Chapter 9

Forces influence the motion and properties of fluids.

Jumping off the platform of a boat, a SCUBA diver plunges into the cold waters of the Atlantic Ocean. He lets air out of his vest to allow himself to sink beneath the surface. He breathes in air from a tank attached to his back. Fish, whales, and octopuses float and swim by at different depths.

If someone were to ask you to identify what part of this scene had to do with fluids, you might easily point out the giant ocean that he is swimming in. A closer look, however, reveals that fluids, and the properties of fluids, are at work all around him. Although he is much smaller than the boat from which he is diving, it floats while he sinks beneath the ocean surface. He is able to breathe under water because oxygen and nitrogen, both fluids, have been compressed into a tank. The marine life around him can control where they swim by altering the amount of air inside their bodies.

Back on land, fluids are at work around us all the time. When force is applied, fluids can be used for mechanisms such as the brakes in a car, or for the tools that your dentist uses. In this chapter, you will learn about the properties of fluids that make it possible to use them in a wide variety of technologies.

What You Will Learn

In this chapter, you will
- **explain** why objects float or sink in a fluid
- **describe** how fluids react to pressure
- **explain** how compression of fluids can be used to create force
- **describe** the relationship among pressure, volume, and temperature of gases

Why It Is Important

Fluid systems are important in our daily lives as well as in industry. An understanding of fluid properties and how forces affect fluid movement can help to explain how natural and constructed fluid systems work.

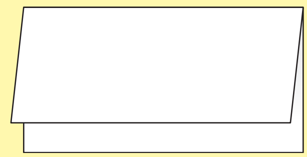
Skills You Will Use

In this chapter, you will
- **predict** whether an object will float or sink in a fluid
- **describe** how hydraulic and pneumatic systems work
- **measure** how fluids react to pressure

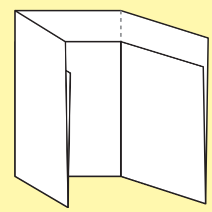
FOLDABLES™ Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 9.

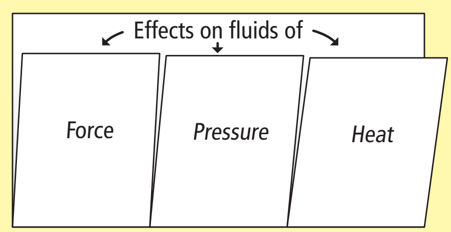
STEP 1 **Fold** a sheet of legal-size unlined paper in half lengthwise. Make the back edge about 3 cm longer than the front edge.



STEP 2 **Turn** the paper so the fold is on the bottom. Then, **fold** it into thirds.



STEP 3 **Unfold** and cut only the top layer along both folds to make three tabs. **Label** the Foldable as shown.



Read and Write As you read this chapter, organize your notes under the appropriate tabs.

9.1 Forces and Buoyancy

There are many factors determining whether an object will sink or float in a fluid. Just like solids, fluids exert forces on objects in their environments. The density of fluids also determines how they will react with other fluids or solids.

Key Terms

Archimedes' principle
average density
balanced forces
buoyancy
buoyant force
force
mass
neutral buoyancy
unbalanced forces
weight

Forces

No matter where you look or what you do, forces are at work all around. As you know, a **force** is anything that causes a change in the motion of an object. You can think of a force as a push or a pull. A force can cause an object to move—for example, when a magnet pulls an iron nail, or when gravity pulls a basketball down to the ground. You can use a force to stop an object, such as when you catch a baseball. You can also use a force to change the motion of an object, like the force applied to the ball in Figure 9.1.

Figure 9.1 The force applied to the tennis ball by the player and racket will make the ball change direction.

Balanced and Unbalanced Forces

Forces sometimes work together, or against each other. Imagine two equal and opposite forces applied to a large box. The students in Figure 9.2 cannot move the box as long as the forces they produce are equal, opposite, and perfectly balanced. **Balanced forces** are equal in strength and opposite to each other in direction.

Figure 9.2 The forces being applied to each side of the box are equal so the box does not move.

Now what would happen to the motion of the large box if two students exerted a force on the same side? Examine the forces applied in the same direction on a large box in Figure 9.3. The box will begin moving in the direction it is pushed, since this force is greater than any opposing forces on the box. **Unbalanced forces** cause a change in the speed or direction of an object. If the forces remain unbalanced, the speed of the box will continue to increase.

Figure 9.3 Forces that are unbalanced will start an object moving, speed up or slow down the object, or change the direction of its movement.

Mass vs. Weight

To understand gravitational forces, you must know the difference between mass and weight. As you know, mass is the amount of matter in an object. For example, an ostrich egg, at 1.5 kg, has much more mass than a typical chicken egg (see Figure 9.4). The **mass** of an object remains the same anywhere in the universe.

