calculate Acceleration

**ACCELERATION DOWN A HILL** You are sliding on a snow-covered hill at a speed of 8 m/s. There is a drop that increases your speed to 18 m/s in 5 s. Find your acceleration.

#### Solution

- This is what you know:*
  - initial speed:  $s_i = 8 \text{ m/s}$
  - final speed:  $s_f = 18 \text{ m/s}$
  - time:  $t = 5 \text{ s}$
- This is what you need to know:* acceleration:  $a = ? \text{ m/s}^2$
- This is the procedure you need to use:* Substitute the known values for initial speed, final speed, and time into the acceleration equation
 
$$a = \frac{(s_f - s_i)}{t} = \frac{18 \text{ m/s} - 8 \text{ m/s}}{5 \text{ s}} = \frac{10 \text{ m/s}}{5 \text{ s}} = 2 \text{ m/s}^2$$
- Check your answer:* Multiply your answer by the time. Add the initial speed. You should get the final speed that was given.

### Practice Problems

- The roller coaster you are on is moving at 10 m/s. 5 s later it does a loop-the-loop and is moving at 25 m/s. What is the roller coaster's acceleration over this time?
- A car you're riding in is slowing down for a stoplight. It was initially traveling at 16 m/s and comes to a stop in 9 s. What is the car's acceleration?

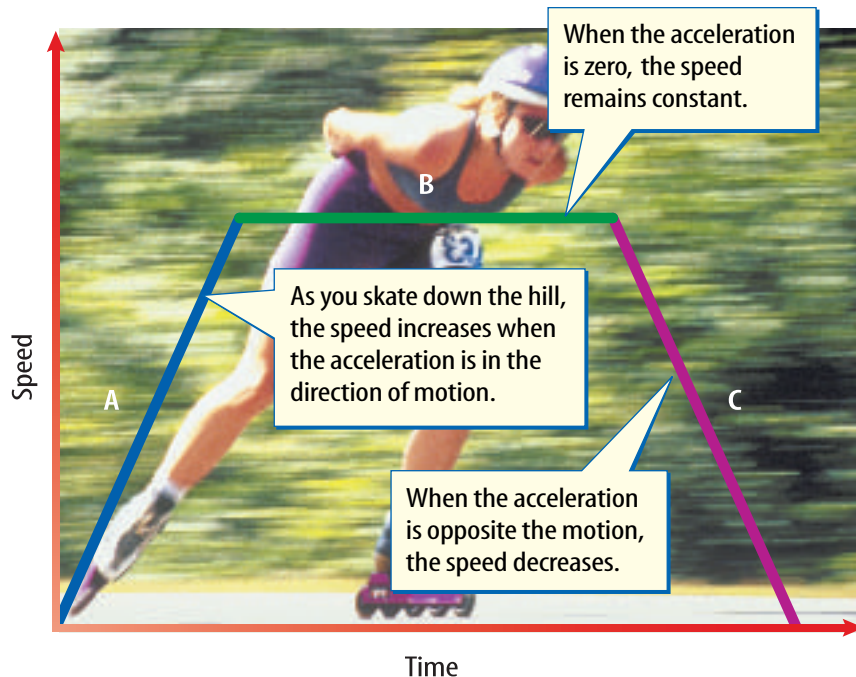
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**Graphing Speed** Picture yourself skating down the side of a hill, across a level valley, and then up another hill on the opposite side. If you were to graph your speed over time, it would look similar to the graph in **Figure 5**.

As you start down the hill, your speed will increase with time, as shown in segment A. The line on the graph rises when acceleration is in the direction of motion. When you travel across the level pavement, you move at a constant speed. Because your speed doesn't change, the line on the graph is horizontal, as shown in segment B. A horizontal line shows that the acceleration is zero. On the opposite side, when you are moving up the hill, your speed decreases, as shown in segment C. Anytime you slow down, acceleration is opposite the direction of motion, and the line on a speed-time graph will slant downward.



**Figure 5** The acceleration of an object can be shown on a speed-time graph.

## section 1 review

### Summary

#### Speed and Velocity

- Average speed is the distance traveled divided by the travel time:

$$s = \frac{d}{t}$$

- The velocity of an object is the speed of the object and the direction of motion.

#### Acceleration

- Acceleration is the change in the velocity divided by the time for the change to occur.
- For motion in a straight line acceleration can be calculated from this equation:

$$a = \frac{(s_f - s_i)}{t}$$

- The slope of a line on a speed-time graph shows an object's acceleration. The line slopes upward if the object is speeding up, and slopes downward if it is slowing down.

### Self Check

1. **Explain** If an airplane is flying at a constant speed of 500 km/h, can it be accelerating?
2. **Infer** whether the instantaneous speed of an object can be greater than its average speed.
3. **Determine** If your speed is constant, can your velocity be changing?
4. **Think Critically** Describe the motion of a skateboard as it accelerates down one side of a halfpipe and up the other side. What would happen if the up side of the pipe were not as steep as the down side?

### Applying Math

5. **Calculate Average Speed** During rush-hour traffic in a big city, it can take 1.5 h to travel 45 km. What is the average speed in km/h for this trip?
6. **Compare** the distances traveled and average speeds of the following two people: Sam walked 1.5 m/s for 30 s and Jill walked 2.0 m/s for 15 s and then 1.0 m/s for 15 s.

# Newton's Laws of Motion

## as you read

### What You'll Learn

- **Describe** how forces affect motion.
- **Calculate** acceleration using Newton's second law of motion.
- **Explain** Newton's third law of motion.

### Why It's Important

Newton's laws explain motions as simple as walking and as complicated as a rocket's launch.

### Review Vocabulary

**gravity:** attractive force between any two objects that depends on the masses of the objects and the distance between them

### New Vocabulary

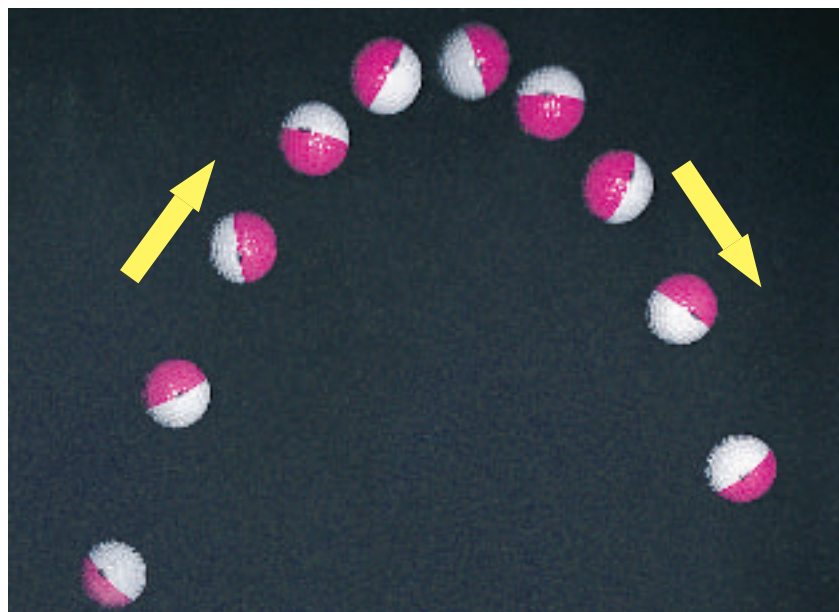
- force
- Newton's laws of motion
- friction
- inertia

## Force

What causes objects to move? In the lunchroom, you pull a chair away from a table before you sit down and push it back under the table when you leave. You exert a force on the chair and cause it to move. A **force** is a push or a pull. In SI units, force is measured in newtons (N). One newton is about the amount of force it takes to lift a quarter-pound hamburger.

