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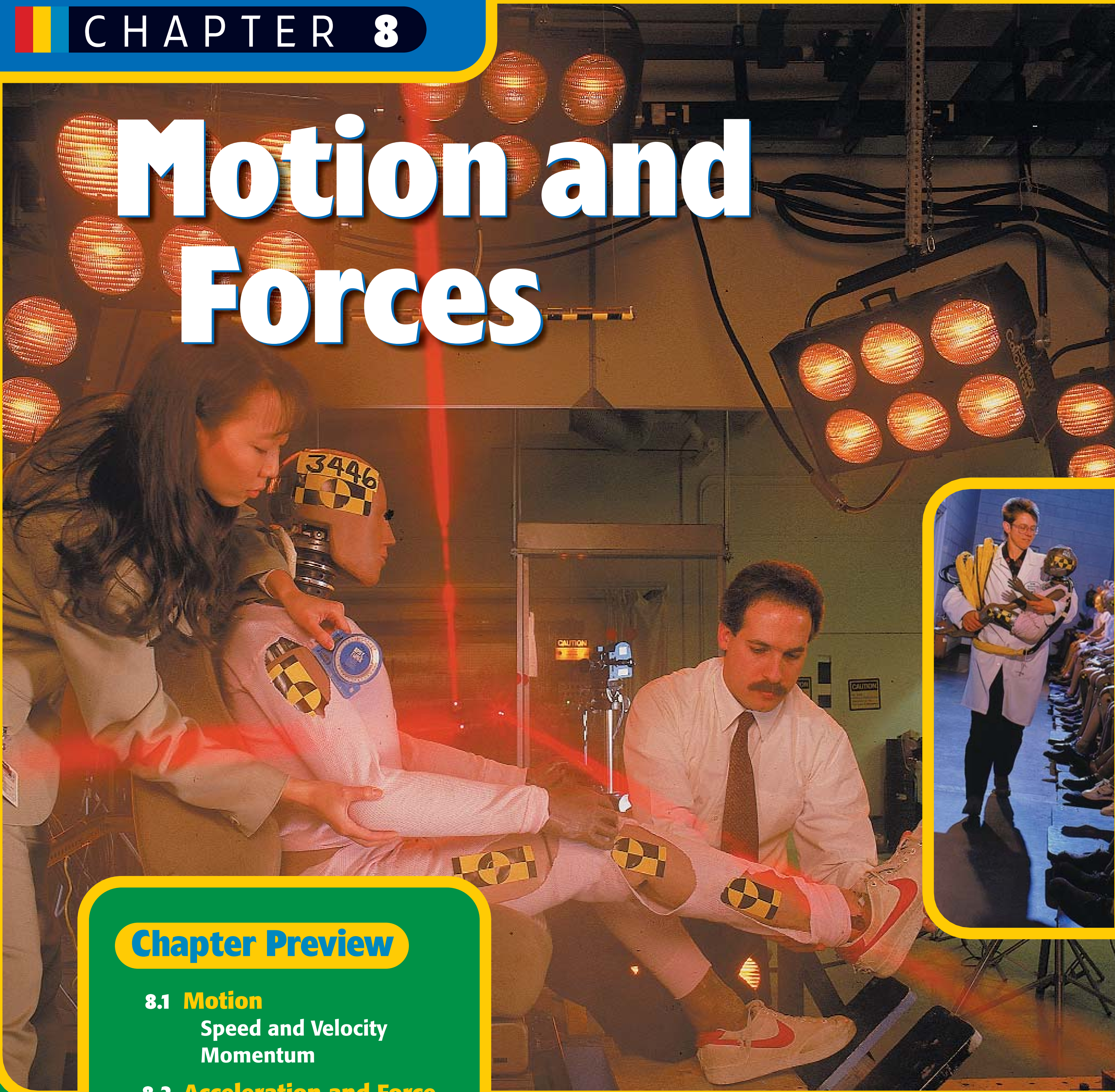
CHAPTER 8

Motion and Forces



Chapter Preview

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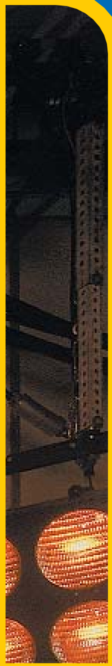
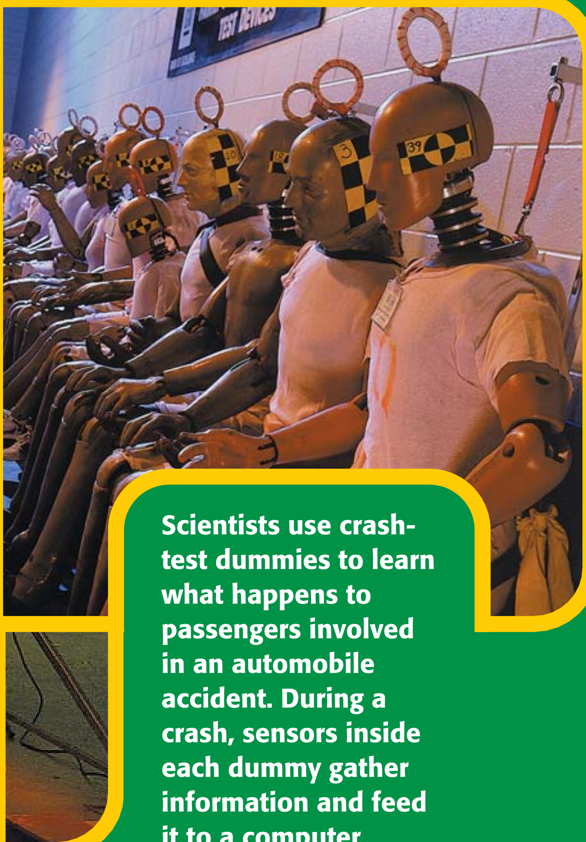
Focus ACTIVITY





Scientists use crash-test dummies to learn what happens to passengers involved in an automobile accident. During a crash, sensors inside each dummy gather information and feed it to a computer outside the car.

Background A car cruises down a track at 48 km/h (30 mi/h). Suddenly, the car smashes into an immovable block of steel and concrete, stopping in only fifteen-hundredths of a second. The occupant is not wearing a seat belt and is thrown against the steering wheel. The occupant's torso experiences the same force of impact it would have received if the occupant had fallen off the roof of a one-story house! The occupant escapes without any injuries because the occupant is a crash-test dummy.

Crash-test dummies come in various sizes and shapes. Each dummy is outfitted with sensors that record how the dummy moves and how hard it presses against different parts of the car during a crash when the dummy is strapped in by a seat belt. Automobile manufacturers use this information to develop and improve seat belts and other safety devices, such as air bags and padded dashboards.

Activity 1 Sit in the driver's seat of a parked car. Without your seat belt fastened, move forward to see what parts of your body would strike the car if you were in a head-on crash. Repeat this test with your seat belt fastened, and then perform the same two tests while sitting in the front passenger seat. Based on your results, where do you think sensors should be placed on a crash-test dummy to provide the most useful information when the dummy is wearing a seat belt? Where should sensors be placed on the dummy when the dummy is not wearing a seat belt?

Activity 2 You can investigate the Earth's pull on objects by using a stopwatch, a board, and two balls of different sizes. Set one end of the board on a chair and the other end on the ground. Time each ball as it rolls down the board. Do this several times with the board at different angles. Does the heavier ball move faster, slower, or take the same amount of time as the lighter one? What factors do you think might have affected the motion of the two balls?

internetconnect

SCILINKS NSTA

TOPIC: Forces
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KEYWORD: HK1081

Motion

KEY TERMS
speed
velocity
momentum

OBJECTIVES

- Relate speed to distance and time.
- Distinguish between speed and velocity.
- Recognize that all moving objects have momentum.
- Solve problems involving time, distance, velocity, and momentum.

We are surrounded by moving things. From a car moving in a straight line to a satellite traveling in a circle around the Earth, objects move in a variety of ways. In everyday life motion is so common, it seems to appear very simple. But, in fact, understanding motion requires some new and advanced ideas. How do we know when an object is moving?

Speed and Velocity

An object is moving if its position changes against some background that stays the same. In **Figure 8-1,** a horse is seen galloping against the background of stationary trees. This stationary background is called a *reference frame*. The change in position in a reference frame is measured in terms of the distance traveled by an object from a fixed point.

Our everyday experience shows that some objects move faster than others. **Speed** describes how fast an object moves. **Figure 8-1** shows speeds for some familiar things. A flying eagle moves faster than a galloping horse. But how do we determine speed?

speed distance traveled divided by the time interval during which the motion occurred

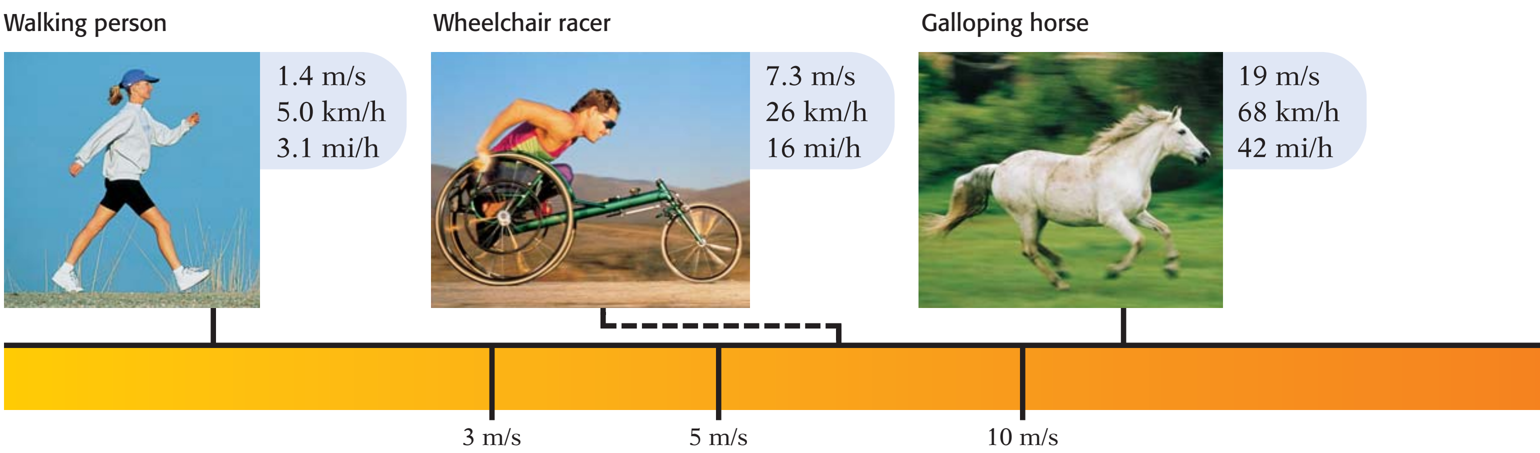

Figure 8-1
We encounter a wide range of speeds in our everyday life.

