Chapter 11

Forces in Fluids

CALIFORNIA Standards Preview

S 8.2 Unbalanced forces cause changes in velocity. As a basis for understanding this concept:

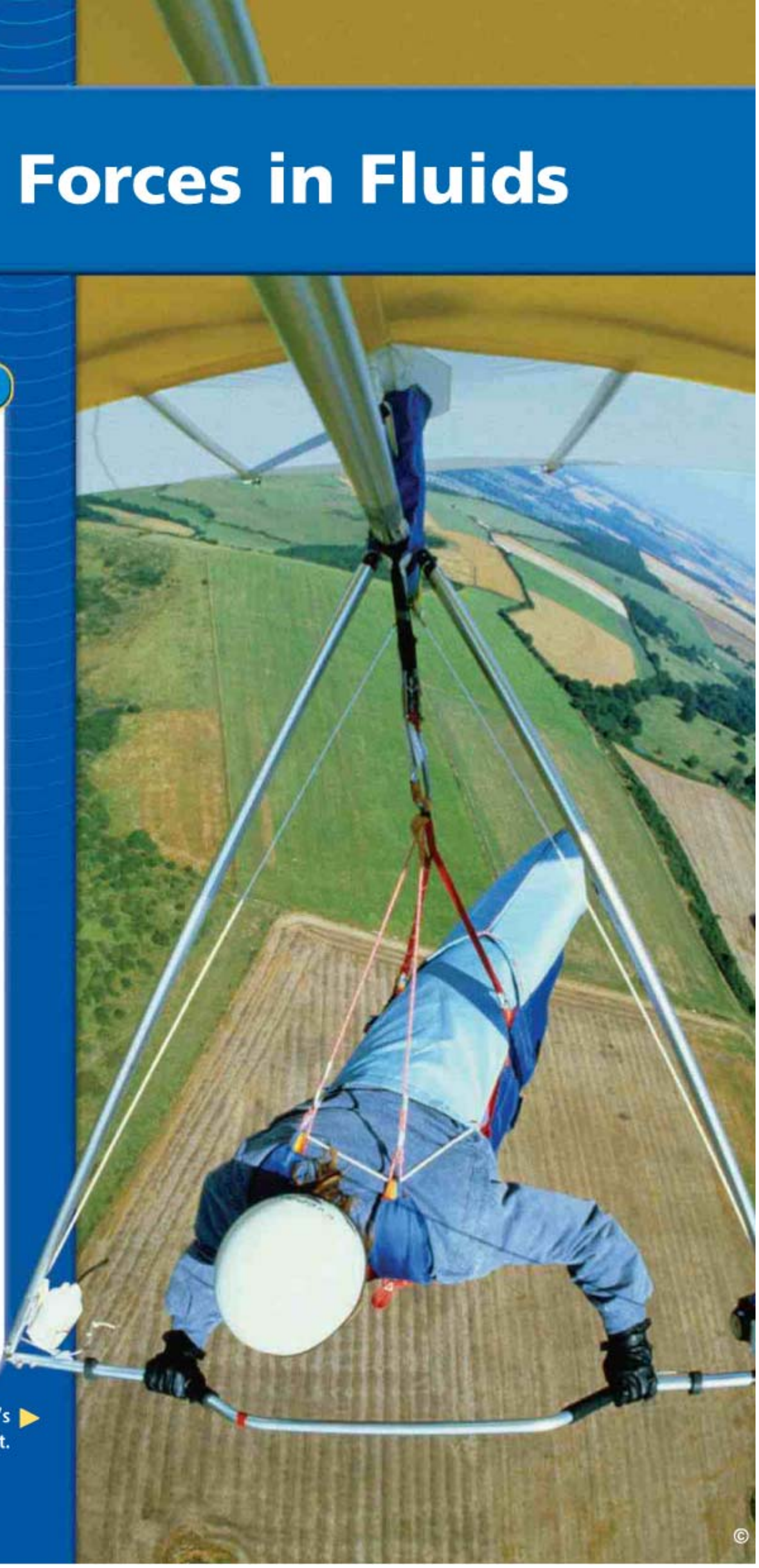
- **e.** Students know that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction).

S 8.8 All objects experience a buoyant force when immersed in a fluid. As a basis for understanding this concept:

- **c.** Students know the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid the object has displaced.
- **d.** Students know how to predict whether an object will float or sink.

S 8.9 Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

- **a.** Plan and conduct a scientific investigation to test a hypothesis.
- **c.** Distinguish between variable and controlled parameters in a test.
- **f.** Apply simple mathematical relationships to determine a missing quantity in a mathematic expression, given the two remaining terms (including speed = distance/time, density = mass/volume, force = pressure × area, volume = area × height).



The force of air pushing on a hang glider's wing helps to keep the glider aloft. ▶

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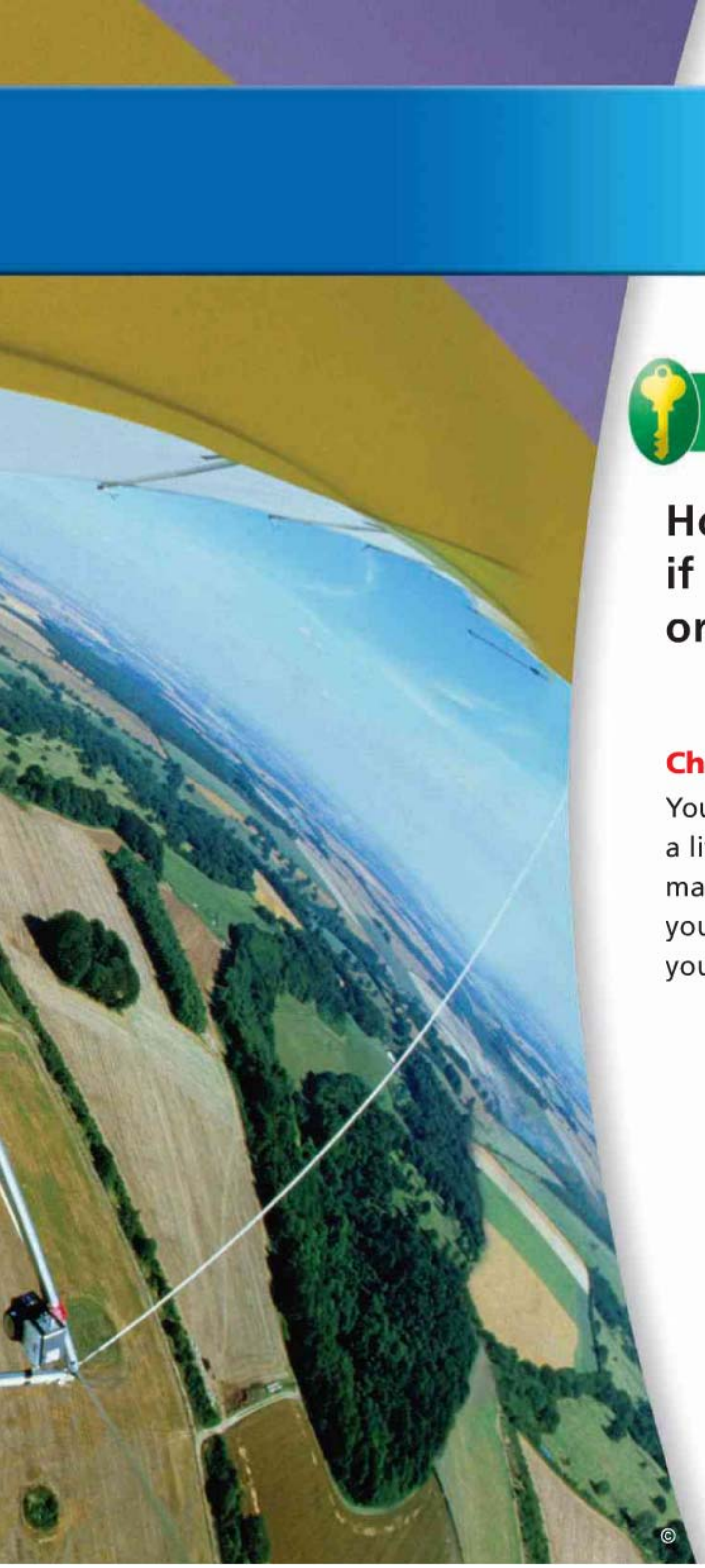


Video Preview

Discovery Channel School

Forces in Fluids

S 8.8.d

Focus on the

BIG Idea

How can you predict if an object will sink or float in a fluid?

Check What You Know

You dive into a pool wearing a life vest. Wearing the vest makes you bigger and makes you weigh more. So why do you float?

Build Science Vocabulary

The images shown here represent some of the Key Terms in this chapter. You can use this vocabulary skill to help you understand the meaning of some Key Terms in this chapter.

Vocabulary Skill

Identify Multiple Meanings

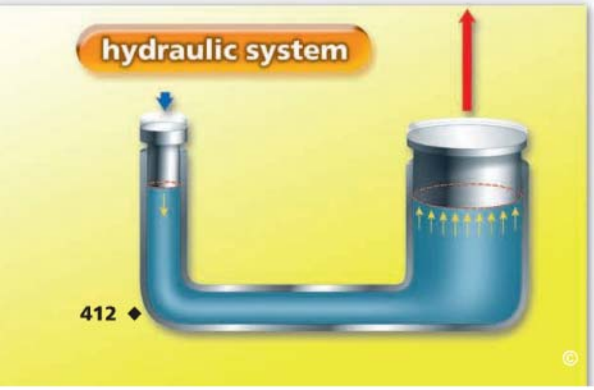
Some familiar words have more than one meaning. Words you use every day may have different meanings in science. Look at the different meanings of the words below.

Word	Everyday Meaning	Scientific Meaning
fluid	*n.* A liquid **Example:** It's good for your health to drink plenty of fluids every day.	*n.* A substance that can easily flow; a gas or a liquid **Example:** Like water, air is a fluid.
force	*v.* To use power to make someone do something **Example:** She had to force herself to get up early.	*n.* A push or a pull exerted on an object **Example:** You exert force when you open and close a door.
pressure	*n.* A feeling of being pushed to do things **Example:** Students may feel pressure from adults to do well on tests.	*n.* The force exerted on a surface divided by the total area over which the force is exerted **Example:** When air leaks from a tire, the pressure is reduced and the tire becomes soft.

Apply It!

Read the sentences below. Then identify the term that has a scientific meaning.

1. When a gas is heated, the *pressure* of the gas increases.
2. Her parents are putting *pressure* on her to find a job.



Chapter 11 Vocabulary

Section 1 (page 416)

pressure
pascal
fluid
barometer

Section 2 (page 424)

density
buoyant force
Archimedes' principle

Section 3 (page 432)

Pascal's principle
hydraulic system

Section 4 (page 437)

Bernoulli's principle
lift

Interactive Textbook

Build Science Vocabulary *Online*
Visit: PHSchool.com
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How to Read Science

Reading Skill

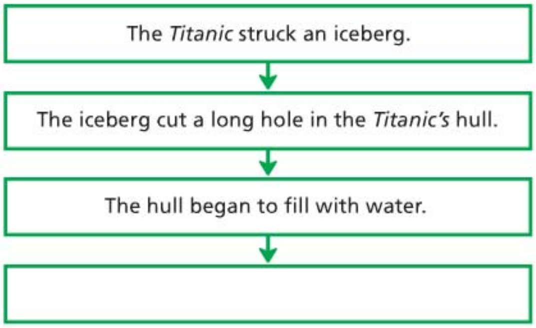
Sequence

Many parts of a textbook are organized by sequence. Sequence is the order in which a series of events occurs. Sometimes the text uses signal words, such as *after, next, then,* and *finally* to show sequence. Look for the signal words in the paragraph below.

> The *Titanic* was the largest ship afloat. A few days into its first voyage, the *Titanic* struck an iceberg. The iceberg cut a long hole in the *Titanic's* hull. Soon after, the hull began to fill with water. Then, the ship's bow slipped under water and the *Titanic* broke in two. Finally, the *Titanic* sank to the bottom of the Atlantic Ocean.

A flowchart can help you understand the sequence. To make a flowchart, write each step in a box. Place the boxes in order.

The *Titanic*



Apply It!

In your notebook, copy the flowchart. Then add the next steps.

As you read Section 3, create a flowchart showing how pressure is transmitted in a fluid. As you read Section 4, create a flowchart on how an atomizer works.

Lab zone

Standards Investigation

S 8.8.d

Staying Afloat

Why doesn't a heavy boat sink? In this investigation, you will design and build a boat that can float in water and carry cargo. You will find out what forces in fluids make an object sink or float.

Your Goal

To construct a boat that can float in water and carry cargo

Your boat must

- be made of metal only
- support a cargo of 50 pennies without allowing any water to enter for at least 10 seconds
- travel at least 1.5 meters
- be built following the safety guidelines in Appendix A

Plan It!

Before you design your boat, think about the shape of real ships. Preview the chapter to find out what makes an object float. Then look for simple metal objects that you can form into a boat. Compare different materials and designs to build the boat that best fits the goals listed above. After your teacher approves your design, build your boat and test it.

Section

1 Pressure

CALIFORNIA
Standards Focus

S 8.8.d Students know how to predict whether an object will float or sink.

S 8.9.f Apply simple mathematical relationships to determine a missing quantity in a mathematic expression, given the two remaining terms (including speed = distance/time, density = mass/volume, force = pressure × area, volume = area × height).

- What does pressure depend on?
- How do fluids exert pressure?
- How does fluid pressure change with elevation and depth?

Key Terms

- pressure
- pascal
- fluid
- barometer

Lab zone **Standards Warm-Up**

Does Water Push Back?

1. Fill a large sink with water. Drop a deflated balloon into the water and note what happens.
2. Now fill the balloon with air and push the balloon into the water. Note what happens when you let go of the balloon.

Think It Over

Drawing Conclusions Compare your observations in Steps 1 and 2. Why did an air-filled balloon act differently from the deflated one?

Outside, deep snow covers the ground. You put on your sneakers and head out, shovel in hand. When you step outside, your foot sinks deep into the snow. It's nearly up to your knees! Nearby, a sparrow hops across the surface of the snow. Unlike you, the bird does not sink. In fact, it barely leaves a mark! Why do you sink into the snow while the sparrow rests on the surface? The answer has to do with pressure.

What Is Pressure?

The word *pressure* is related to the word *press*. You may recall that Earth's gravity pulls you downward with a force equal to your weight. Due to gravity, your feet exert a force on the surface of Earth over an area the size of your feet. In other words, your feet exert pressure on the ground.

Exerting pressure on snow ►

FIGURE 1
Pressure and Area
The amount of pressure depends on the area over which a force is distributed. **Inferring** *Which type of shoe would you use to keep from sinking into deep snow?*

Pressure and Area **The amount of pressure you exert depends on the area over which you exert a force.** The larger the area over which the force is distributed, the less pressure is exerted.

In order to stand on snow without sinking, you can change the area over which you exert the force of your weight. Figure 1 shows that if you wear sneakers, your weight is distributed over the soles of both shoes. You'll exert pressure over an area of only about 250 $\text{cm}^2 \times 2$, or 500 cm^2, and sink into the snow. But if you wear snowshoes, your weight is distributed over a much greater area—about 1,100 $\text{cm}^2 \times 2$, or 2,200 cm^2. Because your weight is distributed over a greater area, the pressure exerted on the snow is much less. Like a sparrow, you can stand on the snow without sinking!

Calculating Pressure **Pressure** is equal to the force exerted on a surface divided by the total area over which the force is exerted. You can calculate pressure using the formula below.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

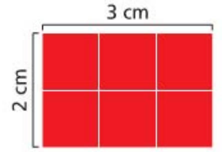
Force is measured in newtons (N). Area is measured in square meters (m^2). Since force is divided by area, the SI unit of pressure is the newton per square meter (N/m^2). This unit of pressure is also called the **pascal** (Pa): $1\ \text{N/m}^2 = 1\ \text{Pa}$. It is named for the French mathematician Blaise Pascal.