Weight, however, is different from mass. **Weight** is the measure of the pull, or force, of gravity acting on an object. Weight is measured in units called Newtons (N). If you were to travel to the Moon, you would weigh approximately one sixth the amount you weigh on Earth, because the force of gravity is one sixth as strong on the Moon. For example, if you weigh 600 N on Earth, you would weigh only 100 N on the Moon. If you were to travel to Jupiter, however, you would weigh 2.35 times more than you weigh on Earth. This is because the force of gravity on Jupiter is 2.35 times stronger than the force of gravity on Earth.

Both fluids and solids have mass and weight, and exert forces on solid objects and on other fluids. As you will learn, these forces play an important role in determining whether an object will sink or float in a fluid.

Figure 9.4 An ostrich egg has 30 times the mass of an average chicken egg.

Did You Know?

Although it seems as if the scales that you step on in a bathroom are measuring mass, they actually measure force. Inside a bathroom scale is a spring that is stretched when you stand on it. The more mass a person has, the more gravity pulls down on the person, and the more the spring is stretched. This means that a bathroom scale measures force exerted by an object downward due to gravity.

Reading Check

1. Define the term force.
2. What is the difference between a balanced force and an unbalanced force?
3. Define the terms mass and weight.
4. Why does the weight of an object change in different places in the universe while the mass remains the same?

Buoyancy: The "Anti-Gravity" Force

Have you ever noticed that doing some things in water is much easier than doing the same activities on land? For example, doing a handstand in the water seems pretty simple compared to trying the same task in the gym. Why do you think it is easier? The answer is based on the forces that water exerts on your body.

When you are swimming in water, there are two forces that work against each other and affect the motion of your body. The force of gravity is pulling you down toward the centre of Earth. At the same time, however, the water is also pushing you up with a buoyant force. **Buoyant force**, or **buoyancy**, is the upward force on objects submerged in or floating on fluids. A buoyant force pushes away from the centre of Earth. How can you predict whether a buoyant force will be strong enough to make an object float?

Word Connect

A buoy is a floating object that is anchored in the water to warn or guide swimmers and boaters. The word "buoy" can also mean to support or uplift.

Weight and Buoyancy: Archimedes' Principle

The science behind whether an object will sink or float was first discovered by the ancient Greek scientist, Archimedes, around 212 B.C.E. Archimedes first came to the conclusion that the amount of fluid displaced by an object is equal to its volume. He then applied his new idea to another property of fluids. He believed that the displaced fluid held the key to whether the object placed in the fluid would sink or float. Archimedes wondered why he would sink if he stepped into a bathtub, but he would float if he stepped into a boat on the water. He concluded that the amount of buoyant force that would push up against the object immersed in the fluid would equal the force of gravity, or the weight of the fluid that the object displaced.

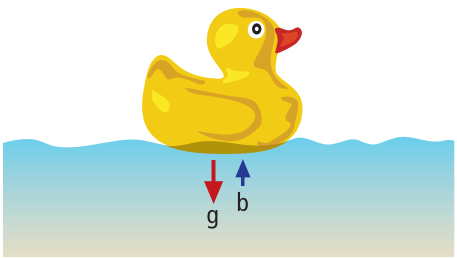


Figure 9.5A The duck weighs more than the volume of water it has displaced, so the force of gravity (g) is stronger than the buoyant force (b) acting on the duck. This means the duck will sink further into the water.

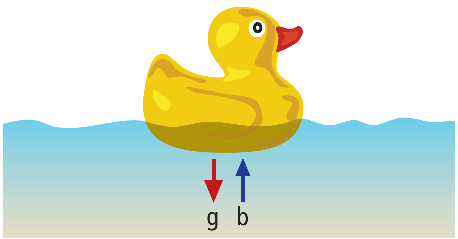


Figure 9.5B The duck has now displaced a volume of water that has the same weight as the entire duck. The force of gravity now equals the buoyant force, and the duck floats.

If the water in a container is still, or at rest, then the water particles are neither rising nor sinking. An object immersed in a fluid such as water does not rise or sink if the amount of force pulling down (gravity) equals the amount of force pushing up (buoyancy). Therefore, the water particles in the lower part of the container must be exerting a buoyant force equal to the weight (or force of gravity) of the water above the object. When the two forces are balanced, this state is known as **neutral buoyancy**.

If 1 L of water is displaced, the object replacing it would have the same volume (1 L) but might have a different weight than the 1 L of water. If the object is heavier than the displaced water, then the weight of the object will be a force greater than the buoyant force that had supported the displaced water. Therefore, the forces are unbalanced and the object will sink. If the object is lighter than the displaced water, the object will rise to the surface and then float. These relationships are shown below.