**Force and Acceleration** For an object's motion to change, a force must be applied to the object. This force causes the object to accelerate. For example, when you throw a ball, as in **Figure 6**, your hand exerts a force on the ball, causing it to speed up. The ball has acceleration because the speed of the ball has increased.

A force also can change the direction of an object's motion. After the ball leaves your hand, if no one catches it, its path curves downward, and it hits the ground. Gravity pulls the ball downward and causes it to change direction, as shown in **Figure 6**. Recall that an object has acceleration when its direction of motion changes. The force of gravity has caused the ball to accelerate. Anytime an object's speed, or direction of motion, or both change, a force must have acted on the object.



**Figure 6** After a golf ball is thrown, it follows a curved path toward the ground.

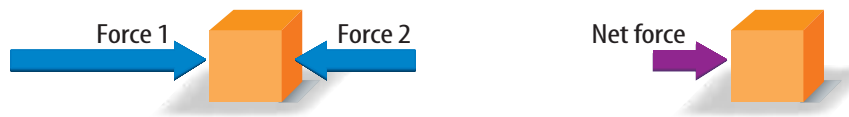
**Explain** how this curved path shows that the ball is accelerating.



When two forces act in the same direction on an object, like a box, the net force is equal to the sum of the two forces.



If two forces of equal strength act on the box in opposite directions, the forces will cancel, resulting in a net force of zero.



When two unequal forces act in opposite directions on the box, the net force is the difference of the two forces.

**Figure 7** When more than one force acts on an object, the forces combine to form a net force.

**Balanced and Unbalanced Forces** More than one force can act on an object without causing its motion to change. If both you and your friend push on a door with the same force in opposite directions, the door doesn't move. Two or more forces are balanced forces if their effects cancel each other and they do not cause a change in an object's motion. If the effects of the forces don't cancel each other, the forces are unbalanced forces.

**Combining Forces** Suppose you push on a door to open it. At the same time, someone on the other side of the door also is pushing. What is the motion of the door? When more than one force acts on an object, the forces combine. The combination of all the forces acting on an object is the net force.

How do forces combine to form the net force? If the forces are in the same direction, they add together to form the net force. If two forces are in opposite directions, the net force is the difference between the two forces and is in the direction of the larger force. **Figure 7** shows some examples of how forces combine to form the net force. If you push on a door with a larger force than the person on the other side pushes, the door moves in the direction of your push. If you push with the same force as the other person, the two forces cancel, and the net force is zero. In this case, the door doesn't move.



### Force and Seed

**Germination** For a fragile seedling to grow, it must exert enough force to push through the soil above it. The force exerted by the seedling as it pushes its way through the soil is due to the water pressure created inside its cells. New cells form as the seedling begins to grow underground. These cells take up water and expand, exerting a pressure that can be 20 times greater than atmospheric pressure. Research some of the factors that can affect how seedlings germinate. Write a paragraph in your Science Journal summarizing what you learned.



## Mini LAB

### Determining Weights in Newtons

#### Procedure:

1. Stand on a **bathroom scale** and measure your weight.
2. Hold a **large book**, stand on the scale, and measure the combined weight of you and the book.
3. Repeat step 2 using a **chair, heavy coat**, and a **fourth object** of your choice.

#### Analysis

1. Subtract your weight from each of the combined weights to calculate the weight of each object in pounds.
2. Multiply the weight of each object in pounds by 4.4 to calculate its weight in newtons.
3. Calculate your own weight in newtons.



## Newton's Laws of Motion

In 1665, Sir Isaac Newton was in college in London. The school temporarily closed down, though, because a deadly plague was spreading rapidly across Europe. Newton, who was 23 years old, returned to his house in the country to wait for the plague to end. During this time, he spent his days observing nature and performing simple experiments. As a result, he made many discoveries, including how to explain the effects of gravity. One of his great discoveries was how forces cause motion. He realized that he could explain the motion of objects using a set of principles, which in time came to be called **Newton's laws of motion**.

### Newton's First Law

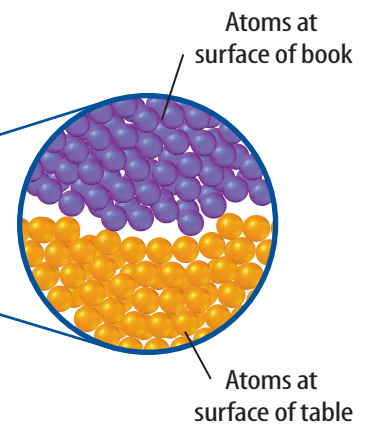
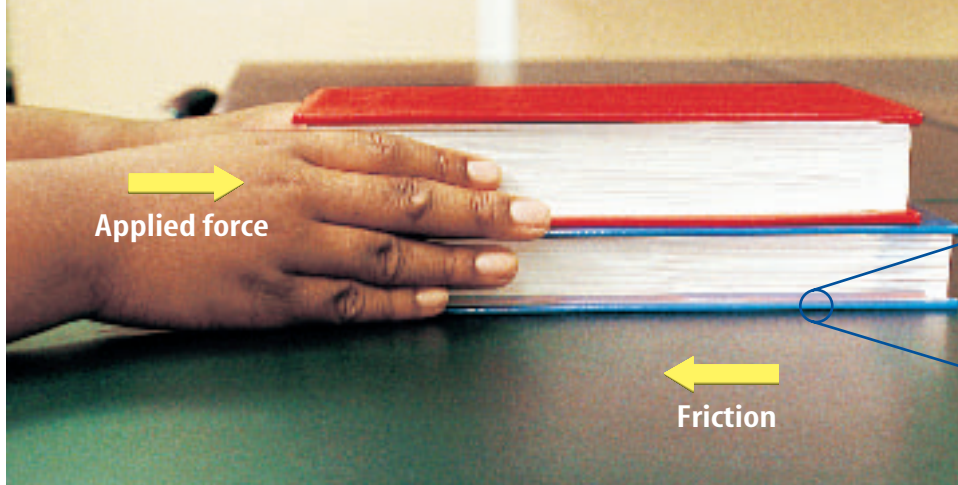
When you give a book on a table a push, it slides and comes to a stop. After you throw or hit a baseball, it soon hits the ground and rolls to a stop. In fact, it seems that anytime you set something in motion, it stops moving after awhile. You might conclude that to keep an object moving, a net force must always be exerted on the object. In reality, that's not true.

Newton and a few others before him realized that an object could be moving even if no net force was acting on it. Newton's first law of motion states that an object will not change its motion unless an unbalanced force acts on it. Therefore, an object that is not moving, like a book sitting on a table, remains at rest until something pushes or pulls it.

What if an object is already moving, like a ball you've just thrown to someone? Newton's first law says the motion of the ball won't change unless an unbalanced force is exerted on it. This means that after the ball is in motion, a force has to be applied to make it speed up, slow down, or change direction. In other words, a moving object, like the ball in **Figure 8**, moves in a straight line with constant speed unless an unbalanced force acts on it.

**Figure 8** After the ball has been hit, it will move along the ground in a straight line until it is acted on by another force.