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Speed measurements involve distance and time

To find speed, you must measure two quantities: distance traveled by an object and the time it takes to travel that distance. Notice that all the speeds shown in **Figure 8-1** are expressed as a distance unit divided by a time unit. The SI unit for speed is meters per second (m/s). Speed is sometimes expressed in other units, such as kilometers per hour (km/h) or miles per hour (mi/h).

Constant speed is the simplest type of motion

When an object covers equal distances in equal amounts of time, it is moving at a **constant speed.** So what does it mean if a race car has a constant speed of 96 m/s? It means that the race car travels a distance of 96 m every second, as shown in **Table 8-1.**

Table 8-1 **Distance-Time Values for a Racing Car**

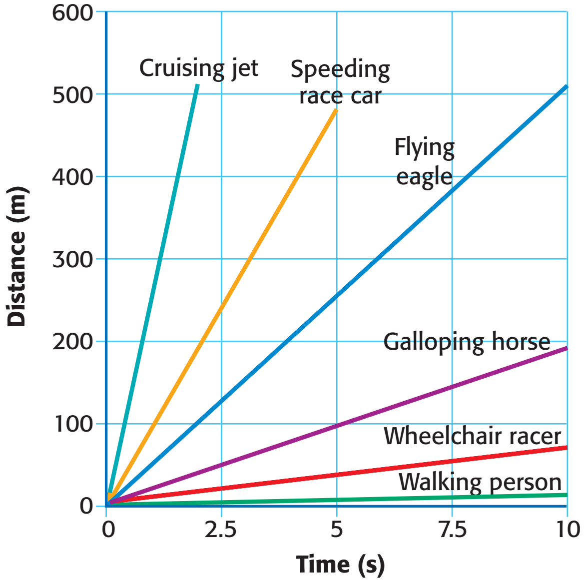
Time (s)	Distance (m)
0	0
1	96
2	192
3	288
4	384

Speed can be determined from a distance-time graph

We can investigate the relationship between speed, distance, and time by plotting a distance-time graph. The distance covered by an object is noted at regular intervals of time. The time and distance values are plotted along the horizontal and vertical axes respectively. For a race car moving with constant speed, the distance-time graph is a straight line as shown in **Figure 8-2.** The speed of the race car can be found by calculating the slope of the line.

Suppose all objects in **Figure 8-1** are moving at a constant speed. The distance-time graph of each object is drawn in **Figure 8-2.** Notice that the distance-time graph of a faster moving object is steeper than a slower moving object. An object at rest, such as a parked car, has a speed of 0 m/s. Its position does not change as time goes by. So, the distance-time graph of a resting object is a flat line with a slope of zero.

Figure 8-2
When the motion of an object is graphed by plotting the distance it travels versus time, the slope of the resulting line is the object's speed.



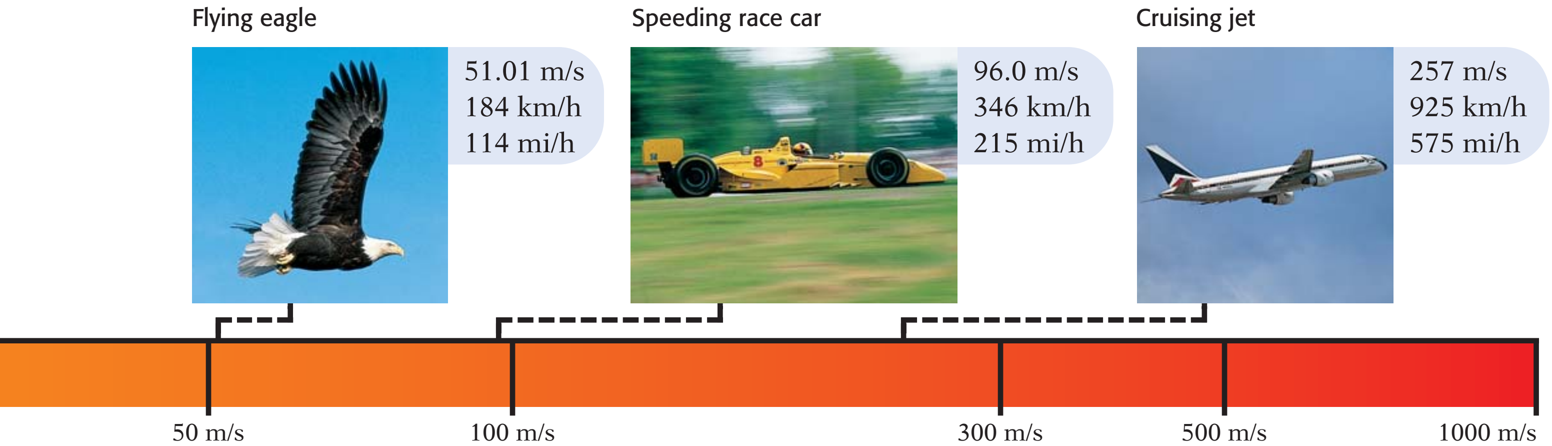


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Figure 8-3
A wheelchair racer's speed can be determined by timing the racer on a set course.

Speed is calculated as distance divided by time

Most objects do not move with constant speed. The speed of an object can change from one instant to another. A useful quantity called *average* speed can be defined. Average speed is simply the distance covered by an object divided by the time it takes to travel that distance. From this definition, we can write a simple mathematical formula to calculate average speed.

Speed Equation

$$speed = \frac{distance}{time} \qquad v = \frac{d}{t}$$

Suppose a wheelchair racer finishes a 132 m race in 18 s. By inserting the time and distance measurements in the formula, you can calculate the racer's average speed.

$$v = \frac{d}{t} = \frac{132\ \text{m}}{18\ \text{s}} = 7.3\ \text{m/s}$$

The racer's average speed over the entire distance is 7.3 m/s. But the racer probably did not travel at this speed for the whole race. The racer's pace might have been faster at the start of the race and slower near the end as the racer got tired. Suppose we are interested in the average speed during just the first half of the race. To calculate the average speed during the first half, we need to find the time it takes to travel the first 66 m.

velocity quantity describing both speed and direction

Connection to SOCIAL STUDIES

Many inventions have increased the speed at which people can travel. Cars have greatly changed the relationship between where people live and where they work. This has led to the growth of suburbs surrounding cities.

Making the Connection

1. Use a map to find the shortest straight-line path between your home and school. Calculate how long it would take you to walk to school along this path at a speed of 5.0 km/h. (**Hint:** 1 mi = 1.6 km)
2. Now determine the shortest route a school bus could take to go from your house to school. If you were to ride in a school bus that travels an average of 70 km/h (40 mi/h), how long would it take you to get to school?
3. Compare results with your classmates. Explain whether all of you would have gone to the same school 100 years ago.

Velocity describes both speed and direction

Sometimes, describing the speed of an object is not enough; you may also need to know the direction in which the object is moving. In 1997, a 200 kg (450 lb) lion escaped from a zoo in Florida. The lion was located by searchers in a helicopter. The helicopter crew was able to guide searchers on the ground by reporting the lion's **velocity,** or its speed and direction of motion. The escaped lion's velocity may have been reported as 4.5 m/s *to the north* or 2.0 km/h *toward the highway*.

Without knowing the direction of the lion's motion, it would have been impossible to predict the lion's position. This example shows the importance of knowing the direction of motion, as well as its speed. By specifying both the speed and direction of motion, you get an object's velocity.

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The direction of motion can be described in various ways. For instance, you can indicate the direction as east, west, south, or north of some fixed point, or you can specify the angle from a fixed line. Also, the direction can be described as positive or negative along the line of motion. So, if a body is moving in one direction, then it has positive velocity, and if it is moving in the opposite direction, then it has negative velocity. *In this book, velocity will always be considered to be positive in the direction of motion.*

Math Skills

Velocity Metal stakes are sometimes placed in glaciers to help measure a glacier's movement. For several days in 1936, Alaska's Black Rapids glacier surged as swiftly as 89 m per day down the valley. Find the glacier's velocity in meters per second. Remember, velocity includes the direction of motion.

1 List the given and unknown values.

Given: *time*, $t = 1$ day

distance, $d = 89$ m

Unknown: *velocity*, $v =$? (m/s and direction)

2 Perform any necessary conversions.

To find the velocity in meters per second, the value for time must be in seconds.

$$t = 1 \text{ day} = 24\ \cancel{\text{h}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{h}}} \times \frac{60 \text{ s}}{1\ \cancel{\text{min}}}$$

$$t = 86\,400 \text{ s} = 8.64 \times 10^4 \text{ s}$$

3 Write the equation for speed.

$$speed = \frac{distance}{time} \qquad v = \frac{d}{t}$$

4 Insert the known values into the equation, and solve.

$$v = \frac{d}{t} = \frac{89 \text{ m}}{8.64 \times 10^4 \text{ s}} \quad \text{(For velocity, include direction.)}$$

$$v = 1.0 \times 10^{-3} \text{ m/s down the valley}$$

Practice

Velocity

1. Find the velocity in meters per second of a swimmer who swims exactly 110 m toward the shore in 72 s.
2. Find the velocity in meters per second of a baseball thrown 38 m from third base to first base in 1.7 s.
3. Calculate the distance in meters a cyclist would travel in 5.00 hours at an average velocity of 12.0 km/h to the southwest.
4. Calculate the time in seconds an Olympic skier would take to finish a 2.6 km race at an average velocity of 28 m/s downhill.

Practice HINT

- When a problem requires you to calculate velocity, you can use the speed equation on the previous page.
- The speed equation can also be rearranged to isolate distance on the left side of the equation in the following way.

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

Multiply both sides by t.

$$v \times t = \frac{d}{\cancel{t}} \times \cancel{t}$$

$$d = vt$$

You will need to use this form of the equation in Practice Problem 3.

- In Practice Problem 4, you will need to rearrange the equation to isolate time on the left side of the equation.

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REAL WORLD APPLICATIONS

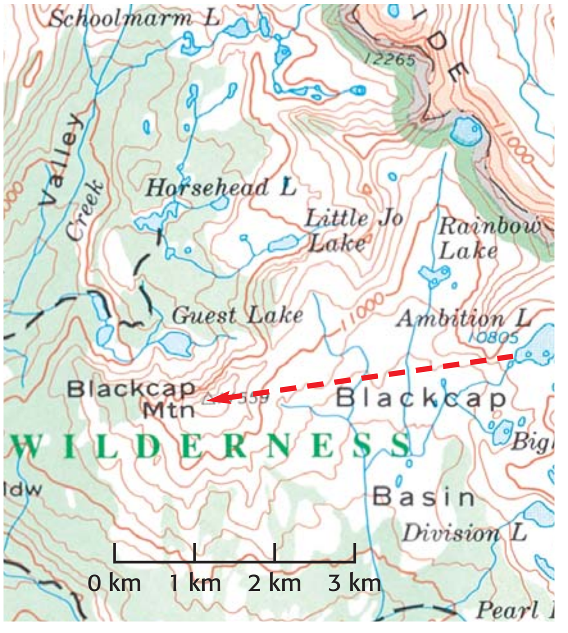
Hiking Experienced hikers use Naismith's rule to help them calculate the length of a trip. Naismith's rule is as follows:

Allow 1 hour for every 5 km (3 mi) you measure on the map, then add 1 hour for every 600 m (2000 ft) you have to climb.