Reading Checkpoint **What is the SI unit of pressure called?**

Math Skills

Area

The area of a surface is the number of square units that it covers. To find the area of a rectangle, multiply its length by its width. The area of the rectangle below is 2 cm × 3 cm, or 6 cm^2.



Practice Problem Which has a greater area: a rectangle that is 4 cm × 20 cm, or a square that is 10 cm × 10 cm?

FIGURE 2
Fluid Particles
The particles that make up a fluid move constantly in all directions. When a particle collides with a surface, it exerts a force on the surface.
Relating Cause and Effect *What will happen to the force exerted by the particles in the chair when you add more air to the chair?*

Fluid Pressure

Solids such as sneakers are not the only materials that exert pressure. Fluids also exert pressure. A **fluid** is a material that can easily flow. As a result, a fluid can change shape. Liquids such as water and oil and gases such as air and helium are examples of fluids. Understanding pressure in fluids will help you to predict whether an object will float or sink.

What Causes Fluid Pressure? Think about the tiny particles that make up a fluid. Particles in a fluid constantly move in all directions, as shown in Figure 2. As they move, the particles collide with each other and with any surface that they meet.

As each particle of a fluid collides with a surface, it exerts a force on the surface. **In a fluid, all of the forces exerted by the individual particles combine to make up the pressure exerted by the fluid.** Because the number of particles is large, you can consider the fluid as a whole. So, the pressure exerted by fluid is the total force exerted by the fluid divided by the area over which the force is exerted.

Air Pressure Did you know that you live at the bottom of 100 kilometers of fluid? This fluid, called air, is the mixture of gases that makes up Earth's atmosphere. These gases press down on everything on Earth's surface, all the time. Air exerts pressure because it has mass. Each cubic meter of air around you has a mass of about 1 kilogram. Because the force of gravity pulls down on this mass of air, the air has weight. The weight of the air is the force that produces air pressure, or atmospheric pressure.

Lab zone Try This **Activity**

Card Trick

1. Fill a small plastic cup to the brim with water. Gently place an index card over the top of the cup.
2. Hold the card in place and slowly turn the cup upside down. Let go of the card. What happens? Without touching the card, turn the container on its side.

Inferring Why does the water stay in the cup when you turn the cup upside down?

Balanced Pressure Hold out your hand, palm up. You are holding up air. At sea level, atmospheric pressure is about 101,300 Pa. The surface area of your hand is about 100 cm^2. So, the weight supported by the surface area of your hand is about 1,000 newtons, or about the same weight as that of a large washing machine!

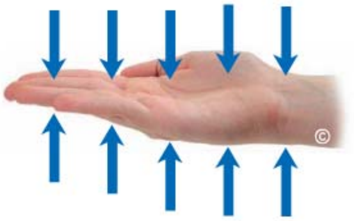
How could your hand possibly support that weight and not feel it? In a stationary fluid, pressure at a given point is exerted equally in all directions. The weight of the atmosphere does not just press down on your hand. It presses on your hand from every direction. The pressures balance each other.

Balanced pressures also explain why the tremendous air pressure pushing on you from all sides does not crush you. Your body contains fluids that exert outward pressure. For example, your lungs and sinus cavities contain air. Your cells and blood vessels contain liquids. Pressure from fluids inside your body balances the air pressure outside your body.

What happens when air pressure becomes unbalanced? Look at Figure 4. When the can is full of air, the air pressure inside the can balances the atmospheric pressure outside the can. When air is removed from the can, the unbalanced force of the outside air pressure crushes the can.

Reading Checkpoint **How is the pressure on your hand balanced?**

FIGURE 3
Atmospheric Pressure
The pressure of Earth's atmosphere is exerted over the entire surface of your hand. The downward pressure is the same as the upward pressure.



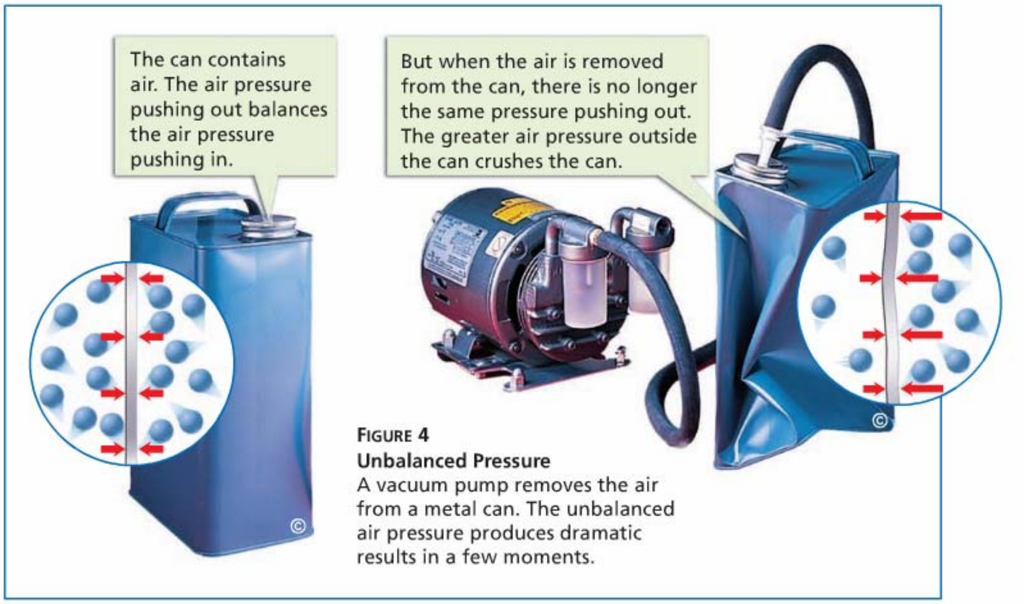
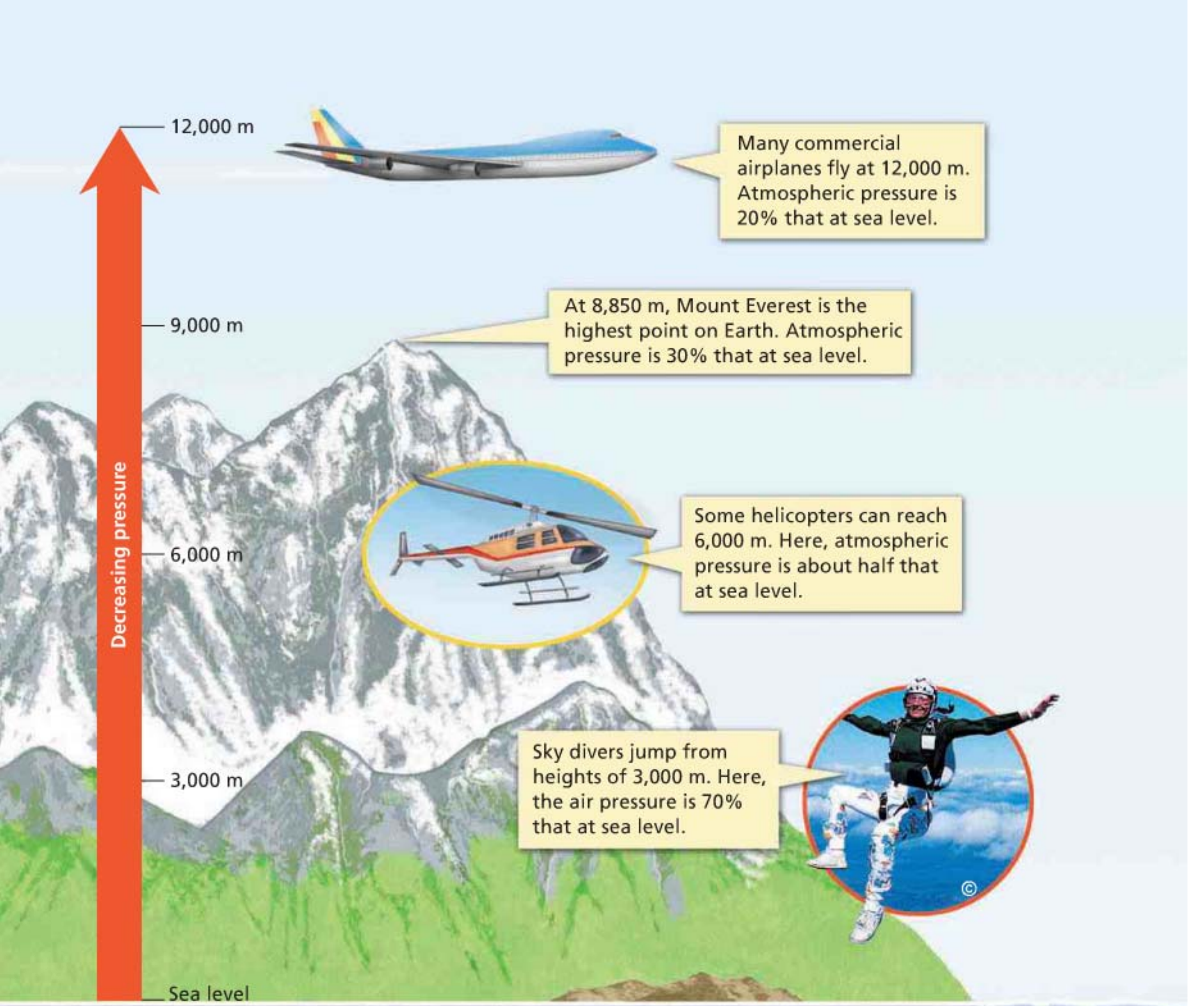


FIGURE 4
Unbalanced Pressure
A vacuum pump removes the air from a metal can. The unbalanced air pressure produces dramatic results in a few moments.



Many commercial airplanes fly at 12,000 m. Atmospheric pressure is 20% that at sea level.

At 8,850 m, Mount Everest is the highest point on Earth. Atmospheric pressure is 30% that at sea level.

Some helicopters can reach 6,000 m. Here, atmospheric pressure is about half that at sea level.

Sky divers jump from heights of 3,000 m. Here, the air pressure is 70% that at sea level.

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FIGURE 5
Pressure Variations

Atmospheric pressure decreases gradually as the elevation above sea level increases. Water pressure increases rapidly as the water depth increases. **Applying Concepts** *Why do airplanes have pressurized cabins?*

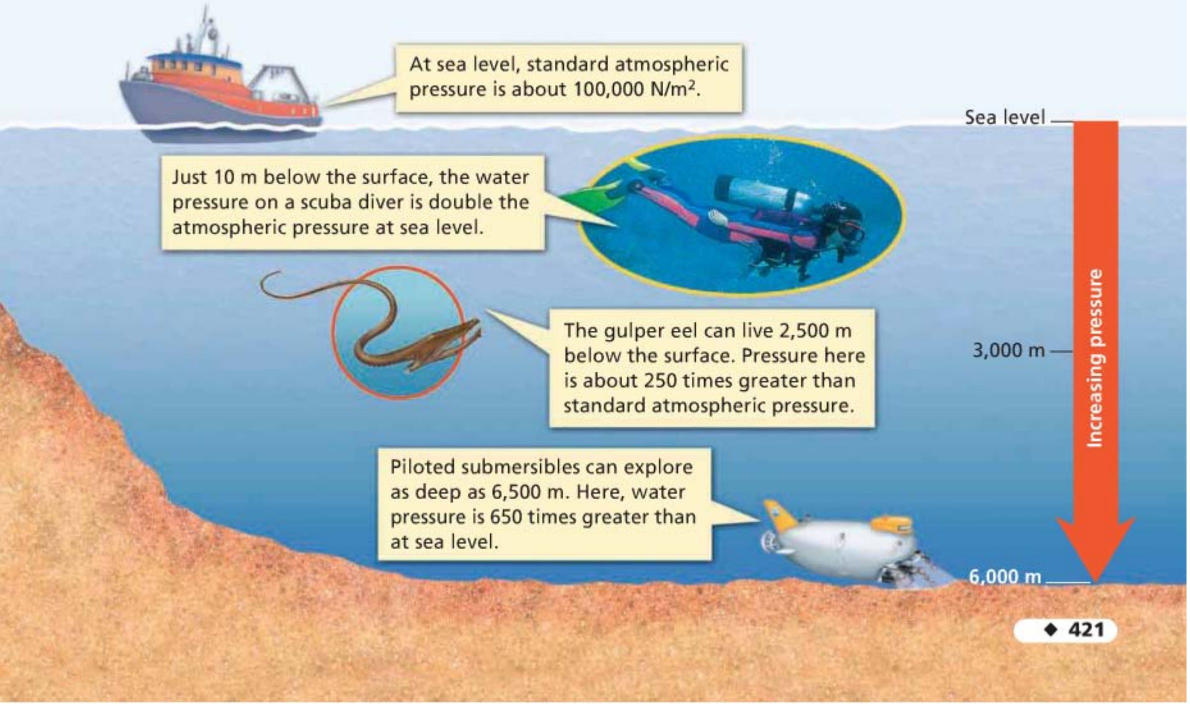
Variations in Fluid Pressure

Have you ever felt your ears "pop" as you rode up in an elevator? What happens to pressure as you climb to a higher elevation or sink to a lower depth within a fluid? Figure 5 shows how pressure changes depending on where you are.

Atmospheric Pressure and Elevation The "popping" in your ears is caused by changing air pressure. At higher elevations, there is less air above you and therefore less air pressure. **Atmospheric pressure decreases as your elevation increases.**

When the air pressure outside your body decreases, the air pressure inside also decreases, but more slowly. So, for a moment, the air pressure behind your eardrums is greater than it is in the air outside. Your body releases this pressure with a "pop," balancing the pressures.

Water Pressure and Depth You experience a different type of presssure change if you dive underwater. **Water pressure increases as depth increases.** So if you dive into a body of water, pressure becomes greater as you descend. The deeper you swim, the greater the pressure you feel.



At sea level, standard atmospheric pressure is about 100,000 N/m^2.

Just 10 m below the surface, the water pressure on a scuba diver is double the atmospheric pressure at sea level.

The gulper eel can live 2,500 m below the surface. Pressure here is about 250 times greater than standard atmospheric pressure.

Piloted submersibles can explore as deep as 6,500 m. Here, water pressure is 650 times greater than at sea level.

FIGURE 6
Aneroid Barometer
An aneroid barometer measures atmospheric pressure.
Interpreting Photographs *What type of weather might be coming when atmospheric pressure decreases?*

Water pressure is a result of the weight of the water above a particular point. At greater depths, there is more water above that point and therefore more weight to support. In addition, air in the atmosphere pushes down on the water. Therefore, the total pressure at a given point beneath the water results from the weight of the water plus the weight of the air above it. In the deepest parts of the ocean, the pressure is more than 1,000 times the air pressure you experience every day.

Measuring Pressure You can measure atmospheric pressure with an instrument called a **barometer.** Weather forecasters use the pressure reading from a barometer to help forecast the weather. Rapidly decreasing atmospheric pressure usually means a storm is on its way. Increasing pressure is often a sign of fair weather.

The barometer you usually see hanging on a wall is an aneroid barometer. Forecasters will often express the pressure in units of millimeters of mercury or inches of mercury. Those units are based on the original type of barometer, which measured how far the atmosphere pushed liquid mercury up a tube. Standard atmospheric pressure at sea level may be reported as 760 millimeters of mercury, which is about the same as 101,300 Pa.

Reading Checkpoint **What instrument measures atmospheric pressure?**

Section 1 Assessment

S 8.8.d, S 8.9.f
E-LA: Reading 8.1.0

Vocabulary Skill **Identify Multiple Meanings**
Use the scientific meanings for *fluid* and *pressure* to help you define the term *fluid pressure.*

Reviewing Key Concepts

HINT

1. a. **Reviewing** What two factors does pressure depend on?

HINT

   b. **Comparing and Contrasting** Who exerts more pressure on the ground—a 500-N woman standing in high heels with a total area of 0.005 m^2, or the same woman standing in work boots with a total area of 0.05 m^2? Calculate the pressure she exerts on the ground in both cases.