**Friction** Newton's first law states that a moving object should never slow down or change direction until a force is exerted on it. Can you think of any moving objects that never slow down or change direction? A book slides across a table, slows down, and comes to a stop. Because its motion changes, a force must be acting on it and causing it to stop. This force is called friction.

**Friction** is a force between two surfaces in contact that resists the motion of the surfaces past each other. It always acts opposite to the direction of motion, as shown in **Figure 9**. To keep an object moving when friction is acting on it, you have to keep pushing or pulling on the object to overcome the frictional force.

 **Reading Check** *In what direction is the force of friction exerted?*

The size of the friction force depends on the two surfaces involved. In general, the rougher the surfaces are, the greater the friction will be. For example, if you push a hockey puck on an ice rink, it will go a great distance before it stops. If you try to push it with the same force on a smooth floor, it won't slide as far. If you push the puck on a rough carpet, it will barely move.

**Inertia and Mass** You might have noticed how hard it is to move a heavy object, such as a refrigerator, even when it has wheels. If you try pushing someone who is much bigger than you are—even someone who is wearing skates or standing on a skateboard—that person won't budge easily. It's easier to push someone who is smaller. You also might have noticed that it is hard to stop someone who is much bigger than you are when that person is moving. In each case, including the one shown in **Figure 10**, the object resists having its motion changed. This tendency to resist a change in motion is called **inertia**.

You know from experience that heavy objects are harder to move and harder to stop than light objects are. The more matter an object has, the harder it will be to move or stop. Mass measures the quantity of matter. The more mass an object has, the greater its inertia is.

**Figure 9** Friction is caused by the roughness of the surfaces in contact. The enlargement shows how the table and book surfaces might look if you could see their atoms.

**Figure 10** The cart has inertia and resists moving when you push it. **Compare** the inertia of the cart when empty to the inertia of the cart when holding the projector.





### Topic: Sir Isaac Newton

Visit [red.msscience.com](http://red.msscience.com) for Web links to information about the contributions made to science and mathematics by Sir Isaac Newton.

**Activity** Make a time line to show what you learn.

## Newton's Second Law

According to Newton's first law, a change in motion occurs only if a net force is exerted on an object. Newton's second law tells how a net force acting on an object changes the motion of the object. According to Newton's second law, a net force changes the velocity of the object and causes it to accelerate.

Newton's second law of motion states that if an object is acted upon by a net force, the acceleration of the object will be in the direction of the net force, and the acceleration equals the net force divided by the mass. According to the second law of motion, acceleration can be calculated from this equation:

### Newton's Second Law

$$\text{acceleration (in m/s}^2\text{)} = \frac{\text{net force (in N)}}{\text{mass (in kg)}}$$

$$a = \frac{F_{\text{net}}}{m}$$

## Applying Math

## Solve a Simple Equation

**ACCELERATION OF A BASKETBALL** You throw a 0.5-kg basketball with a force of 10 N. What is the ball's acceleration?

### Solution

- 1** *This is what you know:*
- mass:  $m = 0.5 \text{ kg}$
  - net force:  $F_{\text{net}} = 10 \text{ N}$

- 2** *This is what you need to know:* acceleration:  $a = ? \text{ m/s}^2$

- 3** *This is the procedure you need to use:* Substitute the known values for the net force,  $F_{\text{net}}$ , and mass,  $m$ , into the equation for Newton's second law:

$$a = \frac{F_{\text{net}}}{m} = \frac{10 \text{ N}}{0.5 \text{ kg}} = 20 \frac{\text{N}}{\text{kg}} = 20 \text{ m/s}^2$$

- 4** *Check your answer:* Multiply your answer by the mass. You should get the force that was given.

## Practice Problems

1. You push a 20-kg crate with a force of 40 N. What is the crate's acceleration?
2. Calculate the acceleration of an 80-kg sprinter starting out of the blocks with a force of 80 N.



For more practice, visit [red.msscience.com/math\\_practice](http://red.msscience.com/math_practice)



When pushing a refrigerator, which has a large mass, a large force is required to achieve a small acceleration.

**Mass and Acceleration** When a net force acts on an object, the object's acceleration depends on its mass. The more mass an object has, the more inertia it has, so the harder it is to accelerate. Imagine using the same force to push an empty grocery cart that you use to push a refrigerator, as shown in **Figure 11**. With the same force acting on the two objects, the refrigerator will have a much smaller acceleration than the empty cart. More mass means less acceleration if the force acting on the objects is the same.

If you were to push an empty grocery cart with the same force, its acceleration would be larger.

**Figure 11** The acceleration of an object depends on both the net force applied and the object's mass. **Compare** the accelerations of a 900-kg car and a 12-kg bicycle if the same net force of 2,000 N is applied to each.

## Newton's Third Law

Suppose you push on a wall. It might surprise you to know that the wall pushes back on you. According to Newton's third law, when one object exerts a force on a second object, the second object exerts an equal force in the opposite direction on the first object. For example, when you walk, you push back on the sidewalk and the sidewalk pushes forward on you with an equal force.

The force exerted by the first object is the action force. The force exerted by the second object is the reaction force. In **Figure 12**, the action force is the swimmer's push on the pool wall. The reaction force is the push of the pool wall on the swimmer. The action and reaction forces are equal, but in opposite directions.

**Figure 13** on the next page shows how Newton's laws affect astronauts in space and the motion of the space shuttle.

**Figure 12** When the swimmer pushes against the pool wall, the wall pushes back with an equal and opposite force.







Figure 13

**N**ewton's laws of motion are universal—they apply in space just as they do here on Earth. Newton's laws can be used to help design spacecraft by predicting their motion as they are launched into orbit around Earth and places beyond. Here are some examples of how Newton's laws affect space shuttle missions.

▼ Newton's second law explains why a shuttle remains in orbit. Earth exerts a gravitational force on a shuttle, causing the shuttle to accelerate. This acceleration causes the direction of the shuttle's motion to constantly change, so it moves in a circular path around the planet.



◀ According to Newton's third law, every action has an equal and opposite reaction. Launching a space shuttle demonstrates the third law. Fuel burning in the rocket's combustion chamber creates gases. The rocket exerts a force on these gases to expel them out of the nozzle at the bottom of the rocket. The reaction force is the upward force exerted on the rocket by the gases.



▶ According to Newton's first law, the motion of an object changes only if the object is acted upon by an unbalanced force. An astronaut outside the shuttle orbits Earth along with the shuttle. If the astronaut were to push on the shuttle, the shuttle would push on the astronaut. According to the first law of motion, this would cause the astronaut to move away from the shuttle.





**Force Pairs Act on Different Objects** If forces always occur in equal but opposite pairs, how can anything ever move? Won't the forces acting on an object always cancel each other? Recall that in Newton's third law, the equal and opposite forces act on different objects. When you push on the book, your force is acting on the book. When the book pushes back on you, its force is acting on you. One force of the force pair acts on the book, and the other force acts on you. Because the forces act on different objects, they don't cancel.

**Reading Check** Why don't action and reaction forces cancel?

**Examples of Newton's Third Law** Think about what happens when you jump from a boat, as shown in **Figure 14**. If you jump off a small boat, the boat moves back. You are pushing the boat back with your feet with the same force with which it is pushing you forward. Because you have more mass than the boat, it will accelerate more than you do. When you jump off a big boat with a large mass, the force you exert on the boat gives it only a tiny acceleration. You don't notice the large boat moving, but the force it exerts on you propels you to the dock.