This rule works for a fit walker who is not carrying a lot of equipment.

Applying Information

1. A group of hikers need to travel from Ambition Lake, at 3293 m (10 805 ft), to Blackcap Mountain, at 3523 m (11 559 ft). They plan to travel by the route shown on the map at right. Use the map's distance scale to determine how far the hikers have to travel.
2. How many feet must the hikers climb?
3. Use Naismith's rule to calculate how long it will take the hikers to reach their destination.
4. Create a spreadsheet or graphing calculator program that applies Naismith's rule. COMPUTER SKILL



The velocity of an object changes if its speed or direction changes or both change. If you watch a car's speedometer, you will notice that the speed changes from time to time. This shows a change in the velocity of the car. Even when a car has a constant speed, its velocity can change if the car turns. Why? Because the car's direction has changed.

Momentum

Velocity is not the only important quantity when objects are in motion. For example, a train is more difficult to stop than a car moving along the same path at the same speed. The train is more difficult to stop because it has a greater mass than the car. What if the car is moving very fast and the train is moving very slowly? In that case, is it possible that the car would be more difficult to stop? How do we know which object would be more difficult to stop?

Moving objects have momentum

momentum a quantity defined as the product of an object's mass and its velocity

The object with more **momentum** would be more difficult to stop. The momentum of an object depends on both its velocity and its mass. For an object moving in a straight line, momentum is calculated by simply multiplying an object's mass by its velocity.

Like velocity, momentum also has direction. An object's momentum is in the same direction as its velocity. The momentum of the bowling ball shown in **Figure 8-4** is directed toward the pins and is calculated by multiplying its mass and its velocity. The SI unit for momentum is kilograms times meters per second (kg•m/s).

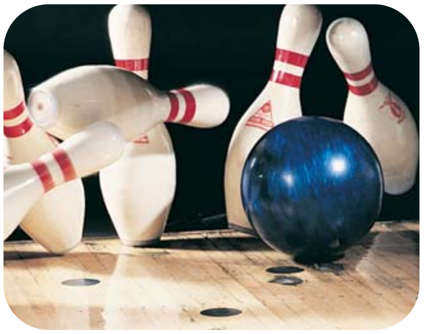


Figure 8-4
Because of the large mass and high speed of this bowling ball, it has a lot of momentum and is able to knock over the pins easily.

Momentum Equation (for straight-line motion)

$$momentum = mass \times velocity$$
$$p = mv$$

The momentum equation shows that for a given velocity, the more mass an object has, the greater its momentum is. A massive semi truck on the highway, for example, has much more momentum than a sports car traveling at the same velocity. The momentum equation also shows that the faster an object is moving, the greater its momentum is. For instance, a fast-moving train has much more momentum than a slow-moving train with the same mass. If an object is not moving, its momentum is zero.

Math Skills

Momentum Calculate the momentum of a 6.00 kg bowling ball moving at 10.0 m/s down the alley.

1 List the given and unknown values.

Given: *mass*, $m = 6.00$ kg
velocity, $v = 10.0$ m/s down the alley
Unknown: *momentum*, $p = ?$ kg•m/s (and direction)

2 Write the equation for momentum.

$$momentum = mass \times velocity$$
$$p = mv$$

3 Insert the known values into the equation, and solve.

$$p = mv = 6.00 \text{ kg} \times 10.0 \text{ m/s}$$
$$p = 60.0 \text{ kg•m/s down the alley}$$

Practice

Momentum

1. Calculate the momentum of the following objects:
   a. a 75 kg speed skater moving forward at 16 m/s
   b. a 135 kg ostrich running north at 16.2 m/s
   c. a 5.0 kg baby on a train moving eastward at 72 m/s
   d. a 0.8 kg kitten running to the left at 6.5 m/s
   e. a 48.5 kg passenger on a train stopped on the tracks

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![PHYSICAL SCIENCE INTERACTIVE TUTOR]

Disc Two, Module 11:
Conservation of Momentum
Use the Interactive Tutor to learn more about this topic.

The law of conservation of momentum

Imagine that two cars of different masses and traveling with different velocities collide head on. Can you predict what will happen after the collision? Momentum can be used to predict the motion of the cars after the collision. This is because in the absence of outside influences, the momentum is conserved.

The total amount of momentum in a system is conserved.

In other words, the total momentum of the two cars before a collision is the same as the total momentum after the collision. This is true if the cars bounce off each other or get tangled together. Cars can bounce off each other to move in opposite directions. If the cars stick together after a head-on collision, the cars will continue in the direction of the car that originally had the greater momentum.

SECTION 8.1 REVIEW

SUMMARY

- The average speed of an object is defined as the distance the object travels divided by the time of travel.
- The distance-time graph of an object moving at constant speed is a straight line. The slope of the line is the object's speed.
- The SI unit for speed is meters per second (m/s).
- The velocity of an object consists of both its speed and direction of motion.
- The momentum of an object moving in a straight line is calculated by multiplying the object's mass and velocity. An object's momentum is in the same direction as its velocity.
- The SI unit for momentum is kilograms times meters per second (kg•m/s).

CHECK YOUR UNDERSTANDING

1. **Identify** the following measurements as speed, velocity, or momentum:
   a. 88 km/h
   b. 10 m/s straight up
   c. 18 kg•m/s down
   d. 19 m/s to the west
2. **Describe** the measurements necessary to find the average speed of a moving train.
3. **Determine** the units of a caterpillar's speed if you measure the distance the caterpillar travels in centimeters and the time it takes to travel this distance in minutes.
4. **Explain** why knowing the velocity of an airplane is more important to a traveler than knowing only the airplane's speed.
5. **Describe** why your velocity changes when you ride a Ferris wheel even if the wheel turns at a constant speed.
6. **Creative Thinking** Describe the motion of a ball in a typical sport. Identify times when the ball moves with a constant velocity and times when its velocity changes.

Math Skills

7. What is the speed in kilometers per hour of a train that travels 3701 km in 87 hours?
8. What is the velocity in meters per second of a sailboat that travels 149 m away from the shore in 16.8 s?
9. What is the momentum of a 1.35 kg baseball moving at 3.75 m/s away from home plate after a hit?

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8.2

Acceleration and Force

OBJECTIVES

- Calculate the acceleration of an object.
- Describe how force affects the motion of an object.
- Distinguish between balanced and unbalanced forces.
- Explain how friction affects the motion of an object.

KEY TERMS

acceleration
force
balanced forces
unbalanced forces
friction
gravity

When you pedal hard to gain speed on your bicycle, your velocity changes. It changes again when you slow down to stop. Your velocity also changes as you round a curve in the road because your direction of motion changes. Any change in velocity is called an **acceleration.** The cyclist in **Figure 8-5** is accelerating as he turns the corner.

acceleration change in velocity divided by the time interval in which the change occurred

Acceleration

To find the acceleration of an object moving in a straight line, we need to measure the object's velocity at different times. For an object moving in a straight line, acceleration can be calculated by dividing the change in the object's velocity by the time in which the change occurs. The change in an object's velocity is symbolized by Δv. The SI unit for acceleration is meters per second per second, or meters per second squared (m/s^2).

Acceleration Equation (for straight-line motion)

$$acceleration = \frac{final\ velocity - initial\ velocity}{time} \qquad a = \frac{\Delta v}{t}$$

What does an acceleration value tell you? If the acceleration is small, that means the speed is increasing very gradually. If the acceleration has a greater value, the object is speeding up more rapidly. For example, a human runner's acceleration is about 2 m/s^2. On the other hand, a sports car that goes from 0 to 96 km/h (60 mi/h) in 3.7 s has an acceleration of 7.2 m/s^2.

Because we use only positive velocity in this book, positive acceleration means the object's velocity will increase—it will speed up. Negative acceleration means the object's velocity will decrease—it will slow down.

Figure 8-5
This cyclist accelerates when he turns a corner even if his speed doesn't change.

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PHYSICAL SCIENCE INTERACTIVE TUTOR

Disc Two, Module 9:
Speed and Acceleration
Use the Interactive Tutor to learn more about these topics.

Practice HINT

- When a problem asks you to calculate acceleration, you can use the acceleration equation on page 259.
- The acceleration equation can also be rearranged to isolate time on the left in the following way.

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

Multiply both sides by t.

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

$$\Delta v = at$$

Divide both sides by a.

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

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

You will need to use this form of the equation in Practice Problem 4.

- In Practice Problem 5, you will need to rearrange the equation to isolate final velocity on the left:

$$\textit{final } v = \textit{initial } v + at$$

Math Skills

Acceleration A flowerpot falls off a second-story windowsill. The flowerpot starts from rest and hits the sidewalk 1.5 s later with a velocity of 14.7 m/s. Find the average acceleration of the flowerpot.

1 List the given and unknown values.

Given: *time*, $t = 1.5$ s
initial velocity, initial $v = 0$ m/s down
final velocity, final $v = 14.7$ m/s down
Unknown: *acceleration*, $a = ?$ m/s^2 (and direction)

2 Write the equation for acceleration.

$$\textit{acceleration} = \frac{\textit{final } v - \textit{initial } v}{\textit{time}} \qquad a = \frac{\Delta v}{t}$$

3 Insert the known values into the equation, and solve.

$$a = \frac{\Delta v}{t} = \frac{\textit{final } v - \textit{initial } v}{t} = \frac{14.7 \text{ m/s} - 0 \text{ m/s}}{1.5 \text{ s}}$$

$$a = \frac{14.7 \text{ m/s}}{1.5 \text{ s}} = 9.8 \text{ m/s}^2 \text{ down}$$

Practice

Acceleration

1. Natalie accelerates her skateboard along a straight path from 0 m/s to 4.0 m/s in 2.5 s. Find her average acceleration.
2. A turtle swimming in a straight line toward shore has a speed of 0.50 m/s. After 4.0 s, its speed is 0.80 m/s. What is the turtle's average acceleration?
3. Find the average acceleration of a northbound subway train that slows down from 12 m/s to 9.6 m/s in 0.8 s.
4. Marisa's car accelerates at an average rate of 2.6 m/s^2. Calculate how long it takes her car to accelerate from 24.6 m/s to 26.8 m/s.
5. A cyclist travels at a constant velocity of 4.5 m/s westward, then speeds up with a steady acceleration of 2.3 m/s^2. Calculate the cyclist's speed after accelerating for 5.0 s.