HINT

HINT

2. a. **Summarizing** How do fluids exert pressure?
   b. **Explaining** Why aren't you crushed by the weight of the atmosphere?

HINT

   c. **Inferring** How is your body similar to the can containing air shown in Figure 4?

3. a. **Describing** How does atmospheric pressure change as you move up away from sea level?

HINT

   b. **Comparing and Contrasting** Compare the change in atmospheric pressure with elevation to the change in water pressure with depth.

HINT

   c. **Applying Concepts** Why must an astronaut wear a pressurized suit in space?

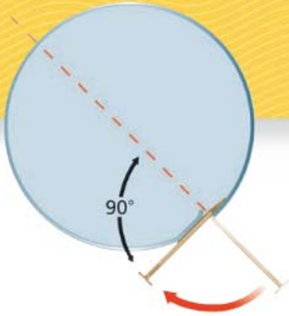
HINT

Lab zone At-Home Activity

Water and Weight Fill a pot with water from the sink. Fill a sandwich bag with water at the same temperature. Seal the bag and drop it into the pot. Note what happens. Then repeat the experiment with a sandwich bag filled with hot water and a sandwich bag filled with water that is just slightly above the freezing point. Describe your observations.

Lab zone

Design Your Own Lab



Spinning Sprinklers

S 8.2.e, 8.9.c

Problem

What factors affect the speed of rotation of a lawn sprinkler?

Skills Focus

designing experiments, controlling variables

Materials

- empty soda can
- fishing line, 30 cm
- waterproof marker
- wide-mouth jar or beaker
- stopwatch
- nails of various sizes
- large basin

Procedure

PART 1 Making a Sprinkler

1. Fill the jar with enough water to completely cover a soda can. Place the jar in the basin.
2. Bend up the tab of a can and tie the end of a length of fishing line to it. **CAUTION:** *The edge of the can opening can be sharp.*
3. Place a mark on the can to help you keep track of how many times the can spins.
4. Using the small nail, make a hole in the side of the can about 1 cm up from the bottom. Poke the nail straight in. Then twist the nail until it makes a right angle with the radius of the can as shown in the figure above. **CAUTION:** *Nails are sharp and should be used only to puncture the cans.*
5. Submerge the can in the jar and fill the can to the top with water.
6. Quickly lift the can with the fishing line so that it is 1–2 cm above the water level in the jar. Practice counting how many spins the can completes in 15 seconds.

PART 2 What Factors Affect Spin?

7. How does the size of the hole affect the number of spins made by the can? Propose a hypothesis and then design an experiment to test the hypothesis. Obtain your teacher's approval before carrying out your experiment. Record all your data.
8. How does the number of holes affect the number of spins made by the can? Propose a hypothesis and then design an experiment to test the hypothesis. Obtain your teacher's approval before carrying out your experiment. Record all your data.

Analyze and Conclude

1. **Designing Experiments** How does the size of the hole affect the rate of spin of the can? How does the number of holes affect the rate of spin of the can?
2. **Controlling Variables** What controlled parameters did you leave unchanged in this experiment? What other parameters might affect the number of spins made by the can?
3. **Interpreting Data** Explain the motion of the can in terms of unbalanced forces.
4. **Classifying** Which of Newton's three laws of motion could you use to explain the motion of the can? Explain.
5. **Communicating** Use the results of your experiment to write a paragraph that explains why a spinning lawn sprinkler spins.

More to Explore

Some sprinkler systems use water pressure to spin. Examine one of these sprinklers to see the size, direction of spin, and number of holes. What would happen if you connected a second sprinkler to the first with another length of hose? If possible, try it.

Section 2

Floating and Sinking

CALIFORNIA Standards Focus

S 8.8.c Students know the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid the object has displaced.

S 8.8.d Students know how to predict whether an object will float or sink.

- How can you predict whether an object will float or sink in a fluid?
- What is the effect of the buoyant force?

Key Terms

- density
- buoyant force
- Archimedes' principle

Lab zone Standards Warm-Up

What Can You Measure With a Pencil?

1. Stick a metal thumbtack in the eraser of an unsharpened wooden pencil. You have built a device called a hydrometer.
2. Place the pencil in a glass of water with the eraser and tack pointing down. Note how far the pencil sinks in the water by marking the edge of the pencil at the water's surface line with a waterproof marker.
3. Remove the pencil from the water. Measure the length the pencil sunk in centimeters.
4. Dissolve 10 spoonfuls of sugar into the glass of water. Try out your hydrometer in this liquid. Again mark how far the pencil sinks. Then remove the pencil from the water and once again measure the length the pencil sunk in centimeters.

Think It Over

Predicting Compare your observations in Steps 3 and 4. Predict what will happen if you use 20 spoonfuls of sugar in a glass of water. Test your prediction.

In April 1912, the *Titanic* departed from England on its first and only voyage. At the time, it was the largest ship afloat—nearly three football fields long. The *Titanic* was also the most technologically advanced ship in existence. Its hull was divided into compartments, and it was considered to be unsinkable.

Yet a few days into the voyage, the *Titanic* struck an iceberg. One compartment after another filled with water. Less than three hours later, the bow of the great ship slipped under the waves. As the stern rose high into the air, the ship broke in two. Both pieces sank to the bottom of the Atlantic Ocean. More than a thousand people died.

◀ **The bow section of the Titanic resting on the ocean floor**

Density

The Titanic sank because of a change in its density. Recall that the **density** of a substance is its mass per unit volume.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

For example, one cubic centimeter (cm^3) of copper has a mass of 8.8 grams, so its density is 8.8 g/cm^3. One cubic centimeter of plastic has a mass of only about 0.93 gram. So the density of plastic is about 0.93 g/cm^3. Copper is more dense than plastic. The density of water is 1.0 g/cm^3. So water is less dense than copper but more dense than plastic.

Comparing Densities of Substances Figure 7 shows several substances and their densities. Each substance has its own density. Some liquids float on top of other liquids. The substances with the greatest densities are near the bottom.

By comparing densities, you can predict whether an object will float or sink in a fluid. An object that is more dense than the fluid it is in sinks. An object that is less dense than the fluid floats on the surface. An object with a density equal to that of the fluid floats at a constant depth.

Reading Checkpoint When will an object float on a fluid's surface?

Math Skills

Calculating Density

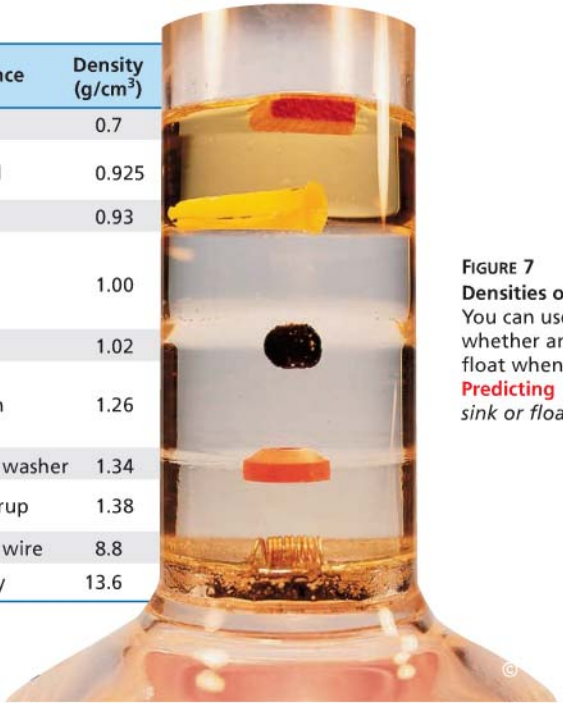
The density of a substance is its mass per unit of volume.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

For example, a sample of liquid has a mass of 24 g and a volume of 16 mL. What is its density?

$$\text{Density} = \frac{24\text{ g}}{16\text{ mL}}$$
$$= 1.5\text{ g/mL}$$

Practice Problem A piece of metal has a mass of 43.5 g and a volume of 15 cm^3. What is its density?



Substance	Density (g/cm^3)
Wood	0.7
Corn oil	0.925
Plastic	0.93
Water	1.00
Tar ball	1.02
Glycerin	1.26
Rubber washer	1.34
Corn syrup	1.38
Copper wire	8.8
Mercury	13.6

FIGURE 7
Densities of Substances
You can use density to predict whether an object will sink or float when placed in a liquid.
Predicting *Will a rubber washer sink or float in corn oil?*

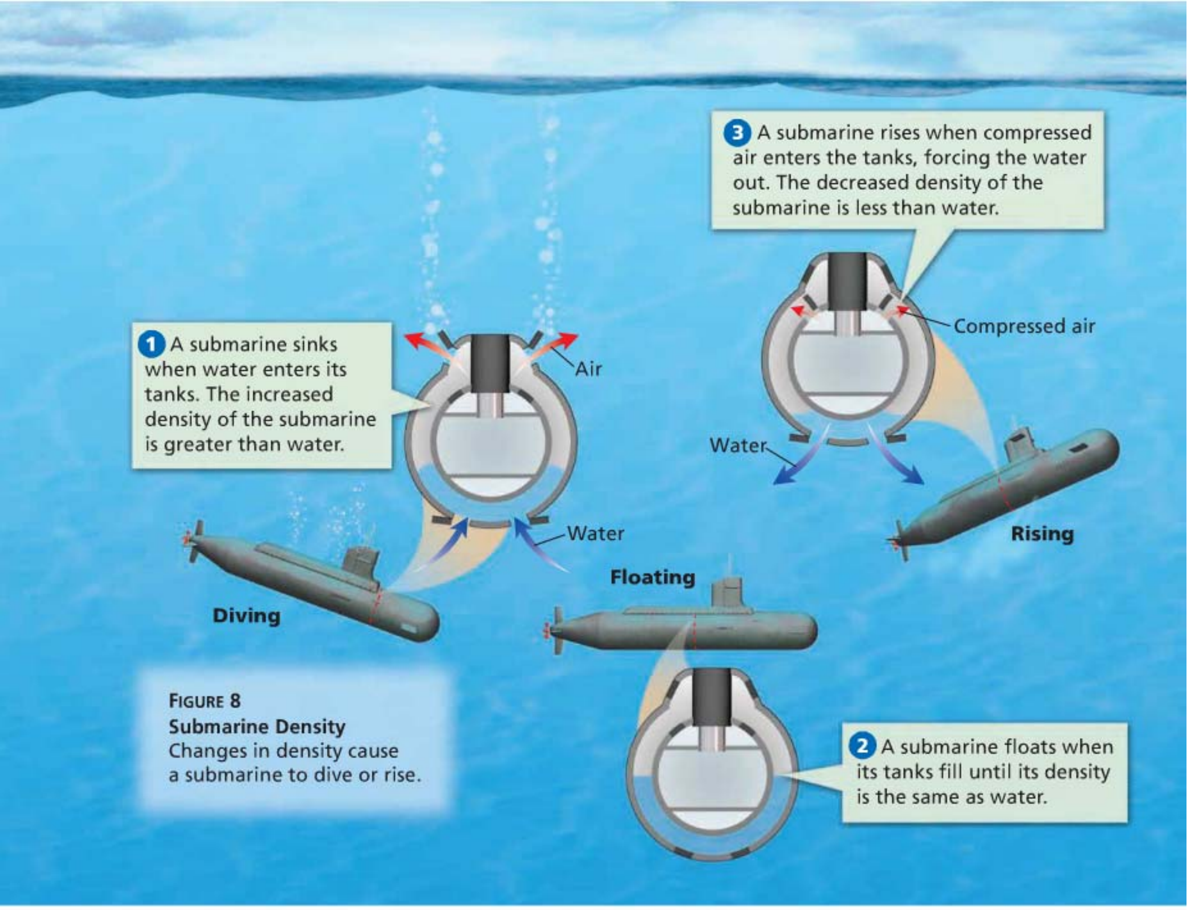


FIGURE 8
Submarine Density
Changes in density cause a submarine to dive or rise.

Changing Density Changing density can explain why an object floats or sinks. For example, you can change the density of water by freezing it into ice. Since water expands when it freezes, the ice occupies more space than the water. That's why ice is less dense than water. But it's just a bit less dense! So most of an ice cube floating on the surface is below the water's surface.

You can make an object sink or float in a fluid by changing its density. Look at Figure 8 to see how this happens to a submarine. The density of a submarine increases when water fills its flotation tanks. This happens because the overall mass of the submarine increases, but its volume remains the same. So the submarine will sink. To make the submarine rise in the water, the engineer pumps water out of the flotation tanks, decreasing the submarine's mass. Its density decreases, and it rises.

✓ **Reading Checkpoint** **When will a submarine rise?**

Buoyancy

Ships are designed to have buoyancy—the ability to float. How is it possible that a huge ship can float easily on the surface of water under certain conditions, and then in a few hours become a sunken wreck? To answer this question, you need to understand the buoyant force.

Gravity and the Buoyant Force If you have ever picked up an object under water, you know that it seems much lighter in water than in air. Water and other fluids exert an upward force called the **buoyant force** that acts on a submerged object. **The buoyant force acts in the direction opposite to the force of gravity, so it makes an object feel lighter.** The less dense the object is, the greater the buoyant force it experiences.

As you can see in Figure 9, a fluid exerts pressure on all surfaces of a submerged object. Since the pressure in a fluid increases with depth, the upward pressure on the bottom of the object is greater than the downward pressure on the top. The result is a net force acting upward on the submerged object. This is the buoyant force.

Remember that the weight of a submerged object is a downward force. If an object's weight is greater than the buoyant force, a net force acts downward on the object. The object will sink. If the weight of an object is equal to the buoyant force, no net force acts on the object. The object will not sink. A submerged object whose weight is equal to the buoyant force also has no net force acting on it. The object will not sink.

Remember that you can also use density to explain why objects float or sink. In Figure 10, the density of the jellyfish is less than that of water, while the turtle's density is equal to that of water. The jellyfish and the turtle float. The density of the lobster is greater than water. The lobster sinks.

FIGURE 9

Buoyant Force

The pressure on the bottom of a submerged object is greater than the pressure on the top. The result is a net force in the upward direction.