**Figure 14** When you jump off a boat, your feet exert a force on the boat, which pushes it backward. The boat also exerts a force on your feet, which pushes you forward.

## section 2 review

### Force

- A force is a push or a pull.
- The net force is the combination of all the forces acting on an object.

### Newton's Laws of Motion

- Newton's first law of motion states that an object's motion will not change unless a force acts on the object.
- Newton's second law of motion states that an object accelerates in the direction of the net force and that the acceleration can be calculated from this equation:

$$a = \frac{F_{\text{net}}}{m}$$

- Newton's third law of motion states that when an object exerts a force on another object, the second object exerts an equal and opposite force on the first object.

### Self Check

1. **Explain** how the inertia of an object is related to the object's mass.
2. **Apply** If a force of 5 N to the left and a force of 9 N to the right act on an object, what is the net force?
3. **Infer** whether balanced forces must be acting on a car moving at a constant speed.
4. **Think Critically** A book sliding across a table slows down and comes to a stop. Explain whether this violates Newton's first law of motion.

### Applying Math

5. **Calculate Net Force** Find the net force exerted on a 0.15-kg ball that has an acceleration of 20 m/s<sup>2</sup>.
6. **Use a Spreadsheet** Enter the formula  $a = F_{\text{net}}/m$  into a spreadsheet. Find the acceleration for masses from 10 kg to 200 kg. Graph your results.

# Work and Simple Machines

## as you read

### What You'll Learn

- **Define** work.
- **Distinguish** the different types of simple machines.
- **Explain** how machines make work easier.

### Why It's Important

Machines make doing work easier.

### Review Vocabulary

**radius:** distance from the center of a circle to its edge

### New Vocabulary

- work
- simple machine
- compound machine
- mechanical advantage
- pulley
- lever
- inclined plane

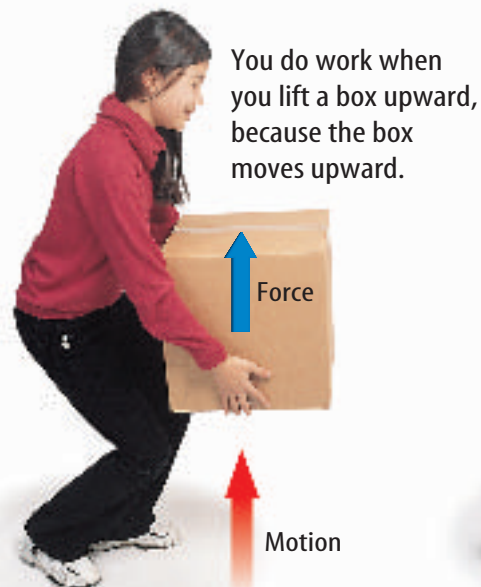
## Work

Newton's laws explain how forces change the motion of an object. If you apply a force upward on the box in **Figure 15**, it will move upward. Have you done any work on the box? When you think of work, you might think of doing household chores or even the homework you do every night. In science, the definition of work is more specific—**work** is done when a force causes an object to move in the same direction as the force that is applied.

**Effort Doesn't Always Equal Work** If you push against a wall, do you do work? For work to be done, two things must occur. First, you must apply a force to an object. Second, the object must move in the same direction as the force you apply. If the wall doesn't move, no work is done.

Picture yourself picking up and carrying the box in **Figure 15**. You can feel your arms exerting a force upward as you lift the box. The box moves upward in the direction of your force, so you have done work. If you carry the box forward, you still can feel your arms applying an upward force on the box, but the box is moving forward. Because the direction of motion is not the same as the direction of the force applied by your arms, no work is done by your arms.

Even though the box moves forward, your arms are exerting an upward force and do no work.



**Figure 15** Work is done only when an object moves in the direction of the applied force.



## Calculating Work

For work to be done, a force must be applied, and an object must move. The greater the force that is applied, the more work that is done. Which of these tasks would involve more work—lifting a shoe from the floor to your waist or lifting a pile of books the same distance? Even though the shoe and the books move the same distance, more work is done in lifting the books because it takes more force to lift the books. The work done can be calculated from the equation below.

### Work Equation

$$\text{work (in J)} = \text{force (in N)} \times \text{distance (in m)}$$

$$W = Fd$$

Work is measured in joules (J). The joule is named for James Prescott Joule, a nineteenth-century British physicist who showed that work and energy are related. Lifting a baseball from the ground to your waist requires about 1 J of work.



**Muscles and Work** Even though the wall doesn't move when you push against it, you may find yourself feeling tired. Muscles in your body contract when you push. This contraction is caused by chemical reactions in your muscles that cause molecules to move past each other. As a result, work is done by your body when you push. Research how a muscle contracts and describe what you learn in your Science Journal.

## Applying Math

### Solve a Simple Equation

**WEIGHT LIFTING** A weight lifter lifts a 500-N weight a distance of 2 m from the floor to a position over his head. How much work does he do?

#### Solution

- 1 *This is what you know:*
  - force:  $F = 500 \text{ N}$
  - distance:  $d = 2 \text{ m}$
- 2 *This is what you need to know:* work:  $W = ? \text{ J}$
- 3 *This is the procedure you need to use:* Substitute the known values for force and distance into the work equation and calculate the work:  

$$W = Fd = (500 \text{ N})(2 \text{ m}) = 1,000 \text{ N m} = 1,000 \text{ J}$$
- 4 *Check your answer:* Divide your answer by the distance. You should calculate the force that was given.

### Practice Problems

1. Using a force of 50 N, you push a computer cart 10 m across a classroom floor. How much work did you do?
2. How much work does an Olympic sprinter do while running a 200-m race with a force of 6 N?



For more practice, visit  
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**Figure 16** The can opener changes the small force of your hand on the handles to a large force on the blade that cuts into the can.

## What is a machine?

How many machines have you used today? Why did you use them? A machine is a device that makes work easier. A can opener like the one in **Figure 16** is a machine that changes a small force applied by your hand into a larger force that makes it easier to open the can.

A **simple machine** is a machine that uses only one movement. A screwdriver is an example of a simple machine. It requires only one motion—turning. Simple machines include the pulley, lever, wheel and axle, inclined plane, wedge, and screw. A **compound machine** is a combination of simple machines. The can opener is a compound machine that combines several simple machines. Machines can make work easier in two ways. They can change the size of the force you apply. They also can change the direction of the force.

 **Reading Check** *How do machines make work easier?*

**Mechanical Advantage** Some machines are useful because they increase the force you apply. The number of times the applied force is increased by a machine is called the **mechanical advantage** (MA) of the machine.

When you push on the handles of the can opener, the force you apply is called the input force ( $F_i$ ). The can opener changes your input force to the force that is exerted by the metal cutting blade on the can. The force exerted by a machine is called the output force ( $F_o$ ). The mechanical advantage is the ratio of the output force to the input force.

### Mechanical Advantage Equation

$$\text{mechanical advantage} = \frac{\text{force out (in N)}}{\text{force in (in N)}}$$

$$\text{MA} = \frac{F_o}{F_i}$$

**Work In and Work Out** In a simple machine the input force and the output force do work. For example, when you push on the handles of a can opener and the handles move, the input force does work. The output force at the blade of the can opener does work as the blade moves down and punctures the can.

An ideal machine is a machine in which there is no friction. Then the work done by the input force is equal to the work done by the output force. In other words, for an ideal machine, the work you do on the machine—work in—is equal to the work done by the machine—work out.