When you press on the gas pedal in a car, you speed up and your acceleration is in the direction of the car's motion. When you press on the brake pedal, your acceleration is opposite to the direction of motion and you slow down. And when you turn the steering wheel, your velocity changes whether or not you speed up or slow down as you make the turn. This is because as you turn a corner the direction of your velocity changes. So acceleration is a common part of many types of motion.

Acceleration can be determined from a velocity-time graph

In the last section you learned that an object's speed can be determined from a distance-time graph of its motion. You can make a velocity-time graph by plotting velocity on the vertical axis and time on the horizontal axis.

A straight line on a velocity-time graph means that the velocity changes by the same amount each time. This is called constant acceleration. The slope of a line on a velocity-time graph gives you the value of the acceleration. A line with a positive slope represents an object that is speeding up. A line with a negative slope represents a slowing object.

The acceleration of an object is zero if its velocity is constant. If you ride your bike in a straight line at a constant speed, you are not accelerating. The bicyclist in **Figure 8-6A** is riding in a straight line with a constant speed of 13.00 m/s, as shown by the data in **Table 8-2.** If you move with a constant speed in a straight line, you are moving with a constant velocity. **Figure 8-6B** and **Figure 8-6C** show two different graphs that tell us about the motion of a cyclist traveling at a constant velocity.

Did You Know?

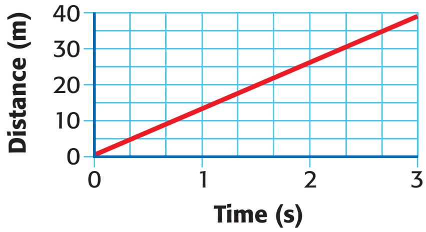
The faster a car goes, the longer it takes a given braking force to bring the car to a stop. Braking distance describes how far a car travels between the moment the brakes are applied and the moment the car stops. As a car's speed increases, so does its *braking distance*. For example, when a car's speed is doubled, its braking distance is four times as long.

Figure 8-6

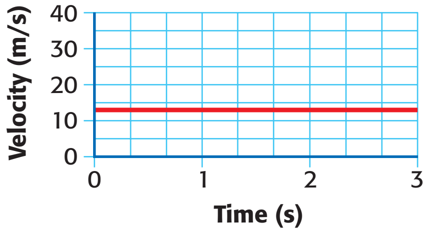
A When you ride your bike straight ahead at a constant speed, you are not accelerating because your velocity does not change.

Table 8-2 **Data for a Bicycle with Unchanging Velocity**

Time (s)	Velocity (m/s)
0	13.00
1	13.00
2	13.00
3	13.00
4	13.00



B If you plot the distance traveled against the time it takes, the resulting graph is a straight line with a slope of 13.00 m/s.



C Plotting the velocity against time results in a horizontal line because the velocity does not change. The acceleration is 0 m/s^2.

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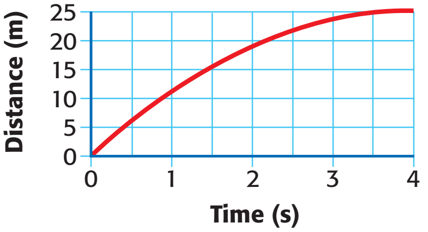
Figure 8-7

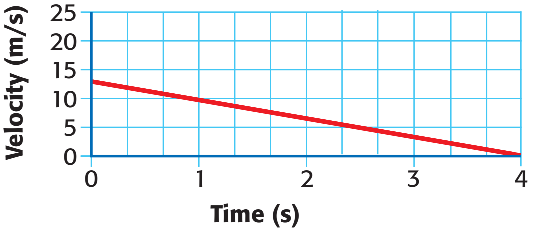
A When you slow down, your velocity changes. Your acceleration is negative because you are decreasing your velocity.

Table 8-3
Data for a Slowing Bicycle

Time (s)	Velocity (m/s)
0	13.00
1	9.75
2	6.50
3	3.25
4	0



B If you plot the distance you travel against the time it takes you, the distance you travel each second becomes shorter and shorter until you finally stop.



C Plotting the velocity against time results in a line with a negative slope, which means the acceleration is negative.

INTEGRATING

MATHEMATICS

In the seventeenth century, both Sir Isaac Newton and Gottfried Leibniz studied acceleration and other rates of change. Independently, each created calculus, a branch of math that allows for describing rates of change of a quantity like velocity.

The rider in **Figure 8-7A** is slowing down from 13.00 m/s to 3.25 m/s over a period of 3.00 s, as shown by the data in **Table 8-3.** You can find out the rate at which velocity changes by calculating the acceleration.

$$a = \frac{3.25\ \text{m/s} - 13.00\ \text{m/s}}{3.00\ \text{s}} = \frac{-9.75\ \text{m/s}}{3.00\ \text{s}} = -3.25\ \text{m/s}^2$$

The rider's velocity decreases by 3.25 m/s each second. The acceleration value has a negative sign because the rider is slowing down. **Figure 8-7B** and **Figure 8-7C** show two different graphs describing the motion of an object that is slowing down.

Force

force the cause of acceleration, or change in an object's velocity

When you throw or catch a ball, you exert a **force** to change the ball's velocity. What causes an object to change its velocity, or accelerate? Usually, many forces act on an object at any given time. The **net force,** the combination of all of the forces acting on an object, determines whether the velocity of the object will change. An object accelerates in the direction of the net force. It won't accelerate if the net force is zero.

Back

Balanced forces do not change motion

In **Figure 8-8A,** the two teams are engaged in a tug-of-war. Both the teams pull the rope by using their weight and by pushing on the ground. You can imagine that the combined effect of the forces exerted by each team is acting at the center of the rope. If each team exerts an equal force, the rope will not move. **Balanced forces,** such as these, completely cancel each other. The combined force equals zero.

balanced forces forces acting on an object that combine to produce a net force equal to zero

Unbalanced forces do not cancel completely

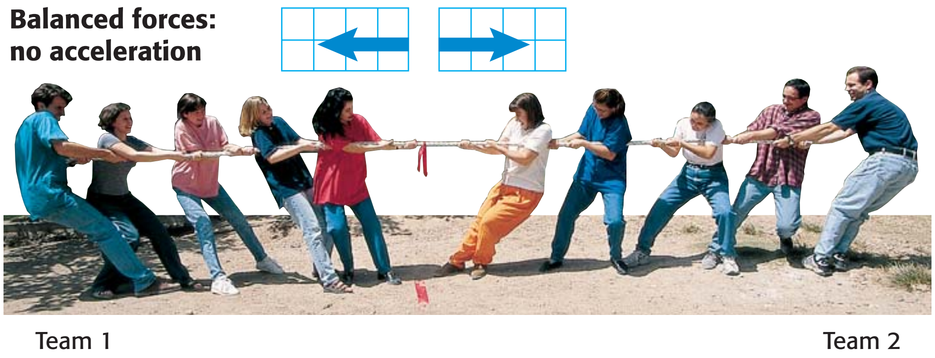
If opposing forces acting on an object do not have the same strength, they do not cancel each other completely. Such **unbalanced forces** are present in the tug-of-war shown in **Figure 8-8B.** Team 2 moves the rope in its direction because the combined effect from its team members results in a greater force. Although part of the force exerted by Team 2 is canceled by the force exerted by Team 1, the additional, or net, force provided by Team 2 causes the rope to move toward Team 2. Team 1 accelerates to the right because the leftward force is smaller than the rightward force.

What if the forces act in different directions but are not exactly opposite? In this situation, the combination of forces acts like a single force on the object. Like all unbalanced forces, the net force will cause the object to accelerate.

unbalanced forces forces acting on an object that combine to produce a net nonzero force

VOCABULARY Skills Tip

The word force *comes from the Latin word* fortis, *meaning "strength." The word* fortress *comes from the same root.*



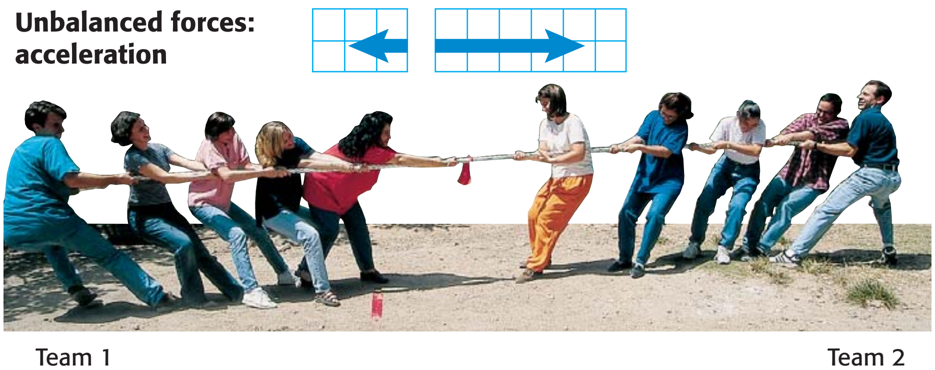


Figure 8-8

A In a tug-of-war, each side exerts a force on the rope. If the opposing forces are equal, they are *balanced*, and the rope does not move.

B If one force is greater than the other, the forces are *unbalanced,* and the rope moves in the direction of the greater force.

Back

Science and the Consumer

Should a Car's Air Bags Be Disconnected?

Air bags are standard equipment in every new automobile sold in the United States. These safety devices are credited with saving almost 1700 lives between 1986 and 1996. However, air bags have also been blamed for the deaths of 36 children and 20 adults during the same period. In response to public concern about the safety of air bags, the National Highway Traffic Safety Administration has proposed that drivers be allowed to disconnect the air bags on their vehicles.

In a collision, air bags explode from a compartment to cushion the passenger's upper body and head.

How Do Air Bags Work?

When a car equipped with air bags crashes into another object, the car comes to an abrupt stop. Sensors in the car detect the sudden change in speed (negative acceleration) and trigger a chemical reaction inside the air bags. This reaction very quickly produces nitrogen gas, causing the bags to inflate and explode out of their storage compartment in a fraction of a second. The inflated air bags cushion the head and upper body of the driver and passengers in the front seat, who keep moving forward at the time of impact because of their inertia. Also, the inflated air bag increases the amount of time over which the stopping force acts. So as the rider moves forward, the air bag absorbs the impact.

What Are the Risks?

Because an air bag inflates suddenly and with great force, it can cause serious head and neck injuries in some circumstances. Seat belts reduce this risk by holding passengers against the seat back, allowing the air bag to inflate before the passenger's head comes into contact with it. In fact, most of the people killed by air bags either were not using seat belts or had not adjusted the seat belts properly.