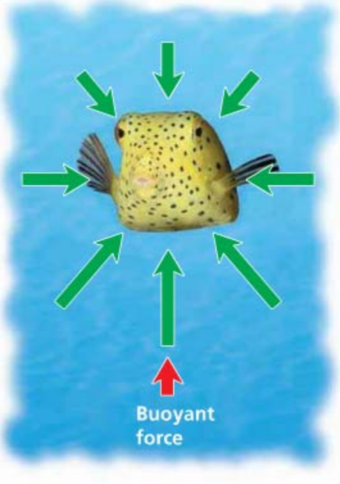
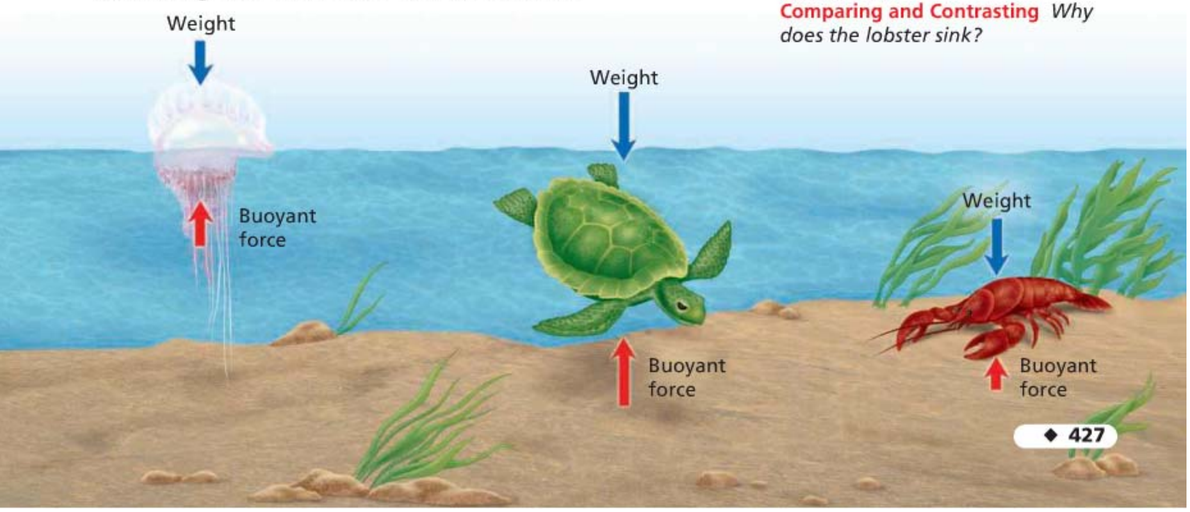


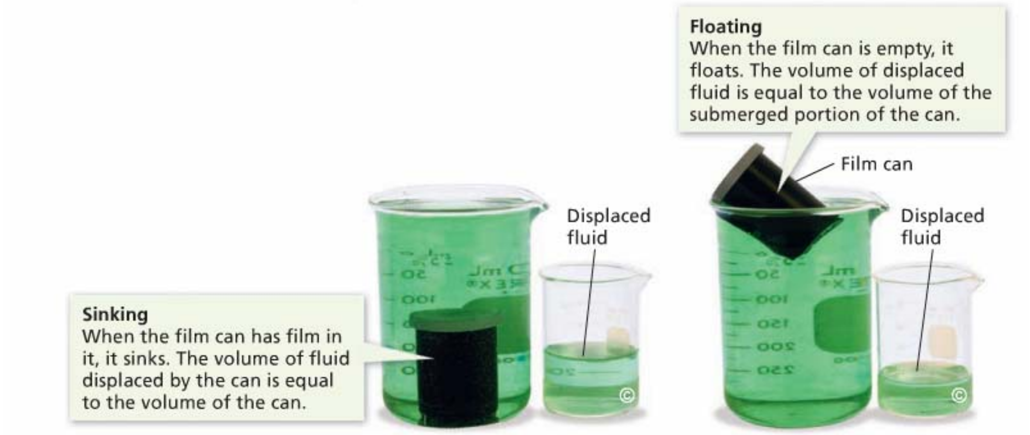
FIGURE 10

Buoyant Force and Weight

The buoyant force works opposite the weight of an object. The forces acting on the jellyfish and turtle are balanced, so they float in place. The forces on the lobster are unbalanced.

Comparing and Contrasting *Why does the lobster sink?*





Floating
When the film can is empty, it floats. The volume of displaced fluid is equal to the volume of the submerged portion of the can.

Sinking
When the film can has film in it, it sinks. The volume of fluid displaced by the can is equal to the volume of the can.

FIGURE 11
Archimedes' Principle
Archimedes' principle applies to sinking and floating objects.
Predicting *If you press down on the floating film can, what will happen to the volume of the displaced fluid in the small beaker?*

Archimedes' Principle

All objects take up space. A submerged object displaces, or takes the place of, a volume of fluid equal to its own volume. A partly submerged object displaces a volume of fluid equal to the volume of its submerged portion only. You can see this in Figure 11.

Archimedes, a mathematician of ancient Greece, discovered a connection between the weight of a fluid displaced by an object and the buoyant force acting on it. **Archimedes' principle** states that the buoyant force acting on a submerged object is equal to the weight of the volume of fluid displaced by the object. Suppose your body displaces 50 liters of water in a swimming pool. The buoyant force on you will be equal to the weight of 50 liters of water, or about 500 N.

Submarines How can a submarine dive and float? Since the buoyant force is equal to the weight of the displaced fluid, the buoyant force on the submerged submarine stays the same. Changing the water level in the flotation tanks changes the weight of the submarine. The submarine sinks when its weight is greater than the buoyant force. It rises when its weight is less than the buoyant force.

Balloons Air is a fluid. A balloon filled with air is denser than the surrounding air because the air inside it is under pressure. The denser air inside makes it fall to the ground. But if the air inside the balloon is heated, it becomes less dense, and the balloon rises. You can also fill a balloon with helium. A helium balloon rises because helium is less dense than air.

✓ Reading Checkpoint **Why does a helium balloon float in air?**

Video Field Trip
Discovery Channel School
Forces in Fluids

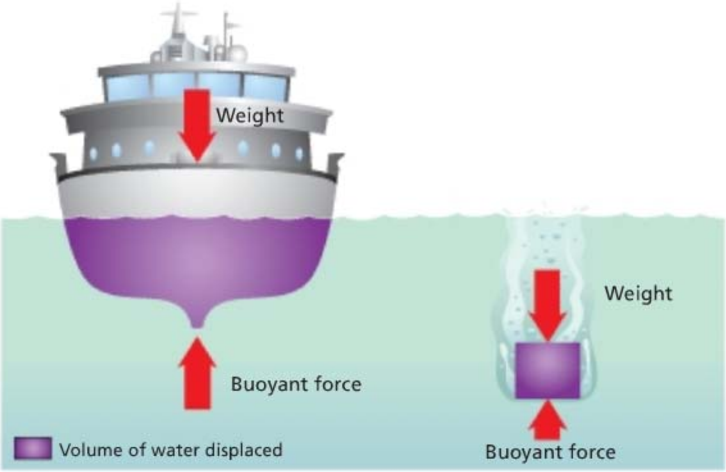


FIGURE 12
Floating Ship
A solid block of steel sinks in water. A steel ship with the same weight floats on the surface.

Ships You can use Archimedes' principle to explain why a ship floats on the surface. Since the buoyant force equals the weight of the displaced fluid, the buoyant force will increase if more fluid is displaced. A large object displaces more fluid than a small object. A greater buoyant force acts on the larger object even if the large object has the same weight as the small object.

Look at Figure 12. The ship's hull has the same mass as the solid block of steel, but its shape causes the ship to displace a greater volume of water. According to Archimedes' principle, the buoyant force is equal to the weight of the displaced water. Since a ship displaces more water than a block of steel, a greater buoyant force acts on the ship. The buoyant force acting on it is equal to its weight, and the ship floats on the surface.

Section 2 Assessment

S 8.8.c, 8.8.d E-LA: Reading 8.1.0

Vocabulary Skill Identify Multiple Meanings
Use the scientific meaning of *force* to define the key term *buoyant force*.

Reviewing Key Concepts

HINT
1. a. **Defining** What is density?

HINT
b. **Explaining** How can you use the density of an object to predict whether it will float or sink in water?

HINT
c. **Applying Concepts** Some canoes have compartments on either end that are hollow and watertight. These canoes won't sink, even when they capsize. Explain why.

HINT
2. a. **Explaining** How does the buoyant force affect a submerged object?

HINT
b. **Summarizing** How does Archimedes' principle relate the buoyant force acting on an object to the fluid displaced by the object?

c. **Calculating** An object that weighs 340 N floats on a lake. What is the weight of the displaced water? What is the buoyant force?

HINT

Lab zone At-Home Activity

Changing Balloon Density Attach paper clips to the string of a helium balloon. Ask a family member to predict how many paper clips you will need to attach to make the balloon sink to the floor. How many paper clips can you attach and still keep the helium balloon suspended in the air? Explain how adding paper clips changes the overall density of the balloon.

Sink and Spill

S 8.8.c, 8.9.a

Problem

How is the buoyant force acting on an object in a fluid related to the weight of the fluid the object displaces?

Skills Focus

controlling variables, interpreting data, drawing conclusions

Materials

- paper towels
- pie pan
- triple-beam balance
- beaker, 600-mL
- jar with watertight lid, about 30-mL
- table salt

Procedure

1. Preview the procedure and copy the data table into your notebook. Predict the relationship you will find between the buoyant force and the weight of the displaced water.
2. Find the mass, in kilograms, of a dry paper towel and the pie pan together. To convert grams to kilograms, divide the mass in grams by 1,000. Multiply the mass by 9.8 m/s^2. This gives you the weight in newtons. Record it in your data table.
3. Place the 600-mL beaker, with the dry paper towel under it, in the middle of the pie pan. Fill the beaker to the very top with water.
4. Fill the jar about halfway with salt. (The jar and salt must be able to float in water.) Find the mass of the salt and the dry jar (with its cover on) in kilograms. Multiply the mass by 9.8 m/s^2. Record this weight in your data table.
5. Gently lower the jar into the 600-mL beaker. (If the jar sinks, take it out and remove some salt. Repeat Steps 2, 3, and 4.) Estimate the fraction of the jar that is underwater, and record it.
6. Once all of the displaced water has been spilled, find the total mass of the paper towel and pie pan containing the water in kilograms. Multiply the mass by 9.8 m/s^2 and record the result in your data table.
7. Empty the pie pan. Dry off the pan and jar.
8. Repeat Steps 3 through 7 several more times. Each time fill the jar with a different amount of salt, but make sure the jar still floats.
9. Record the buoyant force for each trial in your data table. (*Hint*: When an object floats, the buoyant force is equal to the weight of the object.)
10. Calculate the weight of the displaced water in each case. Record it in your data table.

Data Table

Jar	Weight of Empty Pie Pan and Dry Paper Towel (N)	Weight of Jar, Salt, and Cover (N)	Weight of Pie Pan With Displaced Water and Paper Towel (N)	Fraction of Jar Submerged in Water	Buoyant Force (N)	Weight of Displaced Water (N)
1						
2						
3						

Analyze and Conclude

1. **Controlling Variables** In each trial, the jar had a different weight. How did this affect the way that the jar floated?
2. **Interpreting Data** The jar had the same volume in every trial. Why did the volume of displaced water vary?
3. **Drawing Conclusions** What can you conclude about the relationship between the buoyant force acting on an object and the weight of the water it displaces?
4. **Drawing Conclusions** If you put too much salt in the jar, it will sink. What can you conclude about the buoyant force in this case? How can you determine the buoyant force for an object that sinks?
5. **Communicating** Write a paragraph suggesting changes to the experiment that would improve the accuracy of your results.

Design an Experiment

How do you think your results would change if you used a liquid that is more dense or less dense than water? Design an experiment to test your hypothesis. What liquids will you use? Will you need equipment other than what you used for this experiment? If so, what will you need? *Obtain your teacher's permission before carrying out your investigation.*

Section

3 Pascal's Principle

CALIFORNIA Standards Focus

S 8.8.c Students know the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid the object has displaced.

- What does Pascal's principle say about change in fluid pressure?
- How does a hydraulic system work?

Key Terms

- Pascal's principle
- hydraulic system

Lab zone Standards Warm-Up

Why Does the Cartesian Diver Sink?

1. Fill a plastic jar or bottle almost completely with water.
2. Make a Cartesian diver by bending a plastic straw into a U shape. Cut the ends so that each side is 4 cm long. Attach the ends with a paper clip. Drop the straw in the jar, paper clip first.
3. Attach more paper clips to the first one until the straw floats with its top about 0.5 cm above the surface. This is the diver.
4. Put the lid on the jar. Observe what happens when you slowly squeeze and release the jar several times.

Think It Over

Observing Describe the behavior of the Cartesian diver.

At first, you hesitate, but then you hold out your hand. The aquarium attendant places the sea star in your palm. You can feel motion on your skin. The many tiny "feet" on the animal's underside look something like suction cups, and they tickle just a bit! The attendant explains that the sea star has a system of tubes containing water in its body. As the water moves around in the tubes, it creates changes in fluid pressure that allows the sea star to move.

A sea star uses fluid ▶ pressure to move.

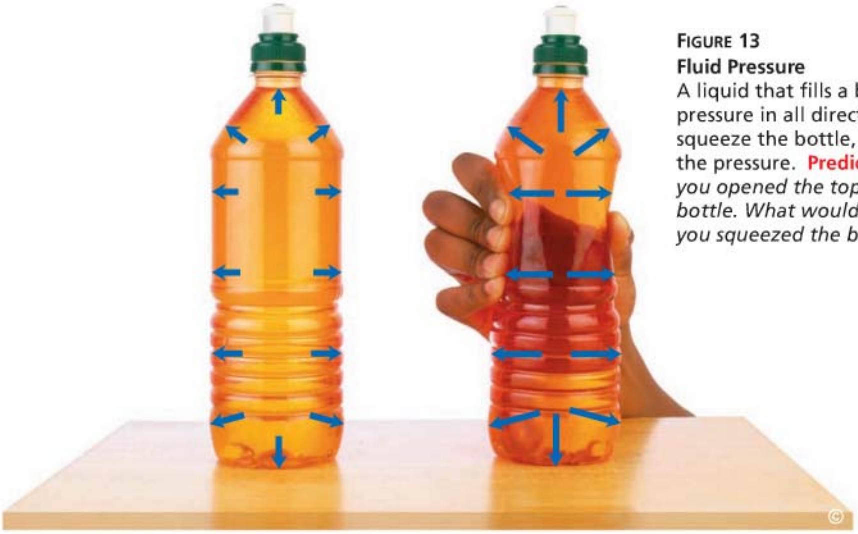


FIGURE 13
Fluid Pressure
A liquid that fills a bottle exerts pressure in all directions. If you squeeze the bottle, you increase the pressure. **Predicting** *Suppose you opened the top of the water bottle. What would happen when you squeezed the bottle? Why?*

Transmitting Pressure in a Fluid

If you did the Standards Warm-Up, you may be wondering why the buoyancy of the Cartesian diver changes. Squeezing the bottle made the diver sink because you increased the pressure on the water inside the bottle. The water pushed into the straw, reducing the size of the pocket of air and increasing the diver's density. This happened no matter where you squeezed the bottle. By changing the fluid pressure at any spot in the closed container, you transmitted pressure throughout the container.

Pascal's Principle In the 1600s, Blaise Pascal developed a principle to explain how pressure is transmitted in a fluid. As you know, fluid exerts pressure on any surface it touches. For example, the colored water in each bottle shown in Figure 13 exerts pressure on the entire surface of the bottle—up, down, and sideways.

What happens if you squeeze the bottle when its top is closed? The water has nowhere to go, so it presses harder on the inside surface of the bottle. The water pressure increases everywhere in the bottle. This is shown by the increased length of the arrows on the right in Figure 13.

Pascal's principle states that pressure increases by the same amount throughout an enclosed or confined fluid. **When force is applied to a confined fluid, the change in pressure is transmitted equally to all parts of the fluid.**

Reading Checkpoint **What is Pascal's principle?**

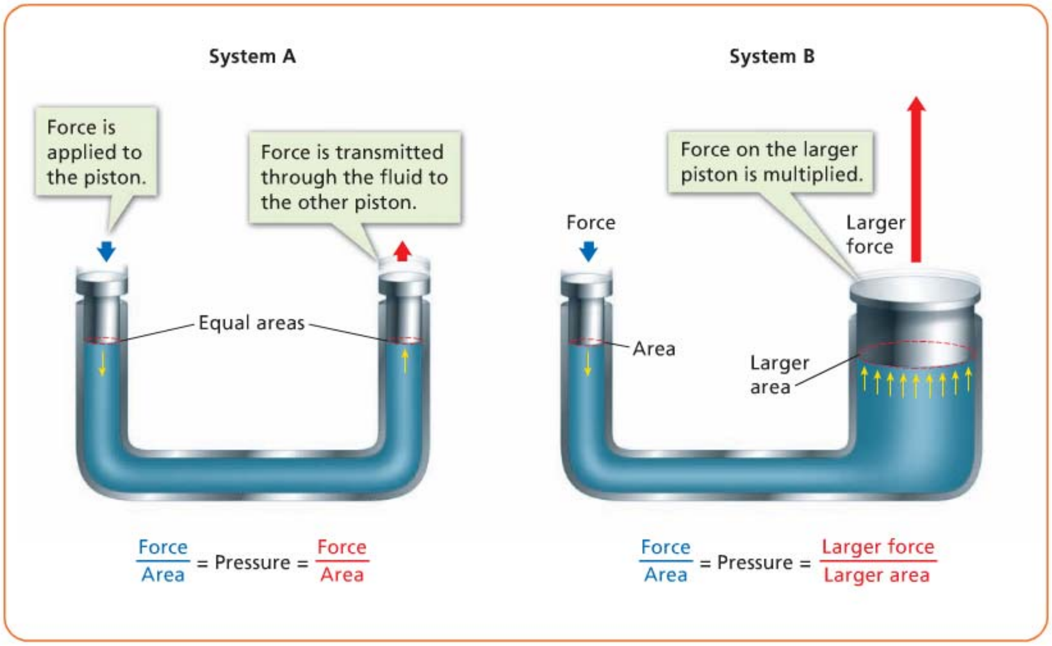


FIGURE 14
Hydraulic Devices
In a hydraulic device, a force applied to one piston increases the fluid pressure equally throughout the fluid. By changing the area of the pistons, the force can be multiplied.
Problem Solving *To multiply the force applied to the left piston four times, how much larger must the area of the right piston be compared to the left piston?*

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Pascal's Principle at Work You can see Pascal's principle at work in Figure 14. A hydraulic device consists of two pistons, one at each end of a U-shaped tube. A piston is like a stopper that slides up and down in a tube.