#### Topic: Early Tools

Visit [red.msscience.com](http://red.msscience.com) for Web links to information about early tools.

**Activity** Write a short story about the nineteenth-century in which the characters use at least three early tools. Include at least one picture or description showing how the tools make work easier.



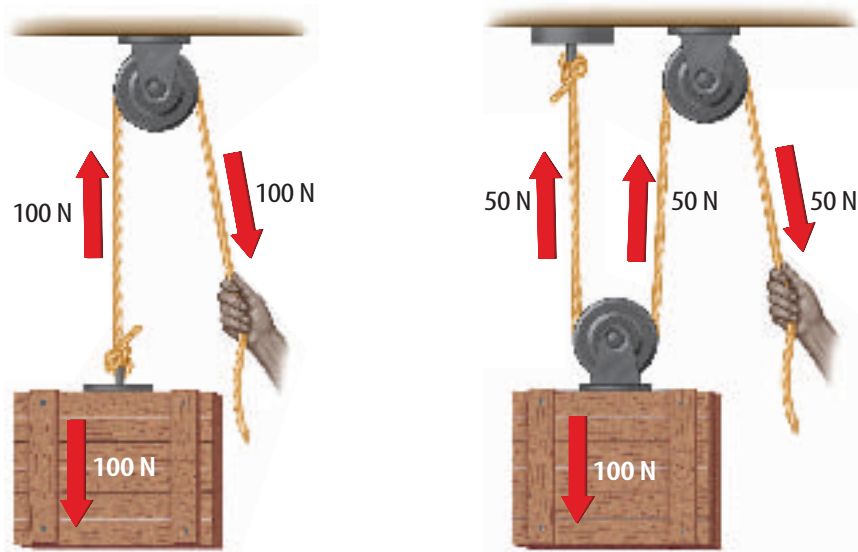
**Increasing Force** A simple machine can change a small input force into a larger output force. Recall that work equals force times distance. So, if the work in is equal to the work out, then smaller input force must be applied over a larger distance than the larger output force. Think again about the can opener. The can opener increases the force you apply at the handle. So the distance you move the handle is large compared to the distance the blade of the can opener moves as it pierces the can.

In all real machines, friction always occurs as one part moves past another. Friction causes some of the input work to be changed into heat, which can't be used to do work. So for a real machine, work out always will be less than work in.

## The Pulley

To raise a window blind, you pull down on a cord. The blind uses a pulley to change the direction of the force. A **pulley** is an object, like a wheel, that has a groove with a rope or cable running through it. A pulley changes the direction of the input force. A rope thrown over a railing can be used as a pulley. A simple pulley, such as the one shown in **Figure 17**, changes only the direction and not the size of the force, so its mechanical advantage is 1.

It is possible to have a large mechanical advantage if more than one pulley is used. The double-pulley system shown in **Figure 17** has a mechanical advantage of 2. Each supporting rope holds half of the weight, so the input force you need to supply to lift the weight is half as large as for a single pulley.



A single pulley changes the direction of the input force.

A combination of pulleys decreases the input force, so the mechanical advantage is greater than 1.

## Mini LAB

### Observing Mechanical Advantage—Pulleys

#### Procedure

1. Tie a 3-m-long rope to the middle of a broomstick or dowel and hold this stick horizontally. Another student should hold another stick horizontally. Wrap the rope around both sticks four times, leaving about 0.5 m between the sticks.
2. A third student should pull on the rope while the other two students try to keep the sticks from coming closer together.
3. Observe what happens. Repeat using only two wraps of the rope and then using eight wraps.

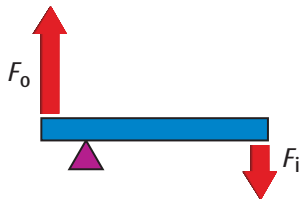
#### Analysis

1. Describe what you observed. Could the students hold the sticks apart?
2. Compare and contrast the results with two, four, and eight turns of the rope around the sticks.

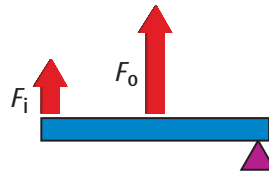
**Figure 17** A pulley changes the direction of the input force and can decrease the input force.



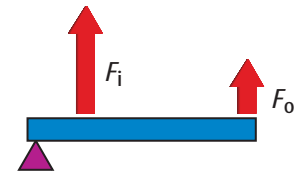
**Figure 18** A lever is classified according to the locations of the input force, output force, and fulcrum.



Sometimes a screwdriver is used as a first-class lever. The fulcrum is between the input and output forces.



A wheelbarrow is a second-class lever. The fulcrum is the wheel, and the input force is applied on the handles. The load, which is where the output force is applied, is between the input force and the fulcrum.



A hockey stick is a third-class lever. The fulcrum is your upper hand, and the input force is applied by your lower hand. The output force is applied at the bottom end of the stick.

## The Lever

Probably the first simple machine invented by humans was the lever. A **lever** is a rod or plank that pivots about a fixed point. The pivot point is called the fulcrum. Levers can increase a force or increase the distance over which a force is applied. There are three types, or classes, of levers. The three classes depend on the positions of the input force, the output force, and the fulcrum.

The three classes of levers are illustrated in **Figure 18**. In a first-class lever, the fulcrum is located between the input force and output force. Usually, a first-class lever is used to increase force, like a screwdriver used to open a can.

If the output force is between the input force and the fulcrum, as in a wheelbarrow, the lever is a second-class lever. The output force always is greater than the input force for this type of lever.

A hockey stick is a third-class lever. In a third-class lever, the input force is located between the output force and the fulcrum. The mechanical advantage of a third-class lever always is less than 1. A third-class lever increases the distance over which the input force is applied.



**The Wheel and Axle** Try turning a doorknob by holding the narrow base of the knob. It's much easier to turn the larger knob. A doorknob is an example of a wheel and axle. Look at **Figure 19**. A wheel and axle is made of two round objects that are attached and rotate together about the same axis. The larger object is called the wheel, and the smaller object is the axle. The mechanical advantage of a wheel and axle can be calculated by dividing the radius of the wheel by the radius of the axle.

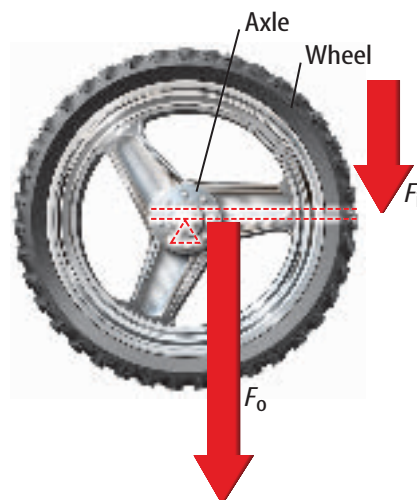
**Reading Check**

*How do the lever, pulley, and wheel and axle make work easier?*

## The Inclined Plane

An **inclined plane** is a sloped surface, sometimes called a ramp. It allows you to lift a heavy load by using less force over a greater distance. Imagine having to lift a couch 1 m off the ground onto a truck. If you used an inclined plane or ramp, as shown in **Figure 20**, you would have to move the couch farther than if you lifted it straight up. Either way, the amount of work needed to move the couch would be the same. Because the couch moves a longer distance up the ramp, doing the same amount of work takes less force.