However, two groups of people are at risk of being injured by air bags even with seat belts on: drivers shorter than about 157 cm (5 ft 2 in.) and infants who ride next to the driver in a rear-facing safety seat.

Alternatives to Disconnecting Air Bags

Always wearing a seat belt and placing child safety seats in the back seat of the car are two easy ways to reduce the risk of injury from air bags. Shorter drivers can buy pedal extenders that allow them to sit farther back and still safely reach the pedals. If the vehicle has a back seat, parents can put their child's safety seat there. Some vehicles without a back seat have a switch that can deactivate the passenger-side air bag. Automobile manufacturers are also working on air bags that inflate less forcefully.

Your Choice

1. **Critical Thinking** Are air bags useful if your car is struck from behind by another vehicle?
2. **Locating Information** Use library resources or the Internet to prepare a report about "smart" air-bag systems.

internet connect

SCILINKS NSTA

TOPIC: Friction
GO TO: www.scilinks.org
KEYWORD: HK1083

Back

Friction and Air Resistance

Imagine a car that is rolling along a flat, evenly paved street. If no force is acting on the car, the car should keep moving at a constant speed. Experience tells you, however, that the car will keep slowing down until it eventually stops. This steady change in the car's speed gives you a clue that a force must be acting on the car. This unbalanced force that acts against the car's direction of motion is **friction.**

Because of friction, a constant force must be applied to a car on a flat road just to keep it moving. In order for the car to reach a certain speed from rest, the forces on the car must be unbalanced. The force pushing the car forward must be greater than the force of friction opposing the car's motion, as shown in **Figure 8-9A.** Once the car reaches its desired speed, the car will maintain this speed if the forces acting on the car are balanced, as shown in **Figure 8-9B.**

Friction also affects objects that aren't moving. For example, when a truck is parked on a hill with its brakes set, as shown in **Figure 8-9C,** friction provides the force needed to balance the force of gravity and prevent the truck from moving downhill.

friction the force between two objects in contact that opposes the motion of either object

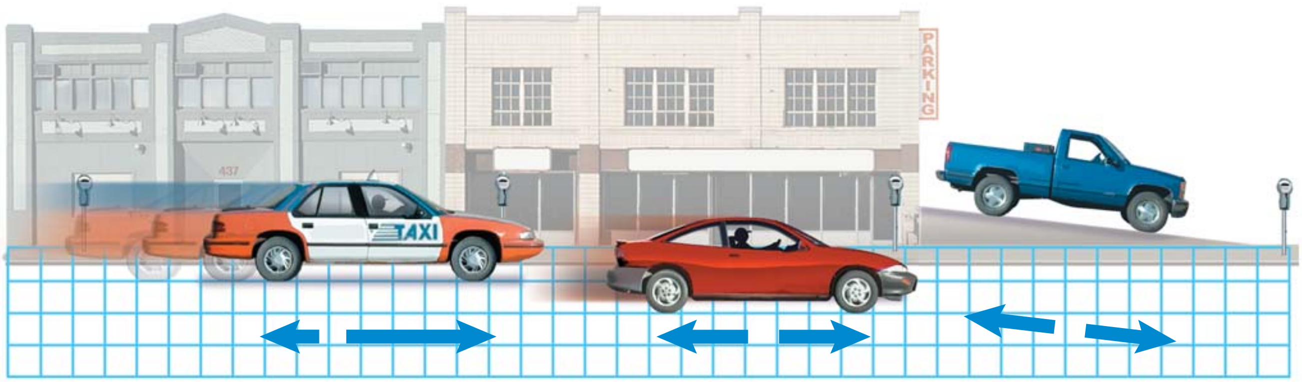
Did You Know?

Another way to think about the effect of force on an object's motion is to use the concept of momentum. The change in momentum for an object is greater when the force is larger or when the force acts over a longer time.

Frictional force varies depending on the surfaces in contact

New jogging shoes often have rough rubber soles. Friction between the new shoes and a carpeted floor will be large enough to prevent you from slipping. Frictional forces are relatively great when both surfaces are rough.

Figure 8-9
Frictional Force and Acceleration



Unbalanced forces: acceleration

A When a car is accelerating, the forces are unbalanced. The force moving the car forward is greater than the opposing force of friction.

Balanced forces: constant speed

B When a car is cruising at constant speed, the force moving the car forward is balanced by the force of friction.

Balanced forces: no motion

C This truck does not roll because the force of friction between the brakes and the wheels balances the force of gravity.

Figure 8-10
With the need for better fuel efficiency and increased speed, car designs have been changed to reduce air resistance. Modern cars are much more aerodynamic.

However, if the soles of your shoes are smooth or if the floor you are walking on has been waxed, you may find it difficult to walk steadily. That's because there is less frictional force if one surface is rough and the other is smooth. Smooth soles and a smooth floor can make it even more difficult to walk because of even less frictional force.

Air resistance is a form of friction

Although friction between a car's tires and the road allows a car to move forward, another type of friction, air resistance, opposes the car's motion. Air resistance is caused by the interaction between the surface of a moving object and the air molecules.

The amount of air resistance on an object depends on its size and shape as well as on the speed with which it moves. Objects with larger surfaces can experience greater air resistance. Air resistance also increases as the object's speed increases. As shown in **Figure 8-10,** car design has changed dramatically over the years. One factor taken into account in designing cars is reducing air resistance. To make cars, trains, and planes move faster without using more fuel, designers have changed the shapes of these vehicles to reduce the resistance between the vehicle and the surrounding air.

Gravity

Gravity is given as the reason why an apple falls down from a tree. But you may not realize that every object exerts a gravitational force on every other object. When an apple breaks from its stem, the apple falls down because the gravitational force between Earth and the apple is much greater than the gravitational force between the apple and the tree. The force of gravity is different from forces such as friction; the force of gravity acts even when the objects do not touch.

gravity the attraction between two particles of matter due to their mass

Mass and distance affect gravitational force

The force of gravity between two objects depends on their masses and on the distance between the two objects. The gravitational force between two objects is proportional to the product of their masses. The greater the mass of an object is, the larger the gravitational force it exerts on other objects. For instance, the gravitational force that the person sitting next to you in the classroom exerts on you is so small that you don't even notice it. You can't help but notice Earth's gravitational force because Earth is extremely massive. The gravitational force between most objects around you is very small.

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Gravitational force also depends on the distance between two objects, as shown in **Figure 8-11.** The force of gravity changes as the distance between the balls changes. If the distance between the two balls is doubled, the gravitational force between them decreases to one-fourth its original value. If the original distance is tripled, the gravitational force decreases to one-ninth its original value. Gravitational force is weaker than other types of forces, even though it holds the planets, stars, and galaxies together.

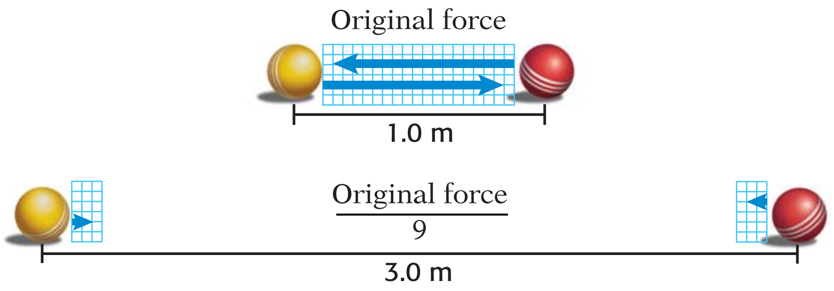

Figure 8-11
Gravitational force rapidly grows weaker as the distance between two objects increases.

SECTION 8.2 REVIEW

SUMMARY

- Acceleration is a change in the velocity of an object. An object accelerates when it speeds up, slows down, or changes direction. Acceleration is caused by a force.
- For straight-line motion, average acceleration is defined as the change in an object's velocity per unit of time.
- The SI unit for acceleration is meters per second squared (m/s^2).
- The forces that act on an object combine to act effectively as one force.
- Friction is the force between two objects in contact; it opposes the motion of either object.
- Gravity is the attraction between two particles due to their mass. The force of gravity is proportional to their mass and inversely proportional to the square of the distance between them.

CHECK YOUR UNDERSTANDING

1. **Describe** three ways in which a car's velocity will change.
2. **Identify** a situation involving balanced forces. Describe the net force, and explain how this force affects the motion of an object.
3. **Identify** a situation involving unbalanced forces. Describe the net force, and explain how it affects the motion of an object.
4. **Evaluate** the following situations, and decide if an unbalanced force is present:
   a. A car turns right without slowing down.
   b. A spacecraft moves in one direction at a constant speed.
   c. A cyclist coasts downhill, going faster and faster.
   d. A tennis racket hits a tennis ball.
5. **Arrange** the following pairs of surfaces in order of most friction to least friction:
   a. a shoe sole and a waxed basketball court
   b. a shoe sole and the frozen surface of a lake
   c. a shoe sole and the sidewalk
6. **Creative Thinking** Explain why Venus, which is slightly less massive than Earth, experiences a stronger gravitational pull from the sun than Earth does.

Math Skills

7. What is the average acceleration of a car that starts from rest and moves straight ahead at 18 m/s in 12 s?
8. Which will be moving faster after 3.0 s, a cyclist maintaining a constant velocity of 15 m/s straight ahead or a race car accelerating forward from a stoplight at 4.0 m/s^2?

8.3

Newton's Laws of Motion

KEY TERMS
inertia
free fall
terminal velocity

OBJECTIVES

- State Newton's three laws of motion, and apply them to physical situations.
- Calculate force, mass, and acceleration with Newton's second law.
- Recognize that the free-fall acceleration near Earth's surface is independent of the mass of the falling object.
- Explain the difference between mass and weight.
- Identify paired forces on interacting objects.

Every motion you observe or experience is related to a force. Sir Isaac Newton described the relationship between motion and force in three laws that we now call Newton's laws of motion. Newton's laws apply to a wide range of motion—a caterpillar crawling on a leaf, a person riding a bicycle, or a rocket blasting off into space.

Newton's First Law

If you slide your book across a rough surface, such as carpet, the book will soon come to rest. On a smooth surface, such as ice, the book will slide much farther before stopping. Because there is less frictional force between the ice and the book, the force must act over a longer time before the book comes to a stop. Without friction, the book would keep sliding forever. This is an example of Newton's first law, which is stated as follows.

An object at rest remains at rest and an object in motion maintains its velocity unless it experiences an unbalanced force.

You experience the effect described by Newton's first law when you ride in a car. As the car comes to a stop, you can feel your body continue to move forward. Your seat belt and the friction between your pants and the seat stop your forward motion. They provide the unbalanced rearward force needed to bring you to a stop as the car stops.