Suppose you fill System A with water and then push down on the left piston. The increase in fluid pressure will be transmitted to the right piston. According to Pascal's principle, both pistons experience the same fluid pressure. Because both pistons have the same surface area, they will experience the same force.

Now look at System B. The right piston has a greater surface area than the left piston. Suppose the area of the small piston is 1 square centimeter and the area of the large piston is 9 square centimeters. The right piston has an area nine times greater than the area of the left piston. If you push down on the left piston, pressure is transmitted equally to the right piston. The force you exert on the left piston is multiplied nine times when it reaches the right piston. By changing the area of the pistons, you can multiply force by almost any amount you wish.

✓ Reading Checkpoint **How is force multiplied in System B?**

Hydraulic Systems

Have you ever wondered how a person can stop a large car by pressing down on a little pedal? Or how mechanics are able to raise cars off the ground so they can repair them? In both cases, hydraulic systems using Pascal's principle are at work. A **hydraulic system** uses liquids to transmit pressure and multiply force in a confined fluid. **A hydraulic system multiplies force by applying the force to a small surface area. The increase in pressure is then transmitted to another part of the confined fluid, which pushes on a larger surface area.** Because they use fluids to transmit pressure, hydraulic systems have few moving parts that can jam, break, or wear down.

Hydraulic Lifts Hydraulic lift systems are used to raise cars off the ground so mechanics can repair them with ease. They are also used to lift the heavy ladder on a fire truck to reach the upper windows of a burning building. In addition, hydraulic lifts are used to operate many pieces of heavy construction equipment such as dump trucks, backhoes, snowplows, and cranes. Next time you see a construction vehicle at work, see if you can spot the hydraulic pistons in action.

Reviewing Math: Algebra and Functions 7.3.3

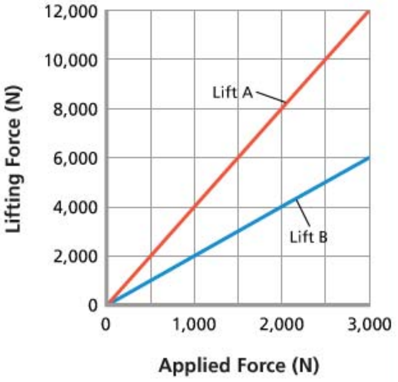
Math Analyzing Data

Comparing Hydraulic Lifts

The graph shows the relationship between the applied force and the lifting force for two hydraulic lifts.

1. **Reading Graphs** Suppose a force of 1,000 N is applied to both lifts. Use the graph to determine the lifting force of each lift.
2. **Reading Graphs** For Lift A, how much force must be applied to lift a 12,000-N object?
3. **Interpreting Data** By how much is the applied force multiplied for Lift A? Lift B?
4. **Interpreting Data** What does the slope of each line represent?
5. **Drawing Conclusions** Which lift would you choose if you wanted to lift a weight of 4,000 N? Explain.

Hydraulic Lifts



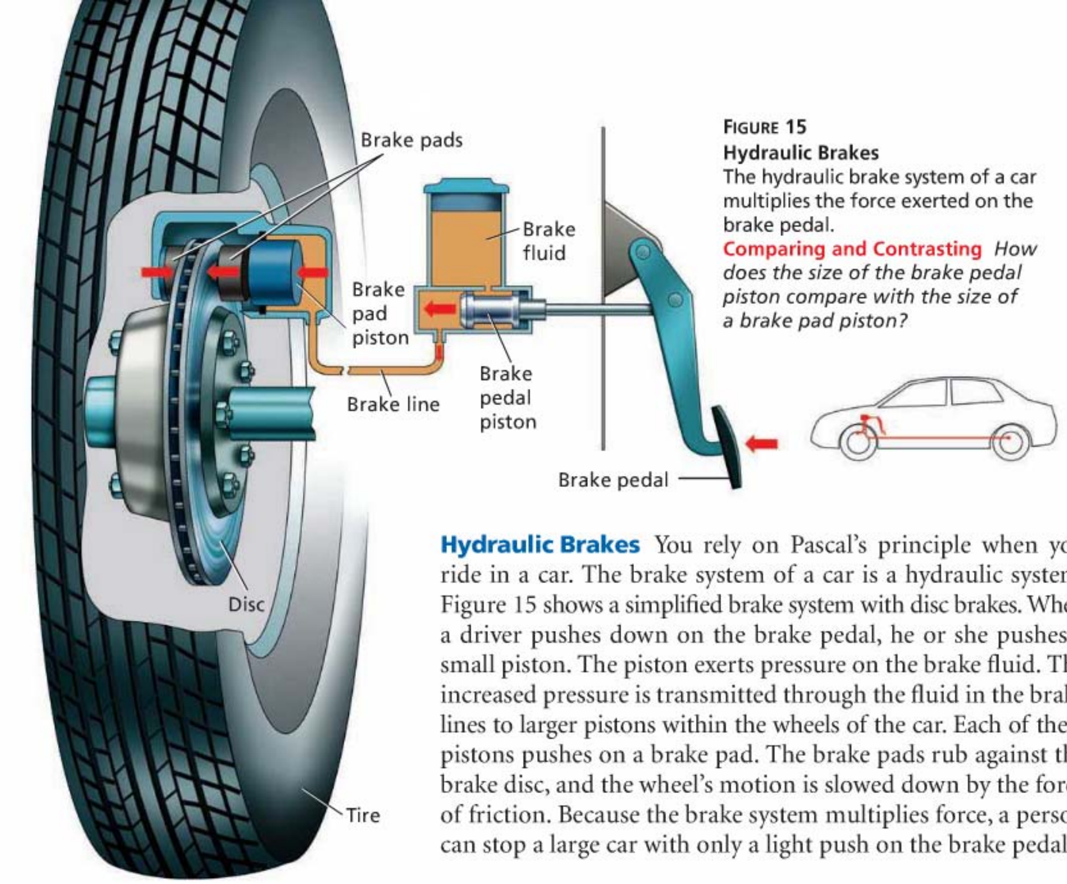


FIGURE 15
Hydraulic Brakes
The hydraulic brake system of a car multiplies the force exerted on the brake pedal.
Comparing and Contrasting *How does the size of the brake pedal piston compare with the size of a brake pad piston?*

Hydraulic Brakes You rely on Pascal's principle when you ride in a car. The brake system of a car is a hydraulic system. Figure 15 shows a simplified brake system with disc brakes. When a driver pushes down on the brake pedal, he or she pushes a small piston. The piston exerts pressure on the brake fluid. The increased pressure is transmitted through the fluid in the brake lines to larger pistons within the wheels of the car. Each of these pistons pushes on a brake pad. The brake pads rub against the brake disc, and the wheel's motion is slowed down by the force of friction. Because the brake system multiplies force, a person can stop a large car with only a light push on the brake pedal.

Section 3 Assessment

S 8.8.c, E-LA: Reading 8.2.0

Target Reading Skill **Sequence** Create a flowchart to show how pressure is transmitted in a fluid.

Reviewing Key Concepts

1. a. **Reviewing** According to Pascal's principle, how is pressure transmitted in a fluid?
   b. **Explaining** How does Pascal's principle help explain the behavior of the Cartesian diver?
   c. **Calculating** Suppose you apply a 10-N force to a 10-cm^2 piston in a hydraulic device. If the force is transmitted to another piston with an area of 100 cm^2, by how much will the force be multiplied?

2. a. **Defining** What is a hydraulic system?
   b. **Explaining** How does a hydraulic system work?
   c. **Sequencing** Describe what happens in the brake system of a car from the time a driver steps on the brake pedal to the time the car stops.

Writing in Science

Cause-and-Effect Letter You are a mechanic who fixes hydraulic brakes. A customer asks you why his brakes do not work. When you examine the car, you notice a leak in the brake line and repair it. Write a letter to the customer explaining why a leak in the brake line caused his brakes to fail.

Section 4

• Tech & Design •

Bernoulli's Principle

CALIFORNIA Standards Focus

S 8.2.e Students know that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction).

- How is fluid presssure related to the motion of a fluid?
- What are some applications of Bernoulli's principle?

Key Terms

- Bernoulli's principle
- lift

Lab zone Standards Warm-Up

Does the Movement of Air Create Unbalanced Forces?

1. Use your thumb and forefinger to hold a sheet of paper by the corners.
2. Hold the paper just below your mouth, so that its edge is horizontal and the paper hangs down.
3. Blow across the top of the paper.
4. Repeat this several times, blowing harder each time.

Think It Over

Inferring On what side of the paper is the force greater? How do you know?

In December 1903, Wilbur and Orville Wright brought an odd-looking vehicle to a deserted beach in Kitty Hawk, North Carolina. People had flown in balloons for more than a hundred years, but the Wright brothers' goal was something no one had ever done before. They flew a plane that was heavier (denser) than air! They had spent years experimenting with different wing shapes and surfaces, and they had carefully studied the flight of birds. Their first flight at Kitty Hawk lasted just 12 seconds. The plane flew more than 36 meters and made history.

What did the Wright brothers know about flying that allowed them to construct the first airplane? And how can the principles they used explain how a jet can fly across the country? The answer has to do with fluid pressure and how a moving fluid can create an unbalanced force.

◀ **On December 17, 1903, the Wright brothers' plane *Flyer* flew for the first time.**

Pressure and Moving Fluids

So far in this chapter, you have learned about fluids that are not moving. What makes a fluid flow? And what happens to fluid pressure when a fluid moves?

Fluid Motion A fluid tends to flow from an area of high pressure to an area of low pressure. This happens, for example, when you sip a drink from a straw. When you start to sip, you remove the air from the straw. This creates an area of low pressure in the straw. The higher air pressure pushing down on the surface of your drink forces the drink up into the straw.

Bernoulli's Principle In the 1700s, Swiss scientist Daniel Bernoulli (bur NOO lee) discovered that the pressure of a moving fluid is different than the pressure of a fluid at rest. **Bernoulli's principle** states that the faster a fluid moves, the less pressure the fluid exerts.

If you did the Standards Warm-Up, you saw that air moving over the paper caused the paper to rise. Bernoulli's principle explains the behavior of the paper. **Bernoulli's principle states that as the speed of a moving fluid increases, the pressure exerted by the fluid decreases.** The air above the paper moves, but the air below the paper does not. The moving air exerts less pressure than the still air. As a result, the still air exerts greater pressure on the bottom of the paper, creating an unbalanced force which pushes the paper up.

Reading Checkpoint **What is Bernoulli's principle?**

FIGURE 16
Making Air Move
Blowing air quickly between two cans lowers the air pressure between them. Higher pressure exerted by the still air to either side pushes the cans toward each other.

Lab zone Try This Activity

Faucet Force

1. Hold a plastic spoon loosely by the edges of its handle so it swings freely between your fingers.
2. Turn on a faucet to produce a steady stream of water. Predict what will happen if you touch the bottom of the spoon to the stream of water.
3. Test your prediction. Repeat the test several times.

Developing Hypotheses Use your observations to develop a hypothesis explaining why the spoon moved as it did.

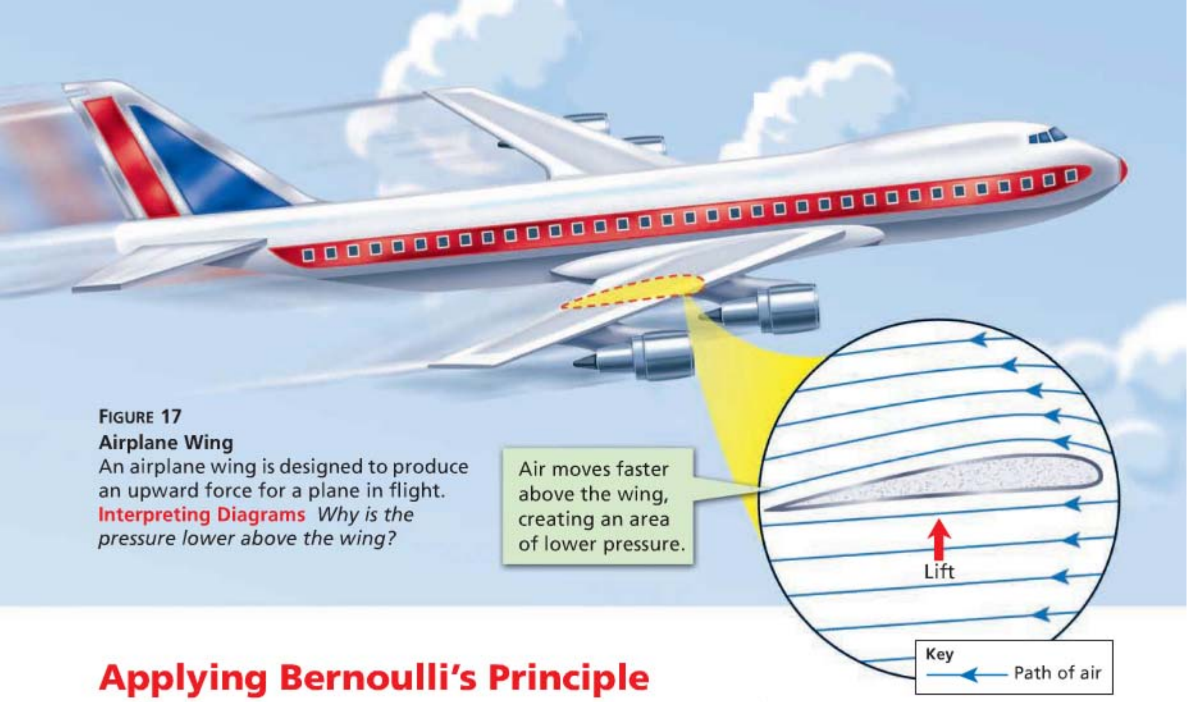


FIGURE 17
Airplane Wing
An airplane wing is designed to produce an upward force for a plane in flight. **Interpreting Diagrams** *Why is the pressure lower above the wing?*

Applying Bernoulli's Principle

The Wright brothers understood Bernoulli's principle. They used it when they built their plane. **Bernoulli's principle helps explain how planes fly. It also helps explain how an atomizer works, why smoke rises up a chimney, and how a flying disk glides through the air.**

Objects in Flight Bernoulli's principle is one factor that helps explain flight—from a small kite to a huge airplane. Objects can be designed so that their shapes cause air to move at different speeds above and below them. If the air moves faster above the object, fluid pressure pushes the object upward. If the air moves faster below the object, fluid pressure pushes it downward.

Because of its design, the wing of an airplane produces **lift,** or an upward force. Look at Figure 17 to see the design of a wing. Both the slant and the shape of the wing are sources of lift. Because the wing is slanted, the wing forces the air downward as the plane moves. The air exerts an equal and opposite force on the wing and pushes it upward. This unbalanced upward force helps an airplane to take off.

The curved shape of a wing also gives an airplane lift. Because the top of the wing is curved, air moving over the top has a greater speed than air moving under the bottom. As a result, the air moving over the top exerts less pressure than the air below. The difference in air pressure above and below the wing creates lift.