The mechanical advantage of an inclined plane is the length of the inclined plane divided by its height. The longer the ramp is, the less force it takes to move the object. Ramps might have enabled the ancient Egyptians to build their pyramids. To move limestone blocks having a mass of more than 1,000 kg each, archaeologists hypothesize that the Egyptians built enormous ramps.



**Figure 19** The radius of the wheel is greater than the radius of the axle. The mechanical advantage of the wheel and axle is greater than 1 because the radius of the wheel is greater than the radius of the axle.



**Figure 20** It is much easier to load this couch into a truck using a ramp. Even though the couch must be pushed a greater distance, less force is required.





**Figure 21** Plant-eaters and meat-eaters have different teeth.



These wedge-shaped teeth enable a meat-eater to tear meat.



The teeth of a plant-eater are flatter and used for grinding.



**The Wedge** When you take a bite out of an apple, you are using wedges. A wedge is a moving inclined plane with one or two sloping sides. Your front teeth are wedges. A wedge changes the direction of the input force. As you push your front teeth into the apple, the downward input force is changed by your teeth into a sideways force that pushes the skin of the apple apart. Knives and axes also are wedges that are used for cutting.

**Figure 21** shows that the teeth of meat-eaters, or carnivores, are more wedge-shaped than the teeth of plant-eaters, or herbivores. The teeth of carnivores are used to cut and rip meat, whereas herbivores' teeth are used for grinding plant material. Scientists can determine what a fossilized animal ate when it was living by examining its teeth.

**The Screw** A road going up a mountain usually wraps around the mountain. Such a road is less steep than a road straight up the side of the mountain, so it's easier to climb. However, you travel a greater distance to climb the mountain on the mountain road. The mountain road is similar to a screw. A screw is an inclined plane wrapped around a post. The inclined plane forms the screw threads. Just like a wedge, a screw also changes the direction of the force you apply. When you turn a screw, the input force is changed by the threads to an output force that pulls the screw into the material. Friction between the threads and the material holds the screw tightly in place.

## section 3 review

### Summary

#### Work

- Work is done when an object moves in the direction of the applied force.
- Work can be calculated from the equation  $W = Fd$ .

#### Simple machines

- Machines are devices that make work easier.
- Mechanical advantage is the number of times the input force is increased by a machine.
- A simple machine is a machine that does work with only one motion.
- The six simple machines are the pulley, lever, wheel and axle, inclined plane, wedge, and screw.

### Self Check

1. **Describe** three different ways that using a machine makes doing work easier.
2. **Explain** why the output work is always less than the input work in a real machine.
3. **Compare** a wheel and axle to a lever.
4. **Think Critically** Identify two levers in your body. Which class of lever do the body levers belong to?

### Applying Math

5. **Calculate Work** Find the work needed to lift a limestone block weighing 10,000 N a distance of 150 m.
6. **Calculate Input Force** Find the input force needed to lift a stone slab weighing 2,500 N using a pulley system with a mechanical advantage of 10.

# Motion

What happens when you roll a small ball down a ramp? It speeds up as it travels down the ramp, and then it rolls across the floor and eventually it stops. You know that as the ball travels down the ramp, gravity is acting to make it speed up. Think about the forces that are acting on the ball as it rolls across the floor. Is there a net force acting on the ball? How would you describe the motion of the ball?



## Real-World Question

How does a ball move when the forces acting on it are balanced and when they are unbalanced?

### Goals

- **Demonstrate** the motion of a ball with unbalanced and balanced forces acting on it.
- **Graph** the position versus time for the motion of the ball.

### Materials

small ball or marble      stopwatch  
meterstick or tape measure      graph paper

### Safety Precautions



## Procedure

1. Place the ball on the floor or a smooth, flat surface.
2. Roll the ball across the floor by giving it a gentle push.
3. **Record Data** As the ball is rolling and no longer being pushed, have one student keep track of the time and have other students record the distance at 1-s intervals for at least 5 s to 10 s.
4. **Record** anything else that you observed about how the ball moved.

5. **Calculate** from your data the distance the ball has traveled at each second.
6. **Make a graph** of the distance the ball travels versus time. Plot the distance traveled on the vertical  $y$ -axis and the time on the horizontal  $x$ -axis.
7. Choose three one-second time intervals. **Calculate** the speed of the ball in each of those time intervals.

## Conclude and Apply

1. **Describe** how the speed of the ball changes as it rolls along the floor.
2. **Describe** the forces acting on the ball before you pushed it and it was at rest. **Infer** whether the forces acting on the ball were balanced or unbalanced.
3. **Describe** the forces acting on the ball as it rolled across the floor. **Infer** whether the forces acting on the ball were balanced or unbalanced.

## Communicating Your Data

Compare your graphs and results with those of other students in your class.

## Methods of Travel

### Goals

- **Research** travel times.
- **Compare** travel times for different methods of travel.
- **Evaluate** the fastest way to travel between two locations.
- **Design** a table to display your findings and communicate them to other students.

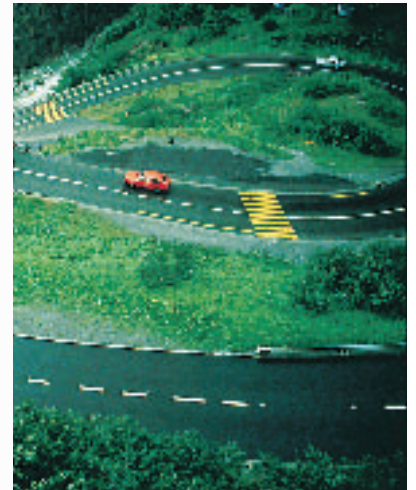
### Data Source



Visit [red.msscience.com/internet\\_lab](http://red.msscience.com/internet_lab) for more information on travel times, methods of travel, distances between locations, and data from other students.

### Real-World Question

How long does it take you to get to the other side of town? How long does it take to get to the other side of the country? If you were planning a road trip from New York City to Los Angeles, how long would it take? How would your trip change if you flew instead? When you plan a trip or vacation, it is useful to first estimate your travel time. Travel time depends on the vehicle you use, how fast you travel, the route you take, and even the terrain. For example, driving over rugged mountains can take longer than driving over flat farmland. With this information, you can plan your trip so you arrive at your final destination on time. Form a hypothesis about what is the fastest form of travel.



### Make a Plan

1. **Choose** a starting point and a final destination.
2. **Identify** the routes commonly used between these two locations.



(t) Helmut Gritscher/Peter Arnold, Inc., (b) Jonathan Naurok/PhotoEdit, Inc.

## Using Scientific Methods

3. **Determine** the common forms of travel between these two locations.
4. **Research** how to estimate travel time. What factors can make your trip take more or less time?



### **Follow Your Plan**

1. Make sure your teacher approves your plan before you start.
2. **Calculate** the travel time and distance between your two locations for different methods of travel.
3. **Record** your data in your Science Journal.

### **Analyze Your Data**

1. **Analyze** the data recorded in your Science Journal to determine the fastest method of travel. Was it better to drive or fly? Did you investigate another method of travel?
2. **Calculate** the average speed of the methods of travel you investigated. Which method had the fastest speed? Which method had the slowest?
3. **Organize Data** Use a computer (home, library, or computer lab) to create a chart that compares the travel times, average speeds, and distances for different methods of travel. Use your chart to determine the fastest method of travel. What other factors affect which method of travel you choose?

### **Conclude and Apply**

1. **Compare** your findings to those of your classmates and data posted at the Web link to the right. What is the greatest distance investigated? The shortest?
2. **Draw Conclusions** What factors can affect travel time for the different methods? How would your travel time be different if you didn't have a direct flight?
3. **Infer** how the average speed of an airplane flight would change if you included your trips to and from the airport and waiting time in your total travel time.