Because infants are more fragile than adults, they are placed in special backward-facing car seats, as shown in **Figure 8-12.** The force that is needed to bring the baby to a stop is safely spread out over the baby's entire body.

Figure 8-12
During an abrupt stop, this baby would continue to move forward. The backward-facing car seat distributes the force that holds the baby in the car.

Quick ACTIVITY

Newton's First Law

1. Place an index card over a glass, and set a coin on top of the index card.
2. With your thumb and forefinger, quickly flick the card sideways off the glass. Observe what happens to the coin. Does the coin move with the index card?
3. Try again, but this time slowly pull the card sideways and observe what happens to the coin.
4. Use Newton's first law to explain your results.

Inertia is the tendency of an object at rest to remain at rest or, if moving, to continue moving with a constant velocity. All objects have inertia because they resist changes in motion. An object with very little mass, such as a baseball, can be accelerated with a small force. But it takes a much larger force to accelerate a car, which has a large mass.

inertia the tendency of an object to remain at rest or in motion with a constant velocity

Newton's Second Law

Newton's first law describes what happens when the net force acting on an object is zero: the object either remains at rest or continues moving at a constant velocity. What happens when the net force acting on an object is not zero? Newton's second law describes the effect of this unbalanced force on the motion of an object.

Force equals mass times acceleration

Newton's second law, which describes the relationship between mass, force, and acceleration, can be stated as follows.

The unbalanced force acting on an object equals the object's mass times its acceleration.

Mathematically, Newton's second law can be written as follows.

Newton's Second Law

$$\textit{force} = \textit{mass} \times \textit{acceleration}$$

$$F = ma$$

Consider the difference between pushing an empty shopping cart and pushing the same cart filled with groceries, as shown in **Figure 8-13.** If you push the cart with the same amount of force in each situation, the empty cart will have a greater acceleration because it has a smaller mass than the full cart. The same amount of force in each case produces different accelerations because the masses are different.

Figure 8-13
Because the full cart has a larger mass than the empty cart, the same force gives the empty cart a greater acceleration.

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What would happen if you and a friend each pushed an empty cart but you used more force? The cart you pushed would have a greater acceleration. When two masses are the same, a greater force provides a greater acceleration.

Although the force in these cases is a push, Newton's second law applies regardless of the type of force involved. The acceleration is always in the direction of the net force.

Force is measured in newtons

Newton's second law can be used to derive the SI unit of force, the newton (N). One newton is the force that can give a mass of 1 kg an acceleration of 1 m/s^2, expressed as follows.

$$1 \text{ N} = 1 \text{ kg} \times 1 \text{ m/s}^2$$

The pound (lb) is sometimes used as a unit of force. One newton is equivalent to 0.225 lb. Conversely, 1 lb is equal to 4.448 N.

Math Skills

Newton's Second Law Zookeepers lift a stretcher that holds a sedated lion. The total mass of the lion and stretcher is 175 kg, and the lion's upward acceleration is 0.657 m/s^2. What is the unbalanced force necessary to produce this acceleration of the lion and the stretcher?

1 List the given and unknown values.

Given: *mass*, $m = 175$ kg
acceleration, $a = 0.657$ m/s^2
Unknown: *force*, $F = ?$ N

2 Write the equation for Newton's second law.

$$force = mass \times acceleration$$
$$F = ma$$

3 Insert the known values into the equation, and solve.

$$F = 175 \text{ kg} \times 0.657 \text{ m/s}^2$$
$$F = 115 \text{ kg}\bullet\text{m/s}^2 = 115 \text{ N}$$

Practice

Newton's Second Law

1. What is the net force necessary for a 1.6×10^3 kg automobile to accelerate forward at 2.0 m/s^2?
2. A baseball accelerates downward at 9.8 m/s^2. If the gravitational force acting on the baseball is 1.4 N, what is the baseball's mass? (**Hint:** Assume gravity is the only force acting on the ball.)
3. A sailboat and its crew have a combined mass of 655 kg. If the sailboat experiences an unbalanced force of 895 N pushing it forward, what is the sailboat's acceleration?

Practice HINT

- When a problem requires you to calculate the unbalanced force on an object, you can use Newton's second law on the previous page.
- The equation for Newton's second law can be rearranged to isolate mass on the left side of he equation in the following way.

$$F = ma$$

Divide both sides by a.

$$\frac{F}{a} = \frac{m\cancel{a}}{\cancel{a}}$$

$$m = \frac{F}{a}$$

You will need to use this form of the equation in Practice Problem 2.

- In Practice Problem 3 you will need to rearrange the equation to isolate acceleration on the left side.

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Free Fall and Weight

When the force of gravity is the only force acting on an object, the object is said to be in **free fall.** The free-fall acceleration of an object is directed toward the center of the Earth. Because free-fall acceleration results from gravity, it is often abbreviated as the letter g. Near Earth's surface, g is approximately 9.8 m/s^2.

free fall the motion of a body when only the force of gravity is acting on it

Free-fall acceleration near Earth's surface is constant

In the absence of air resistance, all objects near Earth's surface accelerate at the same rate, regardless of their mass. This means that if you dropped a 1.5 kg book and a 15 kg rock from the same height, they would hit the ground at about the same moment. For simplicity, we will disregard air resistance for all calculations in this book. We will assume that all objects on Earth accelerate at exactly 9.8 m/s^2.

Why do all objects have the same free-fall acceleration? Newton's second law shows that acceleration depends on both the force on an object and its mass. A heavier object experiences a greater gravitational force than a lighter object. But a heavier object is also harder to accelerate because it has more mass. The extra mass of the heavy object exactly compensates for the additional gravitational force.

Weight equals mass times free-fall acceleration

The force on an object due to gravity is called its weight. On Earth, your weight is simply the amount of gravitational force exerted on you by Earth. If you know the free-fall acceleration, g, acting on a body, you can use $F = ma$ (Newton's second law) to calculate the body's weight. Weight equals mass times free-fall acceleration. Mathematically, this is expressed as follows.

$$weight = mass \times free\text{-}fall\ acceleration$$
$$w = mg$$

Note that because weight is a force, the SI unit of weight is the newton. For example, a small apple weighs about 1 N. A 1.0 kg book has a weight of 1.0 kg $\times$ 9.8 m/s^2 = 9.8 N.

You may have seen pictures of astronauts floating in the air, as shown in **Figure 8-14.** Does this mean that they don't experience gravity? In orbit, astronauts, the space shuttle, and all objects on board experience free fall due to the Earth's gravity. In fact, the astronauts and their surroundings all accelerate at the same rate. Therefore, the floor of the shuttle does not push up against the astronauts and the astronauts appear to be floating. This situation is referred to as *apparent weightlessness.*

Figure 8-14
In the environment of the orbiting space shuttle, astronauts experience apparent weightlessness.

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INTEGRATING

SPACE SCIENCE

Because the planets in our solar system have different masses and sizes, the value of g is different on each planet. Find the weight of a 58 kg person on the following planets:

Earth, where $g = 9.8\ m/s^2$

Mars, where $g = 3.7\ m/s^2$

Venus, where $g = 8.8\ m/s^2$

Neptune, where $g = 11.8\ m/s^2$

▶ **terminal velocity** the maximum velocity reached by a falling object that occurs when the resistance of the medium is equal to the force due to gravity

Weight is different from mass

Mass and weight are easy to confuse. Although mass and weight are proportional to one another, they are not the same. Mass is a measure of the amount of matter in an object. Weight is the gravitational force an object experiences due to its mass.

The weight of an object depends on gravity, so a change in an object's location will change the object's weight. For example, consider a 66 kg astronaut. On Earth, this astronaut weighs 66 kg $\times$ 9.8 m/s^2 = 650 N (about 150 lb), but on the moon's surface, where g is only 1.6 m/s^2, the astronaut would weigh 66 kg $\times$ 1.6 m/s^2 = 110 N (about 24 lb). The astronaut's mass remains the same on Earth, the moon, or an orbiting space shuttle, but the gravitational force acting on the astronaut changes in each place.

Weight influences shape

Gravitational force influences the shapes of living things. On land, large animals must have strong skeletons to support their mass against the force of gravity. The woody trunks of trees serve the same function. For organisms that live in water, however, the downward force of gravity is balanced by the upward forces of the water. For many of these creatures, strong skeletons or other supporting structures are unnecessary. Because a jellyfish has no skeleton, it can drift gracefully through the water but collapses if it washes up on the beach.

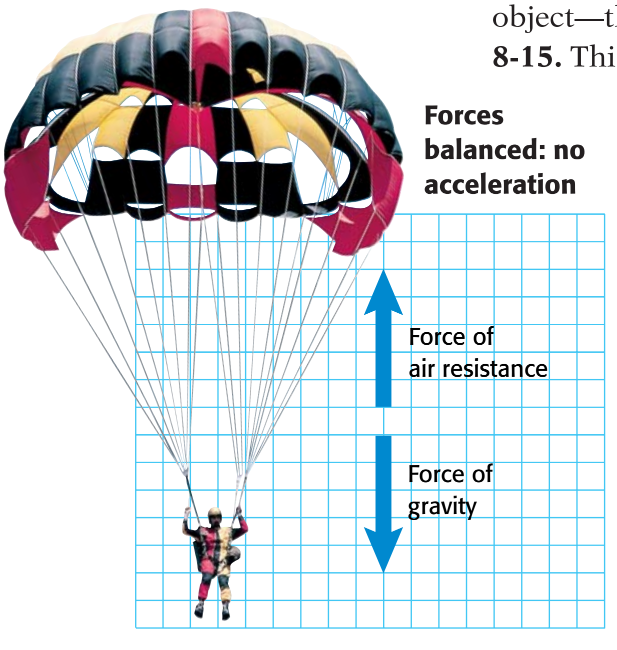
Velocity is constant when air resistance balances weight

Both air resistance and gravity act on objects moving through Earth's atmosphere. For a falling object, when the force of air resistance becomes equal to the gravitational force on the object—the weight—it stops accelerating, as shown in **Figure 8-15.** This happens because the air resistance acts in the opposite direction to the weight. When these two forces are equal, the object stops accelerating and reaches its maximum velocity, the **terminal velocity.**

When sky divers start a jump, their parachutes are closed, and they are accelerated toward Earth by the force of gravity. As their velocity increases, the force they experience due to air resistance increases. When air resistance and the force of gravity are equal, sky divers reach a terminal velocity of about 320 km/h (200 mi/h). But when they open the parachute, air resistance increases greatly. For a while, this slows them down. Eventually, they reach a new terminal velocity of several kilometers per hour, allowing them to land safely.

Figure 8-15

When a sky diver reaches terminal velocity, the force of gravity is balanced by air resistance.



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Newton's Third Law

Figure 8-16
According to Newton's third law, the soccer ball and the foot shown in this photo exert equal and opposite forces on one another.