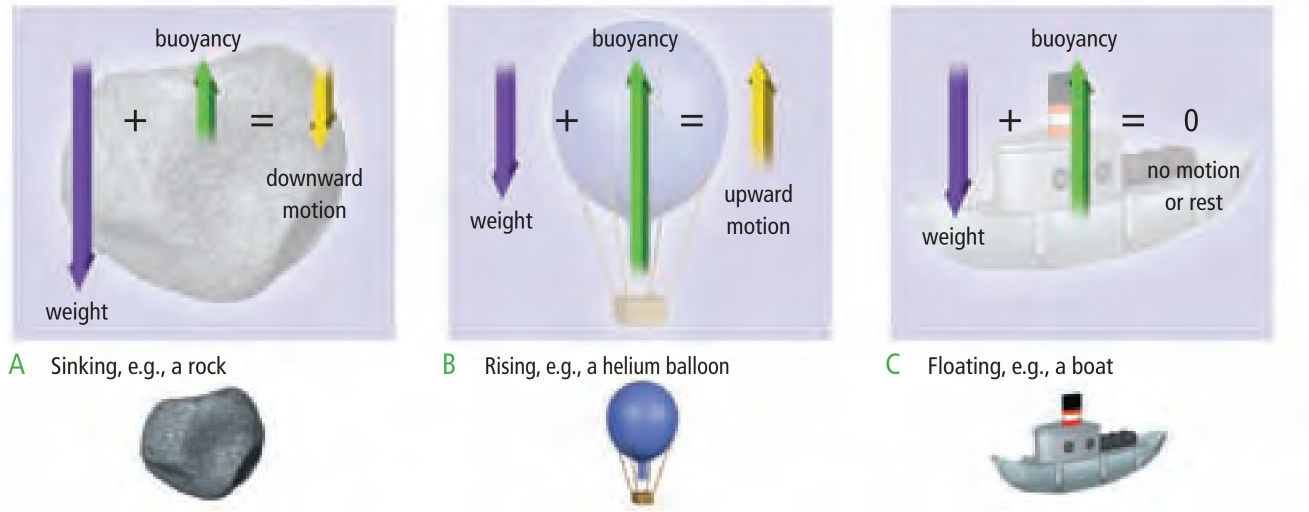


Figure 9.6 The difference between an object's weight and the buoyant force acting on the object will determine whether the object sinks, rises, or floats.

When Archimedes stepped into the bath, he sank because he weighed more than the water he displaced. When he stepped into the boat, however, a larger volume of water was displaced. Boats are often wedge-shaped; the more they are pushed down, the more water they displace. The weight of the displaced water exceeded the combined weight of Archimedes and the boat. Therefore, the buoyant force was greater than the force of gravity, and so Archimedes and the boat floated on the surface.

Suggested Activity

Find Out Activity 9-1B on page 342

Archimedes' made the following conclusion now known as **Archimedes' principle**: *The buoyant force acting on an object equals the weight (force of gravity) of the fluid displaced by the object.*

9-1A The Amazing Floating Egg — Find Out ACTIVITY

Do you think that different liquids exert a similar buoyant force? Find out for yourself in this activity.

What You Need

glass
water
fresh egg
salt
teaspoon

What to Do

1. Place an egg in a glass half-full of water and observe what happens. Record your observations.
2. Stir salt into the water one teaspoon at a time; stop adding salt when the egg floats.
3. When the egg is floating, carefully add more tap water slowly and near the side of the glass so that the fresh water and the salt water do not mix. Continue to add water until the glass is almost full.
4. Observe and record where the egg floats now. Sketch a labelled diagram of your floating egg.

What Did You Find Out?

1. Give a possible explanation for why the egg floated in the salt water.
2. Provide an reasonable explanation for the behaviour of the egg when you added water in step 3.

Archimedes' principle is useful in predicting whether objects will sink or float. Note that the buoyant force does not depend on the weight of the submerged object, but rather on the weight of the displaced fluid. A solid cube of aluminum, a solid cube of iron, and a hollow cube of iron, all having the same volume, would experience the same buoyant force!

Reading Check

1. What is buoyancy?
2. What two forces affect the buoyancy of an object in a fluid?
3. Define neutral buoyancy.
4. What is Archimedes' principle?
5. Using Archimedes' principle, explain why you sink if you step into a body of water.

How Buoyancy and Density are Related

As you observed in the Floating Egg Activity, objects float more easily in salt water than in fresh water. Seawater (salt water) has a density of 1.03 g/mL and fresh water has a density of 1.00 g/mL. The density of salt water is greater than that of fresh water, which means that the particles of salt water are packed together more tightly than those in fresh water. Therefore, one litre of salt water weighs more than one litre of fresh water. When an object displaces one litre of salt water, the buoyant force on the object is greater than it would be in fresh water. That is, salt water can support more weight per volume than fresh water. As shown in Figure 9.7, a buoy floating in salt water extends out of the water more than a buoy in fresh water. The next time you have a chance to swim in the ocean, observe how much more easily you can float on your back!