### **Communicating Your Data**

Find this lab using the link below. Post your data in the table provided. Combine your data with those of other students and make a class travel booklet that estimates travel times for various locations around the world.

 ScienceOnline

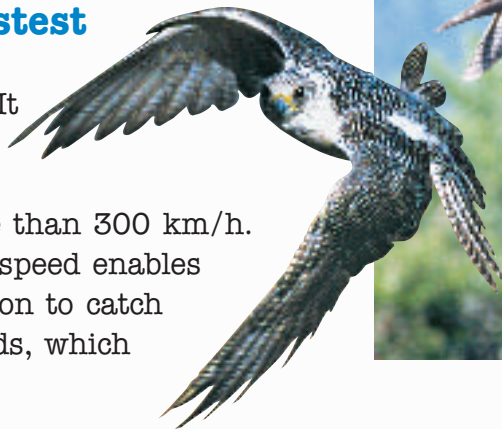
[red.msscience.com/internet\\_lab](http://red.msscience.com/internet_lab)

## Fastest Facts

### Did you know...

#### ...Nature's fastest creature

is the peregrine falcon. It swoops down on its prey, traveling at speeds of more than 300 km/h. That tremendous speed enables the peregrine falcon to catch and kill other birds, which are its main prey.



#### ...The Supersonic Transport (SST)

was the world's fastest passenger jet, and cruised at twice the speed of sound. Traveling at 2,150 km/h, the SST could travel from New York to London—a distance of about 5,600 km—in 2 h 55 min 45 s.

#### Applying Math

How long would it take a peregrine falcon moving at top speed to fly from New York to London?

#### ...The fastest animal on land

is the cheetah. This large cat can sprint at speeds of over 100 km/h. That is about as fast as a car traveling at freeway speeds, though the cheetah can only maintain top speed for a few hundred meters.



### Graph It

Visit [red.msscience.com/science\\_stats](http://red.msscience.com/science_stats) to find the top speeds of four or five land animals. Create a bar graph that compares the speeds.

## Reviewing Main Ideas

### Section 1 Motion

1. Average speed is the distance traveled divided by the time:  $s = d/t$ .
2. An object is accelerating when its speed and/or direction of motion changes.
3. Acceleration can be calculated by dividing the change in speed by the time.

### Section 2 Newton's Laws of Motion

1. Newton's first law states that an object will remain at rest or move at constant speed if no net force is acting on it.
2. Newton's second law states that acceleration is given by this equation:  $a = F_{\text{net}}/m$ .

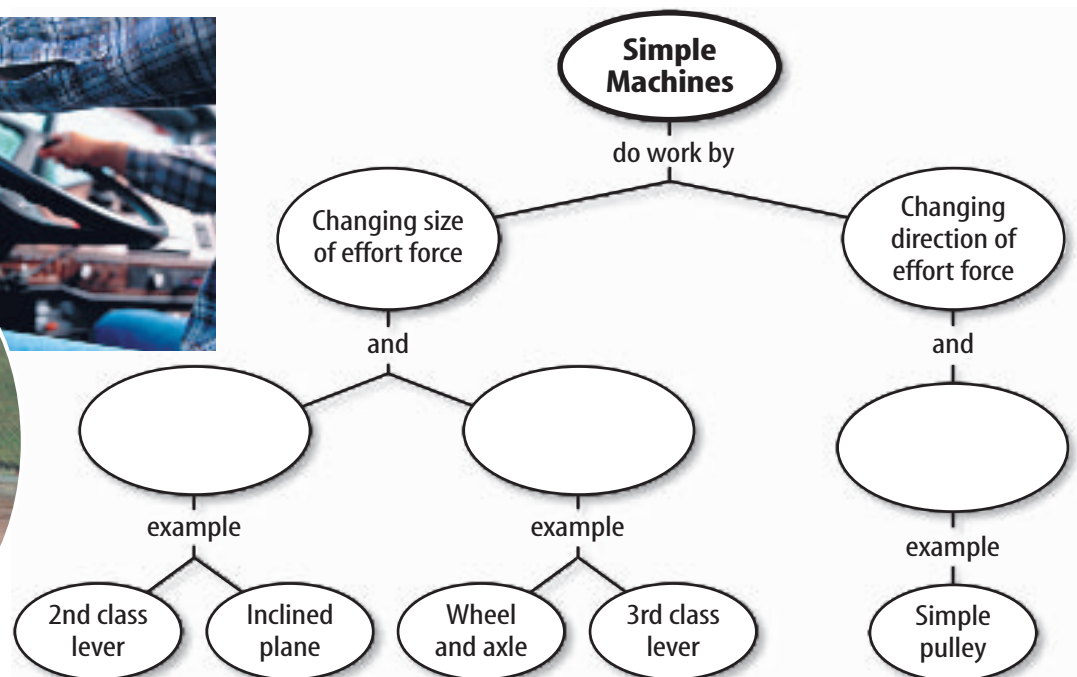
3. Newton's third law states that forces occur in equal but opposite pairs.

### Section 3 Work and Simple Machines

1. Work equals force applied times the distance over which the force is applied:  $W = Fd$ .
2. A machine is a device that makes work easier. It can increase force or distance, or change the direction of an applied force.
3. The mechanical advantage is the output force divided by the input force.
4. The six types of simple machines are the lever, pulley, wheel and axle, inclined plane, wedge, and screw.

## Visualizing Main Ideas

Copy and complete the following concept map on simple machines.



## Using Vocabulary

acceleration p. 133	lever p. 148
average speed p. 130	mechanical advantage p. 146
compound machine p. 146	Newton's laws of motion p. 138
force p. 136	pulley p. 147
friction p. 139	simple machine p. 146
inclined plane p. 149	velocity p. 133
inertia p. 139	work p. 144
instantaneous speed p. 131	

For each set of vocabulary words below, explain the relationship that exists.

1. inertia—force
2. acceleration—velocity
3. lever—pulley
4. force—work
5. work—simple machine
6. Newton's laws of motion—force
7. friction—force
8. force—mechanical advantage
9. average speed—instantaneous speed
10. simple machine—compound machine

## Checking Concepts

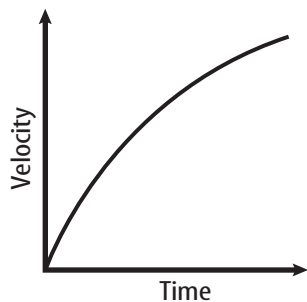
Choose the word or phrase that best answers the question.

11. What decreases friction?
  - A) rough surfaces
  - B) smooth surfaces
  - C) more speed
  - D) more surface area
12. What happens when an unbalanced force is applied to an object?
  - A) The object accelerates.
  - B) The object moves with constant velocity.
  - C) The object remains at rest.
  - D) The force of friction increases.
13. Which is an example of a simple machine?
  - A) baseball bat
  - B) scissors
  - C) can opener
  - D) car
14. What simple machines make up an ax?
  - A) a lever and a wedge
  - B) two levers
  - C) a wedge and a pulley
  - D) a lever and a screw
15. A car is driving at constant velocity. Which of the following is NOT true?
  - A) All the forces acting are balanced.
  - B) A net force keeps it moving.
  - C) The car is moving in a straight line with constant speed.
  - D) The car is not accelerating.
16. A large truck bumps a small car. Which of the following is true?
  - A) The force of the truck on the car is greater.
  - B) The force of the car on the truck is greater.
  - C) The forces are the same.
  - D) No force is involved.
17. What are the units for acceleration?
  - A)  $m/s^2$
  - B)  $kg\ m/s^2$
  - C)  $m/s$
  - D) N
18. What is inertia related to?
  - A) speed
  - B) gravity
  - C) mass
  - D) work
19. Which of the following is a force?
  - A) inertia
  - B) acceleration
  - C) speed
  - D) friction
20. How does a fixed pulley make doing work easier?
  - A) It decreases the distance over which the input force needs to be applied.
  - B) It changes the direction of the input force.
  - C) It increases the input force.
  - D) It decreases the input force.