When you kick a soccer ball with your foot, as shown in **Figure 8-16,** you notice the effect of the force exerted by your foot on the ball. The ball experiences a change in motion. But is this the only force present? Do you feel a force on your foot when kicking the ball? In fact, the soccer ball exerts an equal and opposite force on your foot. The force exerted on the ball by your foot is the action force, and the force exerted on your foot by the ball is the reaction force.

Note that the action and reaction forces are applied to different objects. These forces are equal and opposite, but this is not a case of balanced forces because two different objects are involved. The action force acts on the ball, and the reaction force acts on the foot. This is an example of Newton's third law, also called the law of action and reaction.

For every action force, there is an equal and opposite reaction force.

Newton's third law implies that forces always occur in pairs. But the action and reaction force of a force pair act on different objects. Also, action and reaction forces occur at the same time.

Newton's third law is used in rocketry. Rockets were invented many centuries ago. They have many different sizes and designs, but the basic principle remains the same.

Inquiry Lab

How are action and reaction forces related?

Materials ✔ *2 spring scales* ✔ *2 kg mass*

Procedure

1. Hang the 2 kg mass from one of the spring scales.
2. Observe the reading on the spring scale.
3. While keeping the mass connected to the first spring scale, link the two scales together. The first spring scale and the mass should hang from the second spring scale, as shown in the figure at right.
4. Observe the readings on each spring scale.

Analysis

1. What are the action and reaction forces involved in the spring scale–mass system you have constructed?
2. How did the readings on the two spring scales in step 4 compare? Explain how this is an example of Newton's third law of motion.

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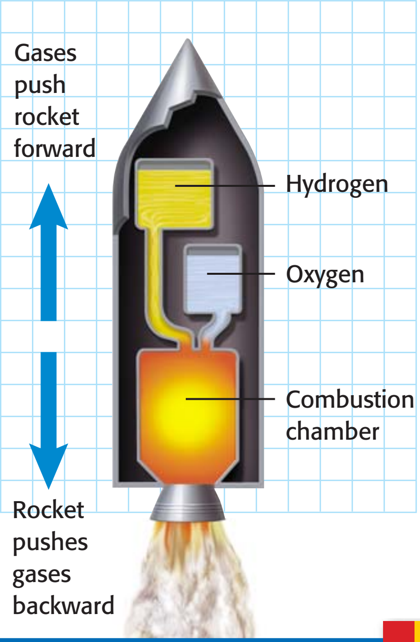
Figure 8-17
All forces occur in action-reaction pairs. In this case, the upward push on the rocket equals the downward push on the exhaust gases.



The push of the hot gases through the nozzle is matched by an equal push in the opposite direction on the combustion (burning) chamber, which accelerates the rocket forward.

Figure 8-17 is a representation of a liquid-fuel rocket. Liquid oxygen and liquid hydrogen are held in separate compartments, as shown. The oxygen and hydrogen react in a combustion chamber to produce a gas with a great deal of energy. This energy causes the gas to press out equally in all directions inside the rocket. The pressure of the gas against one side of the rocket balances the pressure of the gas against the opposite side. However, because the bottom of the combustion chamber is open, gas escapes through the nozzle. Thus, the force of the gas against the front of the rocket is not balanced at the back of the rocket. This unbalanced force pushes the rocket forward.

Rockets burn up most of their fuel during the early stages of flight, mainly because the rocket has more mass to accelerate because of the unused fuel it carries. As the fuel is used, the rocket's mass decreases and the force needed to produce a given acceleration decreases. Because air is more dense in Earth's lower atmosphere, the rocket also experiences greater air resistance initially.

SECTION 8.3 REVIEW

SUMMARY

- An object at rest remains at rest and an object in motion maintains a constant velocity unless it experiences an unbalanced force (Newton's first law).
- The unbalanced force acting on an object equals the object's mass times its acceleration, or $F = ma$ (Newton's second law).
- The SI unit for force is the newton (N). Weight equals mass times free fall acceleration, or $W = mg$.
- For every action force, there is an equal and opposite reaction force (Newton's third law).

CHECK YOUR UNDERSTANDING

1. **State** each of Newton's three laws of motion in your own words, and give an example that demonstrates each law.
2. **Explain** the difference between mass and weight. Does the weight of an object ever change? If so, when?
3. **Identify** the action and reaction forces in each of the following cases:
   a. your hand pushing against a wall
   b. a hammer pounding a nail
   c. a stone striking the bottom of a well
   d. a book sliding to a stop on the ground
4. **Critical Thinking** Using Newton's laws, predict what will happen when a car traveling on an icy road
   a. comes to a sharp bend.
   b. has to stop quickly.

Math Skills

5. What is the acceleration of a boy on a skateboard if the unbalanced forward force on the boy is 15 N? The total mass of the boy and skateboard is 58 kg.
6. How much does a 5.0 kg puppy weigh on Earth?

CHAPTER 8 REVIEW

Chapter Highlights

Before you begin, review the summaries of the key ideas of each section, found on pages 258, 267, and 274. The key vocabulary terms are listed on pages 252, 259, and 268.

UNDERSTANDING CONCEPTS

1. If you jog for 1 hour and travel 10 km, 10 km/h describes your _____.
a. momentum
b. average speed
c. displacement
d. acceleration

2. _____ is speed in a certain direction.
a. Acceleration
b. Friction
c. Momentum
d. Velocity

3. Which of the following objects is not accelerating?
a. a ball being juggled
b. a woman walking at 2.5 m/s along a straight road
c. a satellite circling Earth
d. a braking cyclist

4. The newton is a measure of _____.
a. mass
b. length
c. force
d. acceleration

5. _____ is a force that opposes the motion between two objects in contact with each other.
a. Motion
b. Friction
c. Acceleration
d. Velocity

6. Automobile seat belts are necessary for safety because of a passenger's _____.
a. inertia
b. weight
c. speed
d. gravity

7. The winner of the shot-put event in the Olympics is the person who best uses _____.
a. Newton's first law
b. Newton's second law
c. air resistance
d. the law of gravity

8. An example involving action-reaction forces is _____.
a. air escaping from a toy balloon
b. a rocket traveling through the air
c. a ball bouncing off a wall
d. All of the above

Using Vocabulary

9. State whether 30 m/s to the west represents a *speed,* a *velocity,* or both.

10. Describe the motion of a cyclist at the start of a race. In your answer, use the terms *velocity, acceleration, force,* and *friction.*

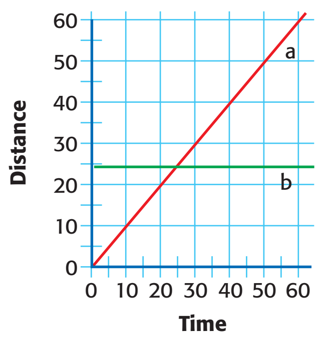
11. A wrestler weighs in for the first match on the moon. Will he weigh more or less on the moon? Explain your answer using the terms *weight, mass, force,* and *gravity.*

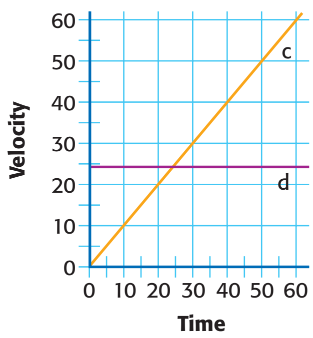
12. "There is no *gravity* in outer space." Write a paragraph explaining whether this statement is true or false. WRITING SKILL

13. Describe a sky diver's jump from the airplane to the ground. In your answer, use the terms *air resistance, gravity,* and *terminal velocity.*

BUILDING MATH SKILLS

14. Graphing The following graphs describe the motion of four different balls—*a, b, c,* and *d.* Using the graphs below, state whether each ball is accelerating, sitting still, or moving at a constant velocity.





CHAPTER 8 REVIEW

15. Velocity An airplane traveling from San Francisco northeast to Chicago travels 1260 km in 3.5 hours. What is the airplane's velocity?

16. Velocity Heather and Matthew take 45 s to walk eastward along a straight road to a store 72 m away. What is their average velocity?

17. Velocity Simpson drives his car with an average velocity of 85 km/h toward the east. How long will it take him to drive 560 km on a perfectly straight highway?

18. Momentum Calculate the momentum of an 85 kg man jogging north along the highway at 2.65 m/s.

19. Momentum Calculate the momentum of a 9.1 kg toddler who is riding in a car moving east at 89 km/h.

20. Acceleration A driver is traveling east on a dirt road when she spots a pothole ahead. She slows her car from 14.0 m/s to 5.5 m/s in 6.0 s. What is the car's acceleration?

21. Acceleration How long will it take a cyclist with a forward acceleration of -0.50 m/s^2 to bring a bicycle with an initial forward velocity of 13.5 m/s to a complete stop?

22. Force A 5.5 kg watermelon is pushed across a table. If the acceleration of the watermelon is 4.2 m/s^2 to the right, what is the net force exerted on the watermelon?

23. Force A block pushed with a force of 13.5 N accelerates at 6.5 m/s^2 to the left. What is the mass of the block?

24. Force The net force on a 925 kg car is 37 N as it pulls away from a stop sign. Find the car's acceleration.

25. Weight A bag of sugar has a mass of 2.26 kg. What is its weight in newtons on the moon, where the acceleration due to gravity is one-sixth that on Earth? (**Hint:** On Earth, $g = 9.8$ m/s^2.)

THINKING CRITICALLY

26. Interpreting Graphics Two cars are traveling east on a highway, as shown in the figure below. After 5.0 s, they are side by side at the *next* telephone pole. The distance between the poles is 70.0 m. Determine the following quantities:

a. the distance car A has traveled during the 5.0 s interval

b. the distance car B has traveled during the 5.0 s interval

c. the average velocity of car A during this 5.0 s time interval

d. the average velocity of car B during this 5.0 s time interval

27. Applying Knowledge If the average velocity of a sea gull in a given time interval is 0 m/s, what can you say about the position of the sea gull at the end of the time interval?

28. Applying Knowledge Which object has more momentum in each of the following?

a. a car and train with the same velocity

b. a moving ball and a still bat

c. two identical balls moving with the same speed in the same direction

d. two identical balls moving at the same speed in opposite directions

29. Problem Solving Why will a boat use more fuel to travel 32 km/h against the wind in a rainstorm than it would to travel at the same velocity for the same time on a sunny day with no wind?

30. Creative Thinking According to Newton's second law, twice the net force results in twice the acceleration. Explain why a stone weighing 20 N doesn't fall twice as fast as a stone weighing 10 N.

31. Applying Knowledge If you doubled the net force acting on a moving object, how would the object's acceleration be affected?