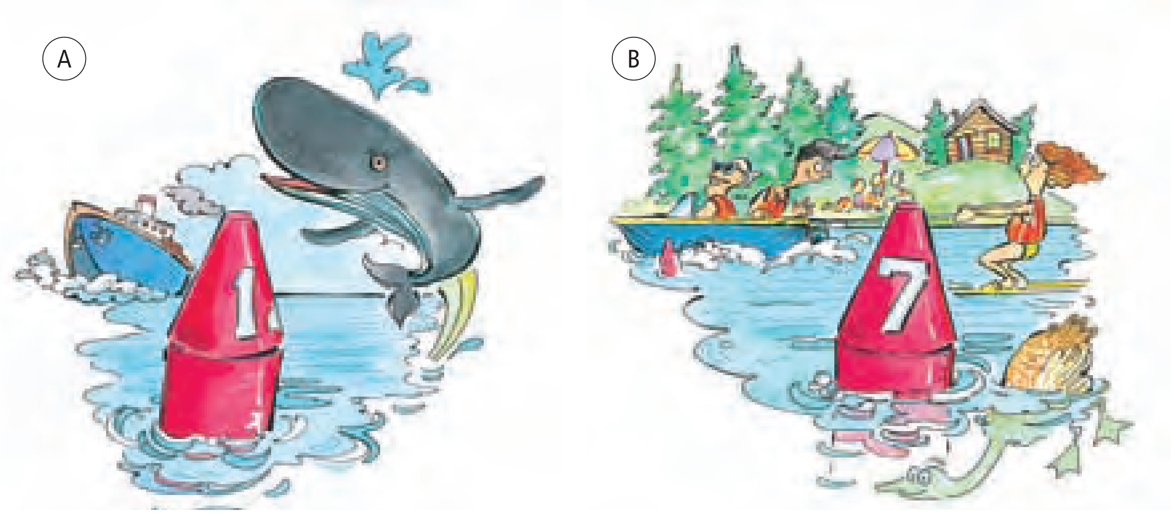


Figure 9.7 Objects experience a greater buoyant force in salt water (A) than in fresh water (B).

The density of the object that is placed in a fluid can also be used to predict whether it will float. If the density of the object is greater than the fluid in which it is placed, it will weigh more than the fluid it displaces and the object will not float. It will sink. If the density of the object is lower than the density of the fluid in which it is placed, it will weigh less than the fluid that it displaces and the object will float. How, then, can you determine the density of an object that is made up of many different parts? You need to know the *average* density of the object.

Average Density

The **average density** of an object is the total mass of all substances that make up the object divided by the total volume. For example, ships can be built of steel (density = 9.0 g/cm^3) as long as they have large, hollow hulls because the density of the air in the hulls is very low (approximately 0.0012 g/cm^3). A hollow hull ensures that the average density of the ship is less than that of water. Similarly, life jackets are filled with a substance of very low density. This way, a life jacket lowers a person's average density, allowing the person to float.

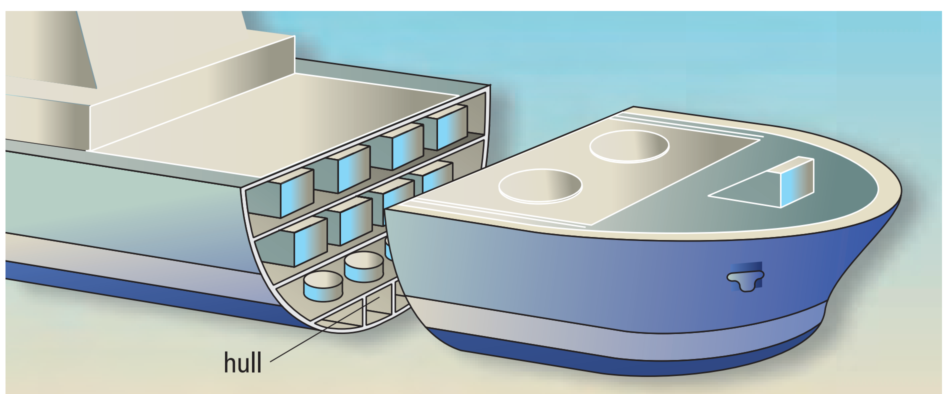


Figure 9.8 By having a large, hollow hull, a ship can float because its average density is less than that of water.

Benefits of Average Density

Average density is useful because it enables objects that would otherwise sink—such as large ships and oil rigs – to float. Average density also helps floating objects to sink. For example, most fish have an organ called a swim bladder (also called an air bladder). This organ, a large sac near the spine of the fish, contains a mixture of air and water. How deep the fish can swim in the water depends on how much air is inside the sac. As the amount of air decreases, the fish sinks lower. As the amount of air increases, the fish rises closer to the surface. This depth-control structure has been adapted for use in the submarine, allowing the submarine's crew to adjust the underwater depth of the vessel (see Figure 9.9).