**Thinking Critically**

- 21. Apply** You run 100 m in 25 s. If you then run the same distance in less time, how does your average speed change?

Use the graph below to answer question 22.



- 22. Make and Use Graphs** A sprinter's speed over a 100-m dash is shown in the graph below. Was the sprinter speeding up, slowing down, or running at a constant speed?
- 23. Explain** why a fast-moving freight train might take several kilometers to stop after the brakes have been applied.
- 24. Measure in SI** Which of the following speeds is the fastest: 20 m/s, 200 cm/s, or 0.2 km/s? Here's a hint: *Express all the speeds in meters per second and compare.*
- 25. Draw Conclusions** You are rolling backward down a hill on your bike and use your brakes to stop. In what direction was the acceleration?
- 26. Infer** whether the forces acting on a car are balanced or unbalanced if the car is turning while moving at a constant speed.
- 27. Compare** the force of friction on a book with the force you apply when you push a book across a table at constant speed.

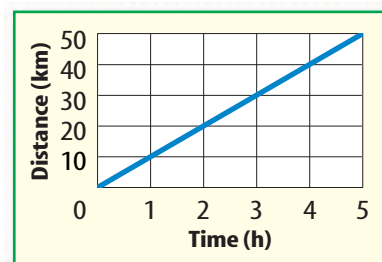
**Performance Activities**

- 28. Oral Presentation** Prepare a presentation, with props, to explain one of Newton's laws of motion to a third-grade class.
- 29. Invention** Design a human-powered compound machine to do a specific job. Identify the simple machines used in your design, and describe what each of the simple machines does.

**Applying Math**

- 30. Work** Find the work done by a force of 30 N exerted over a distance of 3 m.
- 31. Mechanical Advantage** Find the mechanical advantage of a ramp 8 m long that extends from the sidewalk to a 2-m-high porch.
- 32. Force** Find the force exerted by the rocket engines on a space shuttle that has a mass of 2 million kg if it accelerates at  $30 \text{ m/s}^2$ .

Use the graph below to answer question 33.



- 33. Speed and Time** The graph above is a distance-time graph of Marion's bicycle ride. What is Marion's average speed? How long did it take her to travel 25 km?
- 34. Work** At the 1976 Olympics, Vasili Aleseev shattered the world record for weight lifting when he lifted 2,500 N from the floor to over his head, a point 2 m above the ground. How much work did he do?



## Part 1 Multiple Choice

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

- What happens when a ball rolls uphill?
  - Its speed increases.
  - Its acceleration is zero.
  - Its motion and acceleration are in the same direction.
  - Its motion and acceleration are in opposite directions.
- Which of the following is a second-class lever?
 

A. wheelbarrow	C. scissors
B. hockey stick	D. crowbar

Use the figure below to answer questions 3 and 4.



- What is this simple machine called?
 

A. wedge	C. pulley
B. inclined plane	D. screw
- Which of the following statements is true when you use this simple machine?
  - Less force is needed to move the couch.
  - More force is needed to move the couch.
  - The couch is moved a shorter distance.
  - Less work is needed to move the couch.
- Which of the following is the force that resists sliding motion between two surfaces in contact?
 

A. inertia	C. friction
B. acceleration	D. gravity

- How much work do you do if you push with a force of 33 N on a box while sliding it 11 m?
 

A. 22 J	C. 3 J
B. 363 J	D. 44 J
- Which of the following is NOT true about what machines are used to do?
  - They make it easier to do work.
  - They change the direction of a force.
  - They increase the amount of work done on an object.
  - They reduce the force needed to do the work.

Use the figure below to answer questions 8 and 9.

- What does the odometer in a car measure?
  - average speed
  - instantaneous speed
  - distance
  - constant speed
- What does a car's speedometer measure?
  - average speed
  - instantaneous speed
  - distance
  - constant speed
- A skier is going down a hill at a speed of 9 m/s. The hill gets steeper and her speed increases to 18 m/s in 3 s. What is her acceleration?
 

A. $9 \text{ m/s}^2$	C. $3 \text{ m/s}^2$
B. $27 \text{ m/s}^2$	D. $6 \text{ m/s}^2$
- Which of the following does not include a direction?
 

A. displacement	C. speed
B. force	D. velocity

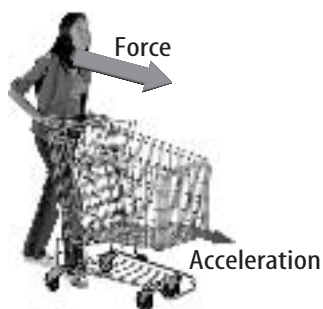


## Part 2 Short Response/Grid In

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

12. How much work do you do if you push with a force of 100 N on a desk that does not move?
13. How is a wedge like an inclined plane?
14. Using a pulley system with a mechanical advantage of 15, how large an input force would be needed to lift a piano weighing 345 N?
15. If a car is traveling at a speed of 120 m/s and then comes to a stop in 5 s, what is its acceleration?

Use the figure below to answer questions 15 and 16.



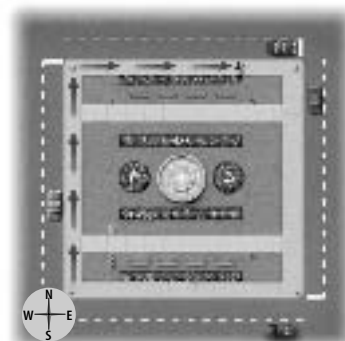
16. If the cart has a mass of 25 kg and the girl pushes with a force of 10 N, what is the cart's acceleration?
17. How would filling the grocery cart with canned goods affect its acceleration if the girl pushes with the same force? Explain.
18. If Newton's first law of motion is correct, why do moving objects on Earth eventually stop moving?
19. What simple machines make up scissors?
20. If two teams in a tug-of-war pull on the rope with the same force, but in opposite directions, what can you say about the net force on the rope?

## Part 3 Open Ended

Record your answers on a sheet of paper.

21. How do safety belts in cars protect people against the effects of Newton's first law of motion?

Use the figure below to answer questions 21 and 22.



22. Describe what happens to your velocity as you walk along the path shown.
23. Describe three ways that your acceleration could change as you walk along the path.
24. Use Newton's third law of motion to explain the direction a boat crew must work the oars to move the boat forward.
25. A man decides to move some furniture in the back of his pick-up truck. What should the driver remember from Newton's second law when the pick-up is carrying a heavy load?
26. Explain the difference between an ideal machine and a real machine in terms of work in and work out.
27. Explain the differences between the three classes of levers in term of the location of the fulcrum, input force, and output force or load.
28. Explain why a child riding in a circle on a merry-go-round at a constant speed is accelerating.