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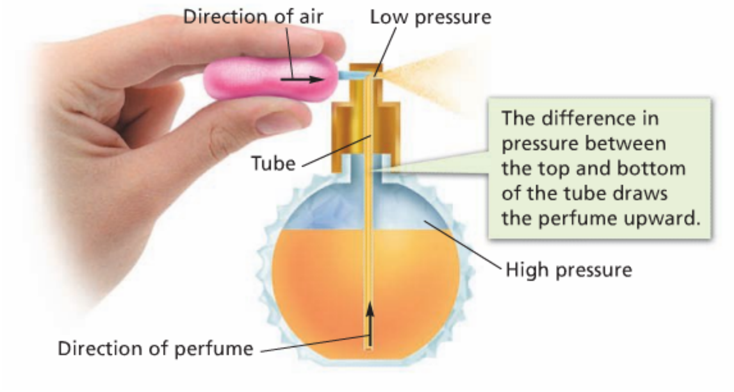


FIGURE 18
Perfume Atomizer
An atomizer is an application of Bernoulli's principle.
Applying Concepts *Why is the perfume pushed up and out of the flask?*

Atomizers Bernoulli's principle can help you understand how the perfume atomizer shown in Figure 18 works. When you squeeze the rubber bulb, air moves quickly past the top of the tube. The moving air lowers the pressure at the top of the tube. The greater pressure in the flask pushes the liquid up into the tube. The air stream breaks the liquid into small drops, and the liquid comes out as a fine mist. In a similar way, pressure differences in the carburetors of older gasoline engines push gasoline up a tube. There, the gasoline combines with air to create the mixture of air and fuel that runs the engine.

Chimneys You can sit next to a fireplace enjoying a cozy fire thanks in part to Bernoulli's principle. Smoke rises up the chimney partly because hot air rises, and partly because it is pushed. Wind blowing across the top of a chimney lowers the air pressure there. The higher pressure at the bottom pushes air and smoke up the chimney. Smoke will rise faster in a chimney on a windy day than on a calm day.

Reading Checkpoint **How does an atomizer work?**

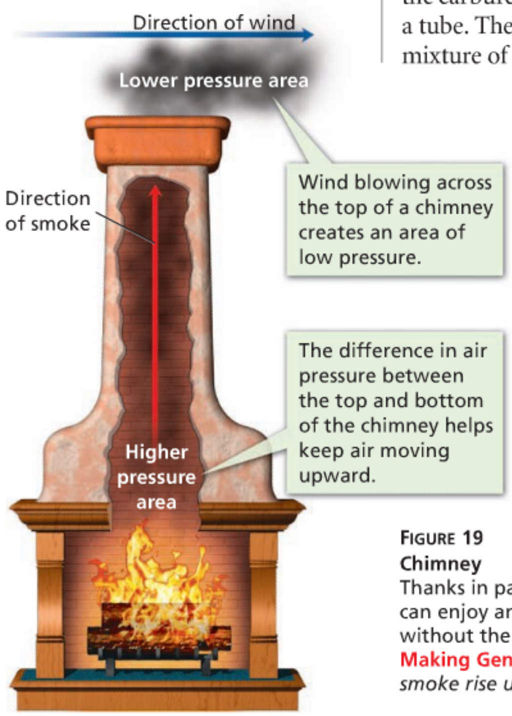
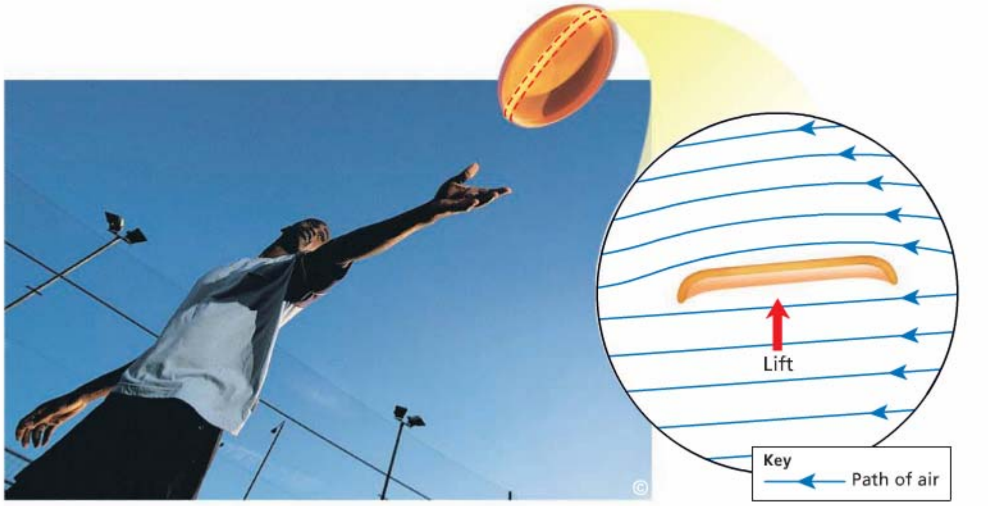


FIGURE 19
Chimney
Thanks in part to Bernoulli's principle, you can enjoy an evening by a warm fireplace without the room filling up with smoke.
Making Generalizations *Why does the smoke rise up the chimney?*



Flying Disks Did you ever wonder what allows a flying disk to glide through the air? The upper surface of a flying disk is curved like an airplane wing. Bernoulli's principle explains that the faster-moving air following the disk's curved upper surface exerts less pressure than the slower-moving air beneath it. A net force acts upward on the flying disk, creating lift. Tilting the disk slightly toward you as you throw it also helps to keep it in the air. A tilted disk pushes air down. The air exerts an equal and opposite force on the disk, pushing it up. The spinning motion of a flying disk keeps it stable as it flies.

FIGURE 20
Flying Disk
Like an airplane wing, a flying disk uses a curved upper surface to create lift. **Comparing and Contrasting** *How does a flying disk differ from an airplane wing?*

Section 4 Assessment

S 8.2.e, E-LA: Reading 8.2.0

Target Reading Skill **Sequence** Create a flowchart to explain how an atomizer works.

Reviewing Key Concepts

HINT
HINT
HINT
HINT
HINT
HINT

1. a. **Reviewing** How can you make fluid flow up a straw?
   b. **Summarizing** What does Bernoulli's principle say about the pressure exerted by a moving fluid?
   c. **Applying Concepts** You are riding in a car on a highway when a large truck speeds by you. Explain why your car is pushed toward the truck.
2. a. **Listing** List four applications of Bernoulli's principle.
   b. **Explaining** Why does the air pressure above an airplane wing differ from the pressure below it? How is this pressure difference involved in flight?
   c. **Relating Cause and Effect** How could strong winds from a hurricane blow the roof off a house?

Lab zone At-Home Activity

Paper Chimney With a family member, see how a chimney works by using a paper cup and a hair dryer. Cut up several small pieces of tissue and place them in the bottom of a paper cup. Hold on to the paper cup with one hand. With your other hand, use the hair dryer to blow cool air across the top of the cup. Explain to your family member how Bernoulli's principle explains how the chimney works.

Technology and Society

• Tech & Design •

Helicopters

S 8.2.e

Most aircraft are like eagles—they take off majestically, glide among the clouds, and land with ease. But helicopters are the hummingbirds of aircraft. They can fly forward, backward, sideways, and up and down. They can stop abruptly and hover in midair. In fact, helicopters can fly circles around other types of aircraft.

Science in Action

On the top of a helicopter are large blades that turn rapidly. These blades are curved on top like the wings of an airplane. Air flowing over the curved blades helps cause lift—the upward force for the helicopter—just as air flowing over wings helps cause lift for most airplanes. Action and reaction forces as described by Newton's third law of motion also play a role in causing lift. As the tilted blades push down on the air, the air pushes up on the blade.

Main Rotor
The main rotor turns the blades and controls their angle.

Blades
Air flows over the curved, rotating blades. Along with action and reaction forces, this helps to give the helicopter lift.

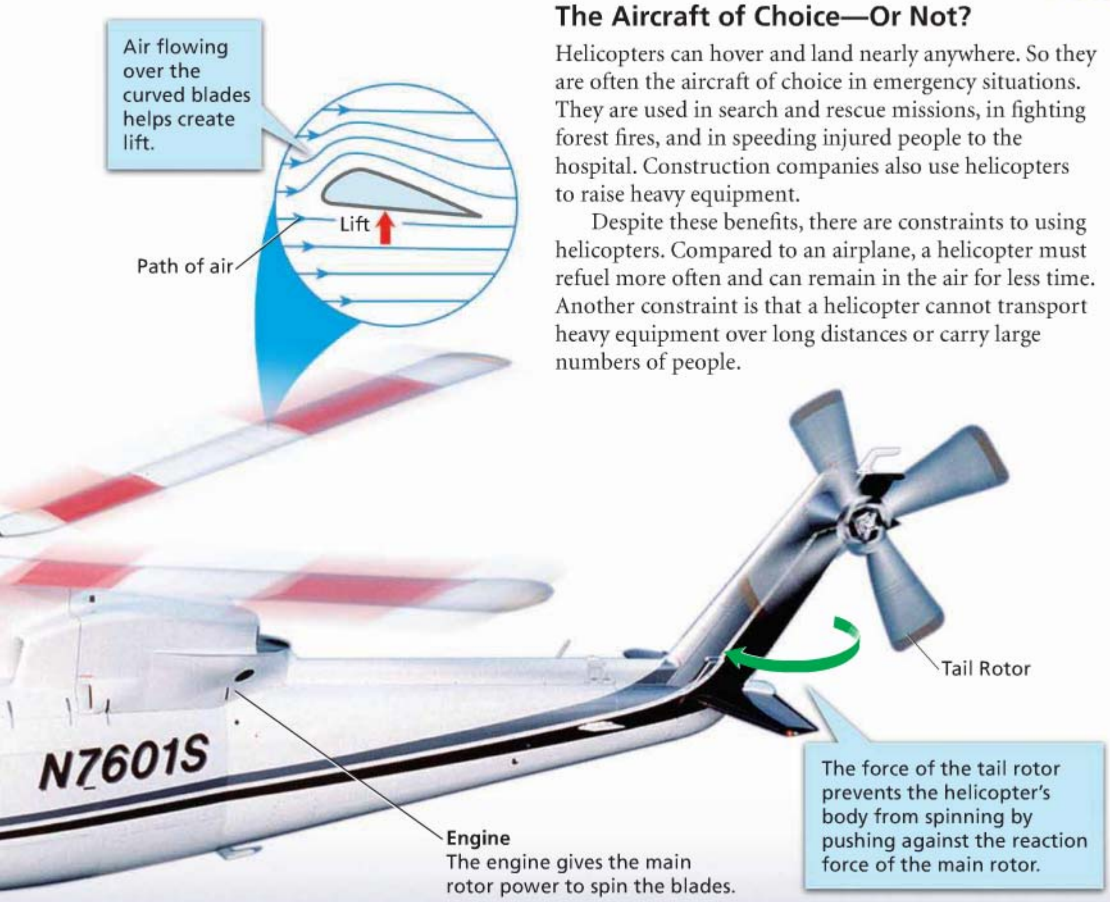
As the main rotor spins, the reaction force pushes the helicopter's body in the opposite direction. If not for the tail rotor, the body would spin too.

Hand Controls and Foot Pedals
These controls are connected to the main rotor. The collective control guides the helicopter up or down. The cyclic control guides the helicopter forward, backward, or sideways. The foot pedals allow the helicopter to rotate in tight circles.

The Aircraft of Choice—Or Not?

Helicopters can hover and land nearly anywhere. So they are often the aircraft of choice in emergency situations. They are used in search and rescue missions, in fighting forest fires, and in speeding injured people to the hospital. Construction companies also use helicopters to raise heavy equipment.

Despite these benefits, there are constraints to using helicopters. Compared to an airplane, a helicopter must refuel more often and can remain in the air for less time. Another constraint is that a helicopter cannot transport heavy equipment over long distances or carry large numbers of people.



Air flowing over the curved blades helps create lift.

Engine
The engine gives the main rotor power to spin the blades.

The force of the tail rotor prevents the helicopter's body from spinning by pushing against the reaction force of the main rotor.

Weigh the Impact

1. Identify the Need

What advantages do helicopters have over airplanes?

2. Research

Using the Internet, research how helicopters are used in national parks, such as Yellowstone National Park. Choose one helicopter mission. Make notes on the mission's difficulty level, purpose, location, procedures, and outcome.

3. Write

Suppose you are a park ranger. Use your notes to write a report to your supervisor explaining why a helicopter was or was not the best technology to use for this mission.

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Chapter 11 Study Guide

The BIG Idea If an object is less dense than a fluid, it will float in the fluid. If an object is more dense than a fluid, it will sink in the fluid.

1 Pressure

Key Concepts S 8.8.d, 8.9.f

- The amount of pressure you exert depends on the area over which you exert a force.
- Pressure $= \frac{\text{Force}}{\text{Area}}$
- In a fluid, all of the forces exerted by the individual particles combine to make up the pressure exerted by the fluid.
- Atmospheric pressure decreases as your elevation increases.
- Water pressure increases as depth increases.

Key Terms

pressure
pascal
fluid
barometer

2 Floating and Sinking

Key Concepts S 8.8.c, 8.8.d

- Density $= \frac{\text{Mass}}{\text{Volume}}$
- By comparing densities, you can predict whether an object will float or sink in a fluid.
- The buoyant force acts in the direction opposite to the force of gravity, so it makes an object feel lighter.

Key Terms

density
buoyant force
Archimedes' principle

3 Pascal's Principle

Key Concepts S 8.8.c

- When force is applied to a confined fluid, the change in pressure is transmitted equally to all parts of the fluid.
- A hydraulic system multiplies force by applying the force to a small surface area. The increase in pressure is then transmitted to another part of the confined fluid, which pushes on a larger surface area.

Key Terms

Pascal's principle
hydraulic system

4 Bernoulli's Principle

Key Concepts S 8.2.e

- Bernoulli's principle states that as the speed of a moving fluid increases, the pressure exerted by the fluid decreases.
- Bernoulli's principle helps explain how planes fly. It also helps explain how an atomizer works, why smoke rises up a chimney, and how a flying disk glides through the air.

Key Terms

Bernoulli's principle
lift

Review and Assessment

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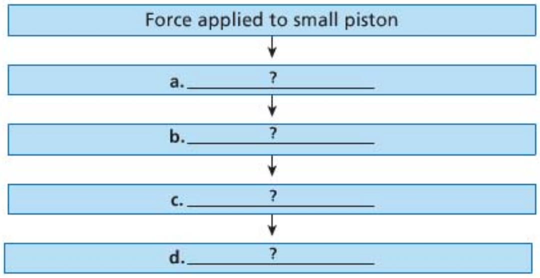
Target Reading Skill

Sequence Create a flowchart that shows how a hydraulic device multiplies force.

How a Hydraulic Device Works



Reviewing Key Terms

Choose the letter of the best answer.

HINT
1. If you divide the force exerted on a surface by the total area of the surface, you will know
a. density. **b.** pressure.
c. lift. **d.** buoyant force.

HINT
2. If you divide the mass of an object by its volume, you also know the object's
a. mass. **b.** weight.
c. density. **d.** pressure.

HINT
3. The weight of an object that floats has the same value as the
a. object's density. **b.** object's mass.
c. object's volume. **d.** buoyant force.

HINT
4. The concept that an increase in pressure on a confined fluid is transmitted equally to all parts of the fluid is known as
a. Pascal's principle.
b. Bernoulli's principle.
c. Archimedes' principle.
d. Newton's third law.

HINT
5. The concept that the pressure in a fluid decreases as the speed of the fluid increases is known as
a. Pascal's principle.
b. Bernoulli's principle.
c. Archimedes' principle.
d. Newton's first law.

Complete the following sentences so that your answers clearly explain the key terms.

HINT
6. If you stand on one foot, you increase the **pressure** you exert on the ground, because __________.

HINT
7. Whether an object will float or sink in a fluid depends on its **density,** which is defined as __________.

HINT
8. A submerged object is easier to lift due to the **buoyant force,** which is __________.

HINT
9. A ship is able to float on the surface of the ocean because of **Archimedes' principle,** which states that __________.