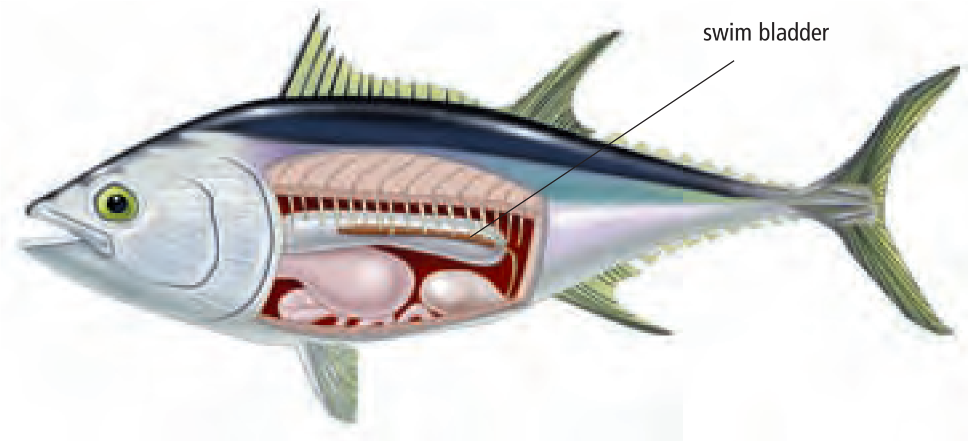


Figure 9.9 Cutaway drawing showing the swim bladder inside a fish. The fish can control its depth in the water by changing the amount of air in the bladder.

Did You Know?

Fish that are adapted to living in deep water, where they experience high pressure, will expand or "blow up" when caught by a fisherman and brought to the water's surface. This is caused by the sudden release of pressure on the swim bladder.

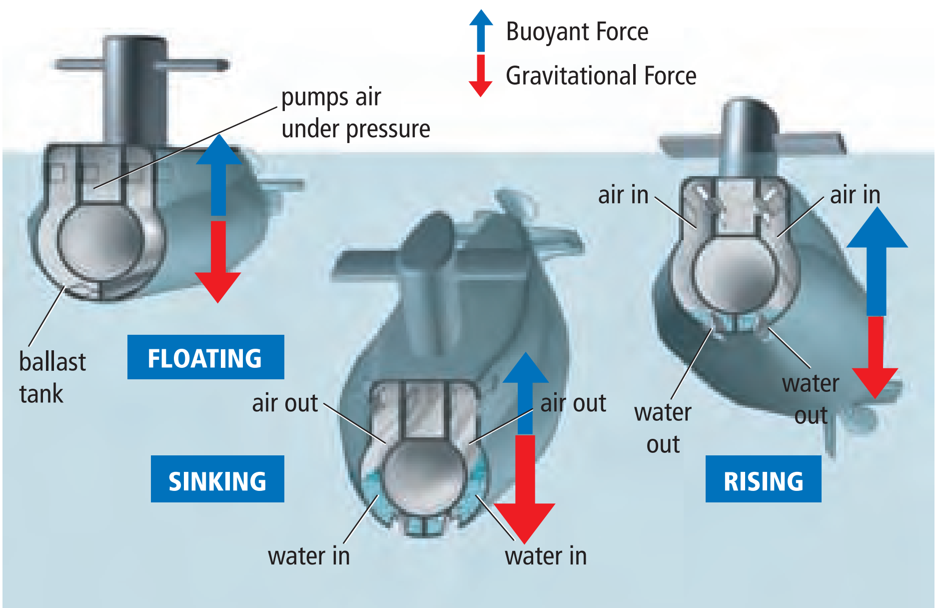


Figure 9.10 Engineers have used the example of a fish's swim bladder to allow crews to control the depth of a submarine. By allowing water to flow in or out, the submarine can rise or sink in the water. The submarine floats when its weight is equal to the buoyant force. The submarine sinks when its weight is greater than the buoyant force.

internet connect

Not too long ago, naval forces worked entirely above the surface of the water. Now, crews can spend months at a time in the deep depths of water in submarines. Find out more about submarines. Start your search at **www.discoveringscience8.ca.**

9-1B Cartesian Diver

Find Out ACTIVITY

Make your own model of a diving device that can adjust its own depth. This device, a Cartesian diver, is named after Rene Descartes, a French philosopher and mathematician who lived about 350 years ago. It demonstrates Archimedes' principle of buoyant forces.

What You Need

1 L plastic pop bottle and cap
water
medicine dropper

What to Do

1. Fill the pop bottle three quarters full with water.
2. Fill the medicine dropper half full with water.
3. Drop the medicine dropper, or "diver," into the pop bottle. Put the cap on the bottle.
4. Squeeze the bottle hard, and then release it. Record your observations and include a sketch.

What Did You Find Out?

1. What happens to the amount of water in the "diver" as you squeeze the bottle?
2. What happens to the water level in the "diver" when you release the bottle?

Extension

3. What explanation can you give for the diver's movements in the water?

Did You Know?

In World War II, blimps were used to watch over convoys of ships. From their position in the sky, blimps could see surfacing submarines and could radio information to the Navy.