32. Problem Solving How will acceleration change if the mass being accelerated is tripled but the net force is halved?

DEVELOPING LIFE/WORK SKILLS

33. Allocating Resources A pizza-delivery car can travel 11 km for every liter (L) of gasoline it uses (26 mi/gal). If the driver's average speed is 28 km/h (18 mi/h), how many hours can the driver travel before emptying a full 35 L gas tank?

34. Making Decisions If you were an engineer designing an air-bag system, would you want the air bag to release vertically or horizontally from its storage compartment? Explain your reasoning. (**Hint:** Consider the direction of the force of the air bag.)

35. Working Cooperatively Read the following arguments about rocket propulsion. With a small group, determine which is correct. Use a diagram to explain your answer.

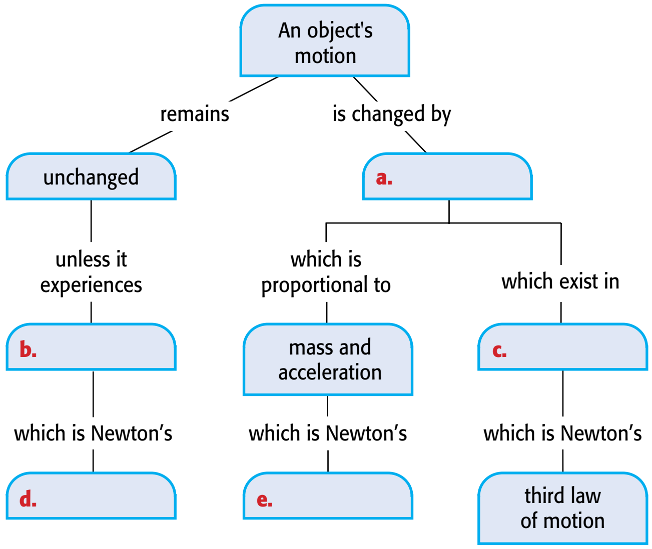
a. Rockets cannot travel in outer space because there is nothing for the gas exiting the rocket to push against.

b. Rockets can travel in outer space because gas exerts an unbalanced force on the front of the rocket. This net force causes the acceleration.

c. Argument b can't be true. The action and reaction forces will be equal and opposite. Therefore, the forces will balance, and no movement would be possible.

INTEGRATING CONCEPTS

36. Concept Mapping Copy the unfinished concept map below onto a sheet of paper. Complete the map by writing the correct word or phrase in the lettered boxes.



37. Connection to Social Studies Research Galileo's work on falling bodies. What did he want to demonstrate? What theories did he try to refute? What arguments did he use to persuade others that he was right? Did he depend on experiments and observations, logic, or other approaches?

38. Integrating Health When you exercise, you move all or parts of your body to oppose various forces. Identify the forces that oppose your body during the following exercises: push-ups, running, and swimming.

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TOPIC: Graphing speed, velocity, acceleration
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KEYWORD: HK1085

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Design Your Own Lab

Introduction

How can you use a rubber band to measure the force necessary to break a human hair?

Objectives

- ***Build*** and calibrate an instrument that measures force.
- ***Use*** your instrument to measure how much force it takes to stretch a human hair until it breaks.

Materials

rubber bands of various sizes
large and small metal paper clips
pen or pencil
metric ruler
standard hooked masses ranging from 10–200 g
comb or hairbrush

Safety Needs

safety goggles

Measuring Forces

Testing the Strength of a Human Hair

1. Obtain a rubber band and a paper clip.
2. Carefully straighten the paper clip so that it forms a double hook. Cut the rubber band and tie one end to the ring stand and the other end to one of the paper clip hooks. Let the paper clip dangle.
3. In your lab report, prepare a table as shown below.
4. Measure the length of the rubber band. Record this length in **Table 1**.
5. Hang a hooked mass from the lower paper clip hook. Supporting the mass with your hand, allow the rubber band to stretch downward slowly. Then remove your hand carefully so the rubber band does not move.
6. Measure the stretched rubber band's length. Record the mass that is attached and the rubber band's length in **Table 1**. Calculate the change in length by subtracting your initial reading of the rubber band's length from the new length.
7. Repeat steps 5 and 6 three more times using different masses each time.
8. Convert each mass (in grams) to kilograms using the following equation.
$$\text{mass (in kg)} = \text{mass (in g)} \div 1000$$
Record your answers in **Table 1**.
9. Calculate the force (weight) of each mass in newtons using the following equation.
$$\text{Force (in N)} = \text{mass (in kg)} \times 9.81\ \text{m/s}^2$$
Record your answers in **Table 1**.

Table 1 **Calibration**

Rubber-band length (cm)	Change in length (cm)	Mass on hook (g)	Mass on hook (kg)	Force (N)
	0	0	0	0

▶ Designing Your Experiment

10. With your lab partner(s), devise a plan to measure the force required to break a human hair using the instrument you just calibrated. How will you attach the hair to your instrument? How will you apply force to the hair?

11. In your lab report, list each step you will perform in your experiment.

12. Have your teacher approve your plan before you carry out your experiment.

▶ Performing Your Experiment

13. After your teacher approves your plan, gently run a comb or brush through a group member's hair several times until you find a loose hair at least 10 cm long that you can test.

14. In your lab report, prepare a data table similar to the one shown at right to record your experimental data.

15. Perform your experiment on three different hairs from the same person. Record the maximum rubber-band length before the hair snaps for each trial in **Table 2**.

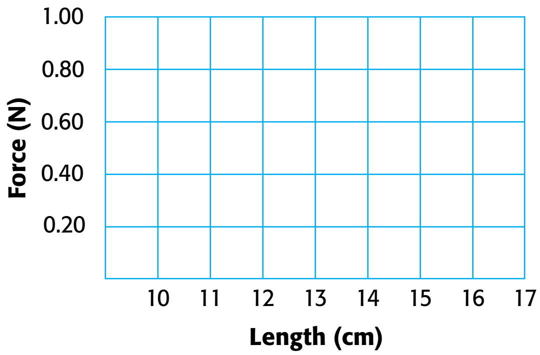
Table 2 **Experimentation**

Trial	Rubber-band length (cm)	Force (N)
Hair 1		
Hair 2		
Hair 3		

▶ Analyzing Your Results

1. Plot your calibration data in your lab report in the form of a graph like the one shown at right. On your graph draw the line or smooth curve that fits the points best.

2. Use the graph and the length of the rubber band for each trial of your experiment to determine the force that was necessary to break each of the three hairs. Record your answers in **Table 2**.



▶ Defending Your Conclusions

3. Suppose someone tells you that your results are flawed because you measured length and not force. How can you show that your results are valid?

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viewpoints

Should Bicycle Helmets Be Required by Law?

In some communities, bicyclists are required by law to wear a helmet and can be ticketed if they do not. Few people dispute the fact that bicycle helmets can save lives when used properly.

But others say that it is a matter of private rights and that the government should not interfere. Should it be up to bicyclists to decide whether or not to wear a helmet and to suffer any consequences?

But are the consequences limited to the rider? Who will pay when the rider gets hurt? Should the rider bear the cost of an injury that could have been prevented?

Is this an issue of public health or private rights? What do you think?

Require Bicycle Helmets

> FROM: Chad A., Rochester, MN

More and more people are getting head injuries every year because they do not wear a helmet. Nowadays helmets look so cool—I wouldn't be ashamed to wear one.

> FROM: Laurel R., Coral Springs, FL

I believe that this is a public issue only for people under the age of 12. Children 12 and under still need guidance and direction about safety and they are usually the ones riding their bicycles out in the road or in traffic. Often they don't pay attention to cars or other motor vehicles around them.

> FROM: Jocelyn B., Chicago, IL

They should treat helmets the same way they treat seatbelts. I was in a tragic bike accident when I was 7. I was jerked off my bike, and I slid on the glass-laden concrete. To make a long story short, I think there should be a helmet law because people just don't know the danger.

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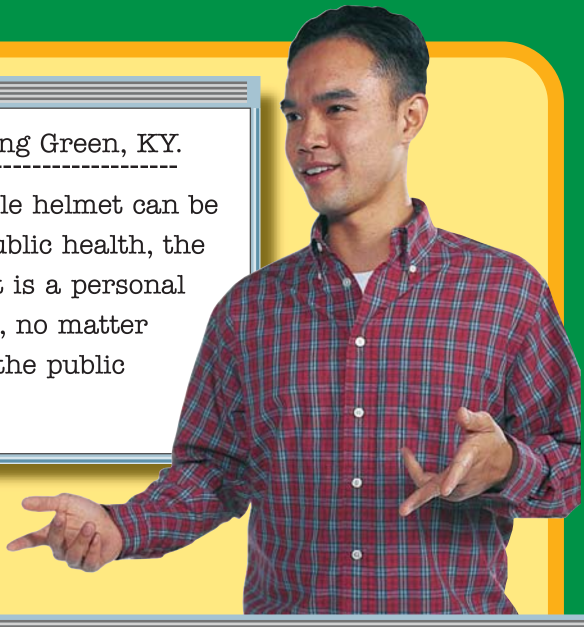
> FROM: Megan J., Bowling Green, KY.

Although wearing a bicycle helmet can be considered a matter of public health, the rider is the one at risk. It is a personal choice, no matter what the public says.



> FROM: Melissa F., Houston, TX

Bicycle helmets shouldn't be required by law. Helmets are usually a little over $20, and if you have five kids, the helmets alone cost $100. You'd still have to buy the bikes.

Don't Require Bicycle Helmets

> FROM: Heather R., Rochester, MN

It has to do with private rights. The police have more serious issues to deal with, like violent crimes. Bicycle riders should choose whether or not they want to risk their life by riding without a helmet.

Your Turn

1. **Critiquing Viewpoints** Select one of the statements on this page that you *agree* with. Identify and explain at least one weak point in the statement. What would you say to respond to someone who brought up this weak point as a reason you were wrong?
2. **Critiquing Viewpoints** Select one of the statements on this page that you *disagree* with. Identify and explain at least one strong point in the statement. What would you say to respond to someone who brought up this point as a reason they were right?
3. **Creative Thinking** Suppose you live in a community that does not have a bicycle helmet law. Design a campaign to persuade people to wear helmets, even though it isn't required by law. Your campaign could include brochures, posters, and newspaper ads.
4. **Acquiring and Evaluating Data** When a rider falls off a bicycle, the rider continues moving at the speed of the bicycle until the rider strikes the pavement and slows down rapidly. For bicycle speeds ranging from 5.0 m/s to 25.0 m/s, calculate what acceleration would be required to stop the rider in just 0.50 s. How large is the force that must be applied to a 50.0 kg rider to cause this acceleration? Organize your data and results in a series of charts or graphs.

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TOPIC: Bicycle helmets
GO TO: go.hrw.com
KEYWORD: HK1Helmet

Should helmets be required by law? Why or why not? Share your views on this issue and learn about other viewpoints at the HRW Web site.