HINT
10. An airplane is able to fly partly due to **Bernoulli's principle,** which states that __________.

Writing in Science

News Report Suppose that you are a newspaper journalist on the day after the Titanic sank. Write a news report that tells what happened. Explain how the buoyancy of a ship is affected when it fills with water. Include information about the various fluid forces involved.

Video Assessment
Discovery Channel School
Forces in Fluids

Review and Assessment

Checking Concepts

11. How does the amount of pressure you exert on the floor when you are lying down compare with the amount of pressure you exert when you are standing up?

12. Why aren't people crushed by the air pressure they experience?

13. Why do you seem to weigh more in air than you do in water?

14. In a hydraulic system, why is the force exerted on a small piston multiplied when it acts on a larger piston?

15. Name two hydraulic systems that an auto mechanic would know well.

16. Why is air pressure at the top of a chimney less than air pressure at the bottom?

Thinking Critically

17. **Making Generalizations** How does the water pressure change at each level in the jug below? How can you tell?

18. **Problem Solving** You have two fluids of unknown density. Suggest a method to determine which is denser, without mixing the two fluids.

19. **Developing Hypotheses** A sphere made of steel is put in water and, surprisingly, it floats. Develop a possible explanation for this observation.

20. **Applying Concepts** One method of raising a sunken ship to the surface is to inflate large bags or balloons inside its hull. Explain why this procedure could work.

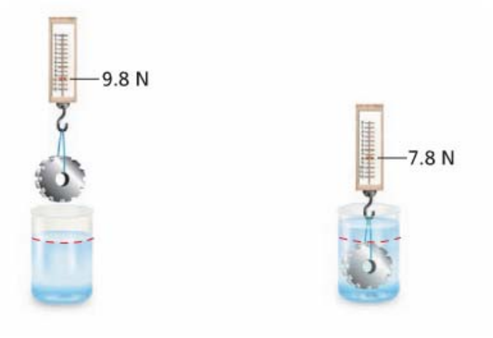
Math Practice

21. **Area** The cover of your textbook measures about 28 cm × 22 cm. Find its area.

22. **Area** A dollar bill measures about 15.9 cm × 6.7 cm. The Chinese yuan note measures 14.5 cm × 7.0 cm. Which currency uses a larger bill?

Applying Skills

The illustration shows an object supported by a spring scale, both in and out of water. Use the illustration to answer Questions 23–25.



23. **Inferring** Why is there a difference between the weight of the object in air and its measured weight in water?

24. **Calculating** What is the buoyant force acting on the object?

25. **Drawing Conclusions** What can you conclude about the water above the dotted line?

Lab zone Standards Investigation

Performance Assessment Test your boat to make sure it does not leak. Display the diagrams of different designs you tried and the observations and data you recorded for each design. Then demonstrate for the class how the boat floats. Point out to your classmates the features you used in your final design.

CALIFORNIA

Standards Practice

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Choose the letter of the best answer.

1. You place a block of wood into a beaker of water and it floats. What can you say about the buoyant force on the block?

A It is equal to the block's weight.
B It is less than the block's weight.
C It is greater than the block's weight.
D It is equal to the weight of the surrounding water. **S 8.8.c**

2. You carefully drop a stone into a beaker full of water. The stone sinks to the bottom and water spills out. What can you say about the weight of the displaced water?

A It is greater than the weight of the stone.
B It is equal to the weight of the stone.
C It is less than the weight of the stone.
D It is equal to the weight of the water still in the beaker. **S 8.8.c**

Use the photos below to answer Question 3.

3. You place a pencil hydrometer into four different unknown liquids, labeled A, B, C, and D. The hydrometer floats at different levels in the four liquids. Which liquid is the most dense?

A Liquid A
B Liquid B
C Liquid C
D Liquid D **S 8.8.d**

4. Why does an airplane rise in the air?

A It experiences a buoyant force because it is less dense than the air.
B The moving air above and below the wings creates an unbalanced force that pushes the airplane up.
C The air pressure above the wings is greater than the air pressure below the wings.
D The airplane's cabin is pressurized. **S 8.2.e**

5. You observe that a chunk of tar sinks in puddles of rainwater but floats on the ocean. An experiment to explain the behavior of the tar should measure

A the difference between atmospheric pressure and water pressure.
B the densities of fresh water, salt water, and tar.
C the height from which the chunk of tar is dropped.
D the depth of each type of water. **S 8.8.d**

6. A helium balloon rises because the helium

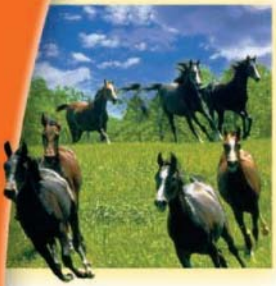
A is hotter than the surrounding air.
B is colder than the surrounding air.
C is less dense than the surrounding air.
D is more dense than the surrounding air. **S 8.8.d**

Apply the BIG Idea

7. Explain why objects experience a buoyant force when immersed in a fluid. How can you find the value of the buoyant force? How can knowing the density of an object and a fluid help you predict if the object will float or sink in the fluid? **S 8.8**

Motion, Forces, and Energy

Unit 3 Review



Chapter 9

Motion and Energy

The BIG Idea

You can describe the motion of an object by its position, speed, direction, and acceleration.

- When is an object in motion?
- How do you calculate speed?
- How do you calculate acceleration?
- What affects an object's kinetic energy and potential energy?

Chapter 10

Forces

The BIG Idea

An unbalanced force will cause a change in an object's velocity.

- How do balanced and unbalanced forces affect velocity?
- Why do objects accelerate during free fall?
- What is Newton's second law of motion?
- What is Newton's third law of motion?
- What keeps a satellite in orbit?

Chapter 11

Forces in Fluids

The BIG Idea

If an object is less dense than a fluid, it will float in the fluid. If an object is more dense than a fluid, it will sink in the fluid.

- How do fluids exert pressure?
- What is the effect of the buoyant force?
- What does Pascal's principle say about change in fluid pressure?
- How is fluid pressure related to the motion of a fluid?

Unit 3 Assessment

Connecting the BIG Ideas

Welcome to the Summer Triathlon. Do you have what it takes to compete in all three athletic events?

Today's triathlon will begin with a 750-m swim. We've set up buoys floating in the water so you can follow the path of the race properly. Don't swim too far away from these floating markers, or you'll go off course and have to get back on track!

Next you will cycle 20 km. When you get to the finish line, remember to brake as quickly as possible so you can start the last leg of the event.

Finally, you will have to run 5 km along the edge of the lake. The view is beautiful, but don't forget to keep your eye on the prize. You'll have to turn around at the halfway mark and change direction because the race finishes at the same bridge where it begins.

Remember to pace yourself! And at the end, we have a special surprise for you. All athletes who complete the triathlon win a medal!

HINT 1. It took you half an hour to run the final 5 km of the triathlon. Using that information, what can you find? *(Chapter 9)*
   a. average speed **b.** instantaneous speed
   c. acceleration **d.** direction

HINT 2. At the end of the bicycle race, what kind of friction do you rely on when you use your hand brakes to come to a stop? *(Chapter 10)*
   a. static friction **b.** sliding friction
   c. rolling friction **d.** fluid friction

HINT 3. Which of the following is a possible density for the buoys floating in the lake? *(Chapter 11)*
   a. 0.9 g/cm³ **b.** 9 g/cm³
   c. 90 g/cm³ **d.** 900 g/cm³

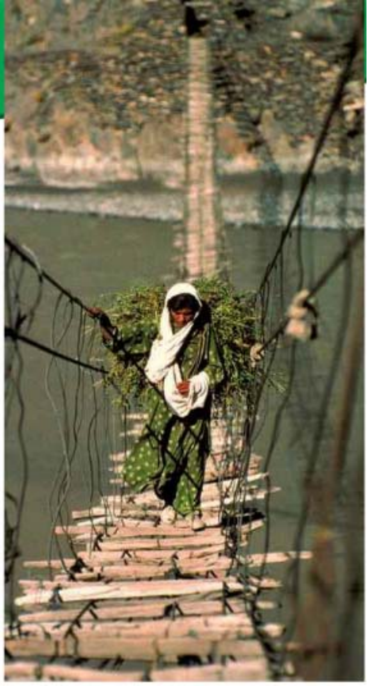
4. **Summary** Write a paragraph that describes the different forces you experienced while running in the triathlon. Did these forces cause changes in your motion? Explain.

S. 8.2.c

Bridges— From Vines to Steel

Have you ever

- balanced on a branch or log to cross a brook?
- jumped from rock to rock in a streambed?
- swung on a vine or rope over a river?



Vine Footbridge
A girl crosses over the Hunza River in northern Pakistan.

Then you have used the same ways that early people used to get over obstacles. Fallen trees, twisted vines, and natural stones formed the first bridges.

Bridges provide easy ways of getting over difficult obstacles. For thousands of years, bridges have also served as forts for defense, scenes of great battles, and homes for shops and churches. They have also been sites of mystery, love, and intrigue. They span history—linking cities, nations, and empires and encouraging trade and travel.

But bridges have not always been as elaborate as they are today. The earliest ones were made of materials that were free and plentiful. In deep forests, people used beams made from small trees. In tropical regions where vegetation was thick, people wove together vines and grasses, then hung them to make walkways over rivers and gorges.

No matter what the structures or materials, bridges reflect the people who built them. The ancient civilizations of China, Egypt, Greece, and Rome all designed strong, graceful bridges to connect and control their empires.

Roman Arch Bridge
Ponte Sant'Angelo is in Rome.

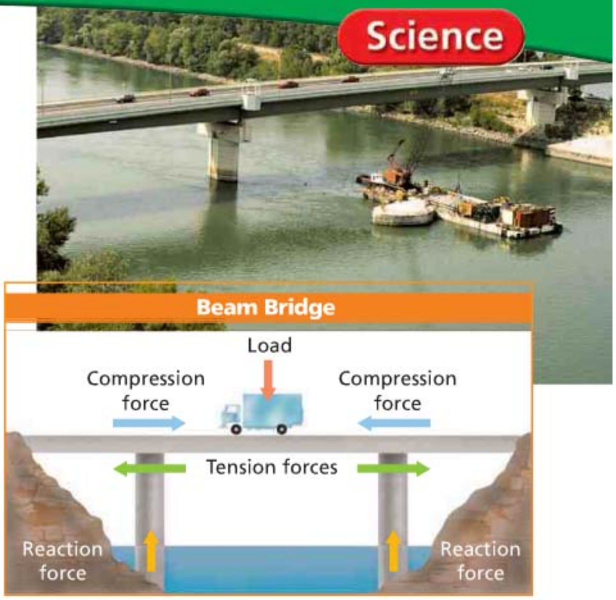
The Balance of Forces

What keeps a bridge from falling down? How does it support its own weight and the weight of people and traffic on it? Builders found the answers by considering the various forces that act on a bridge.

The weight of the bridge and the traffic on it are called the *load*. When a heavy truck crosses a beam bridge, the weight of the load forces the beam to curve downward. This creates tension forces that stretch the bottom of the beam. At the same time, the load also creates compression forces at the top of the beam.

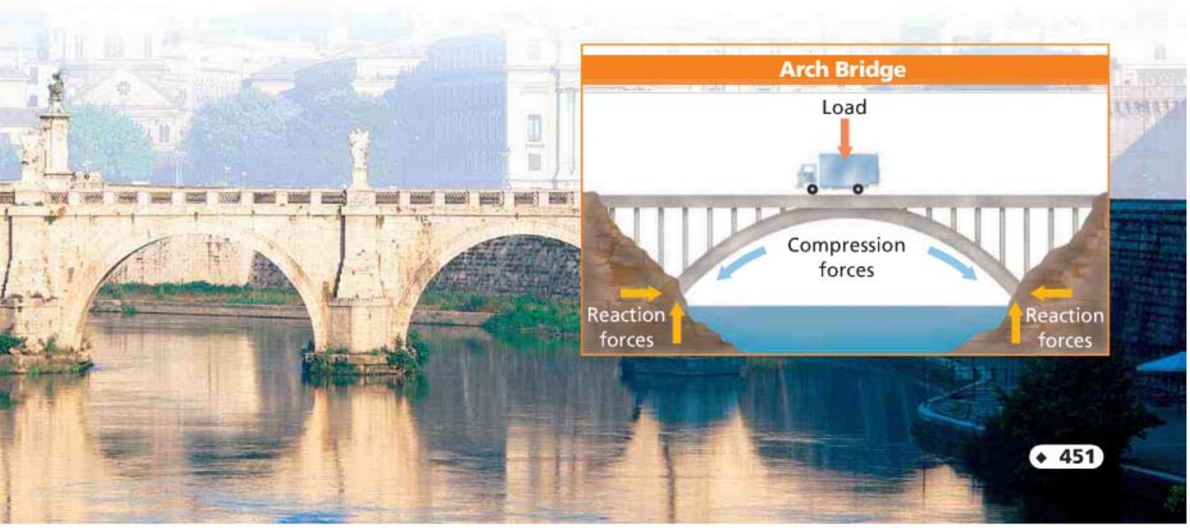
Since the bridge doesn't collapse under the load, there must be upward forces to balance the downward forces. In simple beam bridges, builders anchor the beam to the ground or to end supports called abutments. To cross longer spans or distances, they construct piers under the middle span. Piers and abutments are structures that act as upward forces—reaction forces.

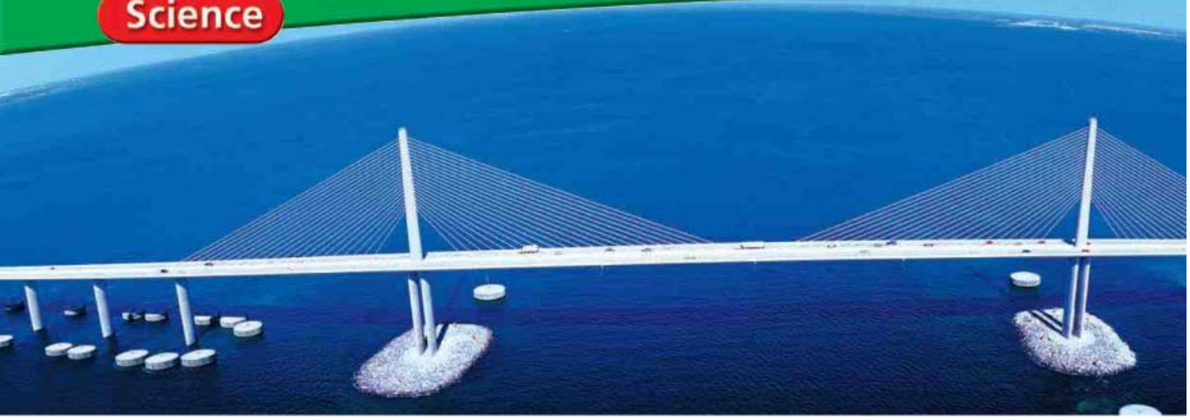
Another type of bridge, the arch bridge, supports its load by compression. A heavy load on a stone arch bridge squeezes or pushes the stones together, creating compression throughout the structure. Weight on the arch bridge pushes down to the ends of the arch. The side walls and abutments act as reaction forces.



Beam Bridge
A beam bridge spans the Rhone River in France (top).

Early engineers discovered that arch bridges made of stone could span wider distances than simple beam bridges. Arch bridges are also stronger and more durable. Although the Romans were not the first to build arch bridges, they perfected the form in their massive, elegant structures. Early Roman arch bridges were built without mortar, or "glue." The arch held together because the stones were skillfully shaped to work in compression. After nearly 2,000 years, some of these Roman arch bridges are still standing.





The Structure of Modern Bridges

By the 1800s in the United States, bridge builders began to use cast iron instead of stone and wood. By the late 1800s, they were using steel, which was strong and relatively lightweight. The use of new building materials was not the only change. Engineers began designing different types of bridges as well. They found that they could build longer, larger bridges by using a suspension structure.