Buoyant Force of Air

Because air is much less dense that water, its buoyant force is much smaller than the buoyant force of water. Nevertheless, the density of air is large enough to support some objects. For example, the Goodyear™ blimp is one of the largest floating airships in the world. It can carry people as well as the materials that make up its structure. This giant airship is filled with helium gas, the second lowest density gas that exists.

An airship such as a blimp can float because its mass is relatively small compared to its enormous volume. Its average density is slightly less than the density of the air surrounding it, so it rises. Hot-air balloons work on much the same principle. When the air inside a balloon is heated, the air particles gain energy and spread out, which forces some of the particles out of the balloon. The air inside the balloon, therefore, becomes less dense than the air surrounding it, so it rises.

Figure 9.11 The Goodyear™ blimp is often seen hovering over open stadiums during sports events.

Measuring Liquid Density

To measure the density of a liquid, you need to use an instrument called a hydrometer. A hydrometer works on Archimedes' principle, and will only sink in a liquid until it has displaced a volume of water with a weight equal to its own weight. Therefore, it will extend farther out of the liquid if the liquid has a higher density, or sink lower if the liquid has a lower density. For example, a hydrometer will extend further out of water (1 g/mL), and will sink lower in vegetable oil, which has a density of 0.9 g/mL.

Hydrometers are widely used in food and beverage industries. Although they measure density, hydrometers can be used to determine other values in a liquid. For example, they can be used to determine the sugar content of canned fruit, or the alcohol content of wine. Industries have tables of specific densities that correspond to the amount of a substance in a liquid. Therefore, they can match the hydrometer reading with the table to make sure that the liquid contents are correct.

Suggested Activity

Investigation 9-1C, on page 344.

Figure 9.12 Hydrometers such as these two examples are used in many industries.

Reading Check

1. What is average density?
2. Using the concept of average density, explain how a ship floats in water.
3. How are buoyancy and density related?
4. Explain how a hydrometer measures the density of a fluid.

9-1C Build a Density Tower

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Observing
- Explaining
- Making conclusions
- Predicting

Safety

- Do not pour substances down the drain. Dispose of them as instructed by your teacher.

Materials

- tall plastic jar or cup (or transparent container) with lid
- cork
- toothpick or wood chip
- paper clips
- rubber gloves
- water, with food colouring added
- vegetable oil

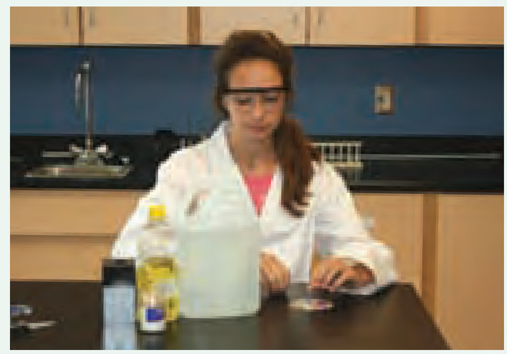
Do you think density plays a role when a fluid supports an object? Find out in this investigation.

Problem

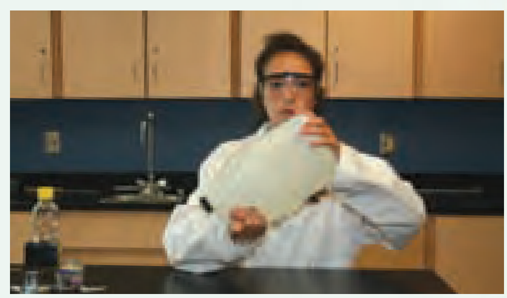
How can you build a tower out of liquids that support each other as well as solids?

Procedure

1. Combine the water, oil, cork, woodchip, and paper clips in the container. Allow the substances to settle (stop moving). Sketch and label the tower and its contents.



2. Shake the tower and allow the substances to settle again. If the shaken tower appears different, draw a new labelled sketch. Wash your hands after this investigation.



Analyze

1. Make a data table and rank the substances in the density tower in order from least dense (1) to most dense (5).
2. Which substances are denser than water? Which substances are less dense than water?

Conclude and Apply

3. Can a solid be less dense than a liquid? Use the particle theory to explain your answer.
4. Does the volume of an object determine its density?

Extend Your Skills

5. Add more items of your choice to the density tower, such as a rubber stopper, a small rubber duck, a small plastic toy, and a safety pin. Predict where you think these objects will settle in the tower. Then test your prediction.

9-1D Measuring Buoyancy

Think About It

You know that all liquids do not have the same density. Investigate whether various liquids exert the same buoyant force.