Suspension bridges are modern versions of long, narrow, woven bridges found in tropical regions. These simple, woven suspension bridges can span long distances. Crossing one of these natural structures is like walking a tightrope. The weight of people and animals traveling over the bridge pushes down on the ropes, stretching them and creating tension forces.

Modern suspension bridges follow the same principles of tension as do woven bridges. A suspension bridge is strong in tension. In suspension bridges, parallel cables are stretched the entire length of the bridge—over giant towers. The cables are anchored at each end of the bridge. The roadway hangs from the cables, attached by wire suspenders. The weight of the bridge and the load on it act to pull apart or stretch the cables. This pulling apart creates tension forces.

The towers of a suspension bridge act as supports for the bridge cables. The abutments that anchor the cables exert reaction forces as well. So forces in balance keep a suspension bridge from collapsing.

Suspension Bridge
The sun rises over the Golden Gate Bridge in California.

Cable-Stayed Bridge
The Sunshine Skyway Bridge spans a broad section of Tampa Bay in Florida. The cables, attached to the center of the roadway, enable travelers to have a clear view.

When the Brooklyn Bridge opened in New York City in 1883, it was the longest suspension bridge in the world. The Golden Gate Bridge in San Francisco, which was opened in 1937, was another great engineering feat.

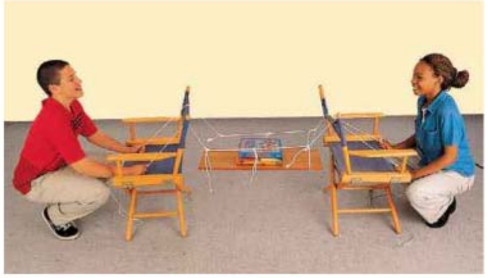
Recently, engineers have developed a new bridge design called the cable-stayed bridge. It looks similar to a suspension bridge because both are built with towers and cables. But the two bridges are quite different. The cables on the cable-stayed bridge attach to the towers, so the towers bear the weight of the bridge and the load on it. In contrast, the cables on a suspension bridge ride over the towers and anchor at the abutments. So on a suspension bridge, both the towers and abutments bear the load.

Science Activity

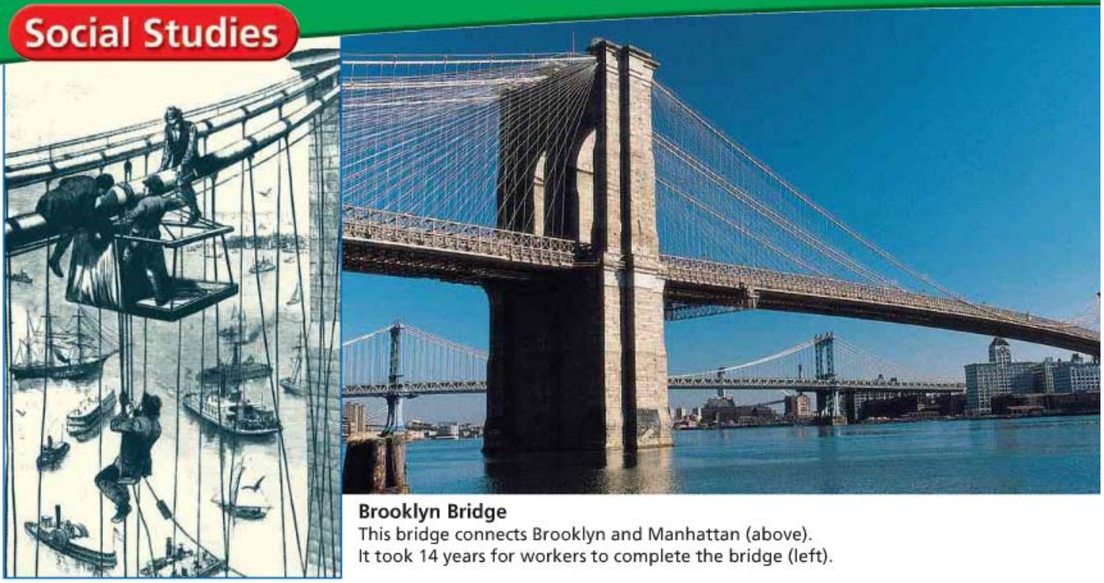
Work in groups to make a suspension bridge, using two chairs, a wooden plank, rope, and some books.

- Place two chairs back-to-back and stretch 2 ropes over the backs of the chairs. Hold the ropes at both ends.
- Tie three pieces of rope to the longer ropes. Place the plank through the loops.
- With a partner, hold the ropes tightly at each end. Load books on top of the plank to see how much it will hold.

Why is it important to anchor the ropes tightly at each end?



Social Studies



Brooklyn Bridge
This bridge connects Brooklyn and Manhattan (above).
It took 14 years for workers to complete the bridge (left).

Against All Odds

When John Roebling was hired in 1868 to build the Brooklyn Bridge, he was already a skilled suspension bridge engineer. He had been working on plans for the bridge since 1855.

But before bridge construction even began in 1869, John Roebling died in a construction accident. Fortunately, he had worked out his bridge design to the last detail. His son, Colonel Washington Roebling, who was also a skilled engineer, dedicated himself to carrying out his father's plans.

The construction dragged on for 14 years and cost nearly 30 lives. Colonel Roebling himself became so disabled that he was forced to direct construction from his home. Using a telescope, Colonel Roebling followed every detail. His remarkable, energetic wife, Emily Warren Roebling, learned enough engineering principles to deliver and explain his orders to the workers.

As soon as the giant towers were up, workers unrolled the steel wire back and forth across the towers to weave the cables. The next step was to twist the wires together. But the workmen were terrified of hanging so high on the bridge and refused to work.

Finally, Frank Farrington, the chief mechanic, crossed the river on a small chair dangling from a wheel that ran across an overhead line. Farrington completed his journey to the roar of the crowd. Somewhat reassured, the builders returned to work. But it took two more years to string the cables. The bridge was one of the greatest engineering achievements of its time.

In the end, the Brooklyn Bridge project succeeded only because of the determination and sacrifices of the Roebling family. It became the model for hundreds of other suspension bridges.

Social Studies Activity

How do you think the Brooklyn Bridge changed the lives of New Yorkers? In groups, research the history of another famous bridge. Present your findings to your class along with drawings and photos. Find out

- when and why the bridge was built
- what type of bridge it is
- what effects the bridge has on people's lives—on trade, travel, and population
- how landforms affected the bridge building
- about events connected to the bridge

TWO GREAT CITIES UNITED

MAY 25, 1883—The Brooklyn Bridge was successfully opened yesterday. The pleasant weather brought visitors by the thousands from all around. Spectators were packed in masses through which it was almost impossible to pass, and those who had tickets to attend the ceremonies had hard work to reach the bridge. Every available housetop and window was filled, and an adventurous party occupied a tall telegraph pole. It required the utmost efforts of the police to keep clear the necessary space.

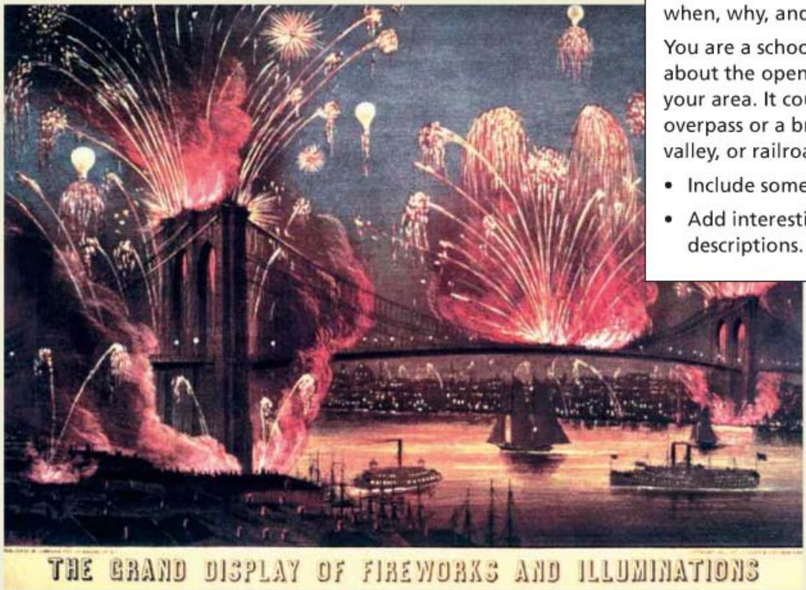
After the exercises at the bridge were completed the Brooklyn procession was immediately re-formed and the march was taken up to Col. Roebling's residence. From the back study on the second floor of his house Col. Roebling had watched through his telescope the procession as it proceeded along from the New York side until the Brooklyn tower was reached. Mrs. Roebling received at her husband's side and accepted her share of the honors of the bridge.

For blocks and blocks on either side of the bridge there was scarcely a foot of room to spare. Many persons crossed and re-crossed the river on the ferry boats, and in that way watched the display. Almost every ship along the river front was converted into a grand stand.

The final ceremonies of the opening of the great bridge began at eight o'clock, when the first rocket was sent from the center of the great structure, and ended at nine o'clock, when a flight of 500 rockets illuminated the sky. The river-front was one blaze of light, and on the yachts and smaller vessels blue fires were burning and illuminating dark waters around them.

———Excerpted with permission from *The New York Times*

Brooklyn Bridge
This historic painting shows fireworks at the opening of the bridge in 1883.



Language Arts Activity

A reporter's goal is to inform and entertain the reader. Using a catchy opening line draws interest. Then the reader wants to know the facts—who, what, where, when, why, and how (5 W's and H).

You are a school reporter. Write about the opening of a bridge in your area. It could be a highway overpass or a bridge over water, a valley, or railroad tracks.

- Include some of the 5 W's and H.
- Add interesting details and descriptions.

Mathematics

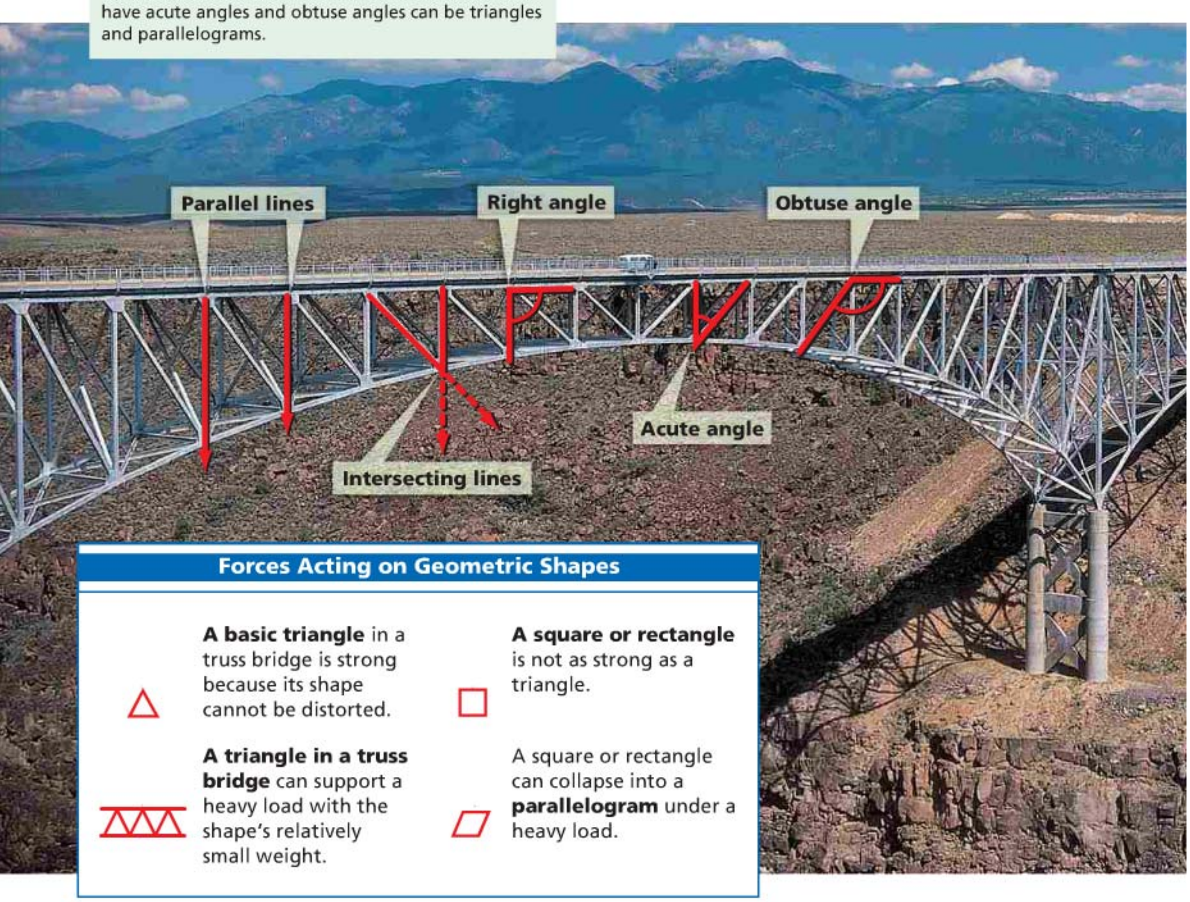
Bridge Geometry

As railroad traffic increased in the late 1800s, truss bridges became popular. Designed with thin vertical and diagonal supports to add strength, truss bridges were actually reinforced beam bridge structures. Many of the early wood truss bridges couldn't support the trains that rumbled over them. Cast iron and steel trusses soon replaced wood trusses.

Using basic triangular structures, engineers went to work on more scientific truss bridge designs. The accuracy of the design is crucial to handling the stress from heavy train loads and constant vibrations. As in all bridge structures, each steel piece has to be measured and fitted accurately—including widths, lengths, angles, and points of intersection and attachment.

Geometric Angles and Figures

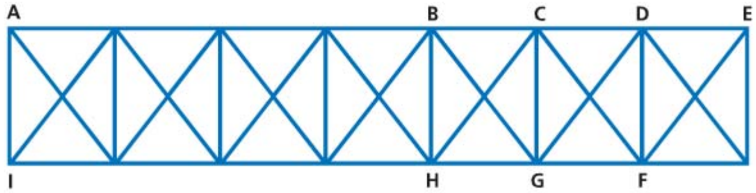
Engineers use various geometric figures in drawing bridge plans. Figures that have right angles are squares, rectangles, and right triangles. Figures that have acute angles and obtuse angles can be triangles and parallelograms.



Forces Acting on Geometric Shapes

△	**A basic triangle** in a truss bridge is strong because its shape cannot be distorted.	□	**A square or rectangle** is not as strong as a triangle.
△▽△▽△	**A triangle in a truss bridge** can support a heavy load with the shape's relatively small weight.	▱	A square or rectangle can collapse into a **parallelogram** under a heavy load.

Math Activity



The chief building engineer has asked you to draw up exact plans for a new truss bridge. How well will you do as an assistant? Review the captions and labels on the previous page. Then answer these questions:

1. Which lines are parallel?
2. Which lines intersect?
3. What kind of figure is formed by *ABHI*?
4. What kind of figure is formed by *HCF*?
5. What kind of angle is *BGF*—obtuse or right?
6. What kind of angle is *CHG*?
7. What kind of triangle is *BHG*? What makes it this kind of triangle?
8. Why is a triangle stronger than a square?

▲ **Truss bridge over Rio Grande Gorge in New Mexico**

Tie It Together

Work in small groups to build a model of a bridge out of a box of spaghetti and a roll of masking tape. Meet as a group to choose the type of bridge you will build. Each bridge should be strong enough to hold a brick. You can build

- a beam bridge
- a truss bridge
- an arch bridge
- a suspension bridge (This one is challenging.)

After drawing a sketch of the bridge design, assign jobs for each team member. Then

- decide how long the bridge span will be
- measure and cut the materials
- build the roadway first for beam, truss, and suspension bridges
- build the arch first in an arch bridge

When your bridge is complete, display it in the classroom. Test the strength of each bridge by placing a brick on the roadway. Discuss the difference in bridge structures. Determine which bridge design is the strongest.