What to Do

Observe the photographs and do the following:

1. You can determine the buoyant force on the mass in each liquid by comparing its weight in air to its weight in the liquid. The amount that the weight is reduced is the buoyant force. You can calculate the buoyant force by using the following formula:

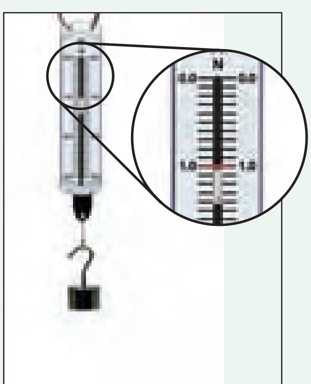
   $F_{\text{buoyant force}} = W_{\text{weight in air}} - W_{\text{weight in liquid}}$

   Using the data in set 1, calculate the buoyant force on the mass in each liquid.
2. Using your calculations from step 1, list the liquids in order of the buoyant force they exert on the mass, from the greatest to the least.
3. Using set 2, list the liquids in order of greatest density to smallest density. How does this list compare to the list in question 2?

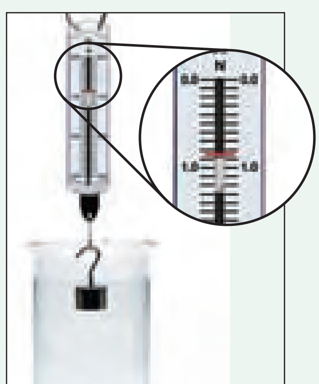
Analyze

1. Give a reasonable explanation for the relationship you found between the density of a liquid and the buoyant force it exerts on the mass.
2. Using set 2, describe any differences that you see in the hydrometers.
3. How do these differences relate to the buoyant forces that these liquids exert on the mass in set 1?

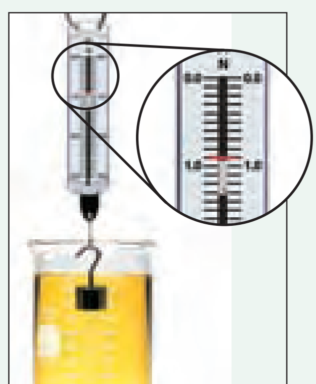
Set 1



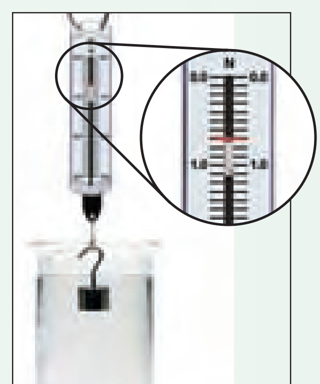
Weight = 1.0 N
100 g mass in air



Weight = 0.85 N
liquid 1

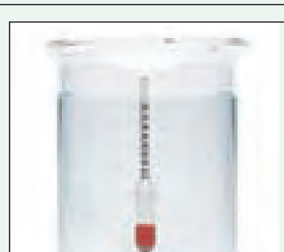


Weight = 0.90 N
liquid 2

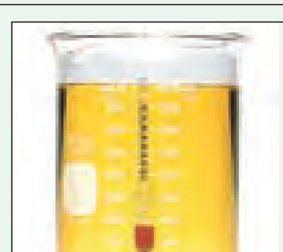


Weight = 0.70 N
liquid 3

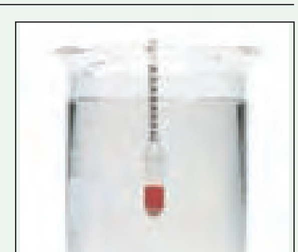
Set 2



Density = 1.0 g/mL
liquid 1



Density = 0.67 g/mL
liquid 2



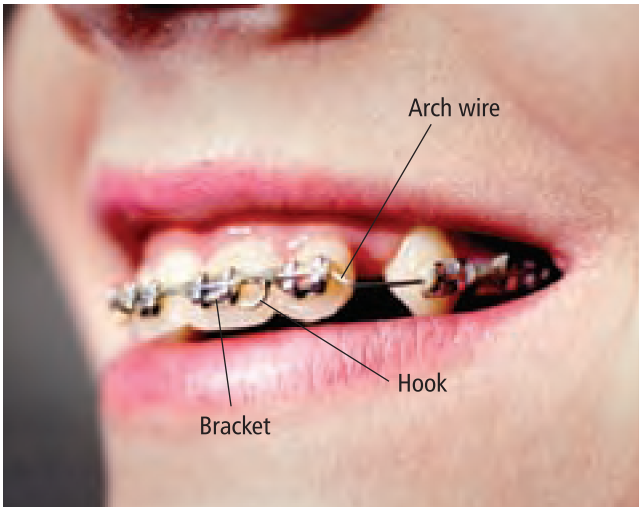
Density = 2.0 g/mL
liquid 3

Science Watch

Brace Yourself for the Force

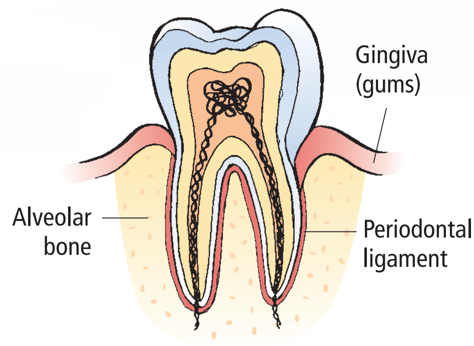
Forces are at work everywhere, but did you know that they at work in a dental office? If you have paid a visit to an orthodontist, you may have a special system of forces at work in your mouth!

An orthodontist is a dentist who specializes in straightening teeth and correcting bites. He or she is an expert in using dental tools to apply constant, light force to the teeth and jaw so that the bone supporting the teeth is rebuilt to hold the teeth in a better position. But just how does it work?



The different parts of orthodontic braces.

The teeth move when the arch wire, (the main wire that is attached to all the brackets, (see picture above) is pulled tighter and puts pressure on the brackets, which in turn, put pressure on your teeth. If more force is needed, springs or rubber bands can be used to exert more force in a specific direction. As the force is exerted on your teeth, the periodontal ligaments are stretched, causing your tooth to loosen. Once the tooth has been moved into the position that the orthodontist wants, the bone grows in to support the tooth in its new position. This is called "bone remodelling."



Space Science in My Braces?

Many of the new technologies in orthodontic brace design come from technologies that were first developed for space travel. For example, new "invisible braces" use a translucent (almost see-through) ceramic material for the brackets that are placed on the teeth. This ceramic material is a spinoff of material that was designed by NASA (National Aeronautics and Space Administration) as a tough material to help protect spacecraft and aircraft.

Check Your Understanding

Checking Concepts

1. A soccer ball is kicked at high speed toward a goalie. The goalie grabs the shot and stops the ball completely. Has the goalie applied a force to the soccer ball? Explain.
2. Peter has a mass of 84 kg. What would Peter's mass be if he travelled to the Moon where the force of gravity is one sixth of what it is on Earth? Explain.
3. Explain why a bathroom scale would not provide an accurate measure of someone's weight on a different planet.
4. Cassie built a model boat with a mass of 320 g. When she tried it out, she found that it displaced 260 g of water. Did the boat sink or float? Explain.
5. (a) How can you make a substance that is *less dense* than water sink? Explain.
   (b) How can you make a substance that is *denser* than water float? Explain.

Understanding Key Ideas

6. A driver and a passenger get out of their car that has run out of gas on a city street. They cannot agree on which gas station is closer, so they begin pushing with equal force on opposite ends of the car.
   (a) Make a sketch of this car-pushing situation. Use arrows to represent the forces on the car. Use your sketch to explain whether the forces on the car are balanced or unbalanced.
   (b) Re-draw the sketch with force arrows illustrating a more effective way for the driver and passenger to get the car to the gas station. Does your sketch illustrate balanced or unbalanced forces? Explain.
7. Create a diagram to explain Archimedes' principle.
8. Explain how the Goodyear™ blimp floats in the air.
9. Explain how average density is used to help submarines sink or float in water.
10. Using what you have learned, from each pair choose which object will float, and which will sink. Explain the reasoning behind your choice.
    (a) Wooden boat vs. water-logged stick
    (b) Metal block vs. metal boat
    (c) A sealed, empty plastic bottle vs. a plastic bottle full of water

Pause and Reflect

It took 2 h for submersibles (underwater vessels) to free-fall 4 km through the icy waters 650 km off the coast of Newfoundland and Labrador to reach the wreck of the *Titanic*. Would it take as long to free-fall the same distance from an airplane? Why or why not? What accounts for the difference?

9.2 Pressure, Hydraulics, and Pneumatics

Pressure in fluids at rest and fluids in motion can produce force, which can be used to operate mechanical devices. Hydraulic systems create pressure that moves through a liquid such as oil or water. Hydraulic systems can greatly multiply force. In pneumatic systems, an enclosed gas such as air transmits a force, causing motion.

Key Terms

compressibility
hydraulics
hydraulic multiplication
hydraulic systems
incompressible
pascal
pneumatic systems
pressure
static pressure

Fighting fires is a high-pressure job, in more ways than one. Without fluid pressure, the water from the hoses could not reach the fire, nor could the air in the firefighters' tank reach their lungs to protect them from the smoke.

Everyone, not just firefighters, relies on fluid pressures in many ways. For example, the water in our showers and taps would not come out without fluid pressure. Many foods and beverages are canned and bottled under pressure to preserve their quality and to keep them safe to eat. Vacuum cleaners, automobile brakes, dentists' chairs, many power tools – even our bodies—all depend on the pressure of fluids in order to function.

Figure 9.13 Firefighters depend on fluid pressure to breathe and to douse flames with water from the hose.

What is Pressure?

If you lean against a wall or any other object, you are exerting pressure on the object. **Pressure** is the force acting on a certain area of a surface. When you press your hand against a wall, you are *applying pressure* on that particular *area* of the wall. If you increase the force, the pressure will also increase. What happens if the area of pressure is increased? Do the Think About It activity below to see for yourself.

9-2A Pop 'em Quick!

Think About It

Suppose you were in a contest to see who could pop the greatest number of balloons in one minute. What could you do to pop the balloons as quickly as possible?

What You Need

2 balloons

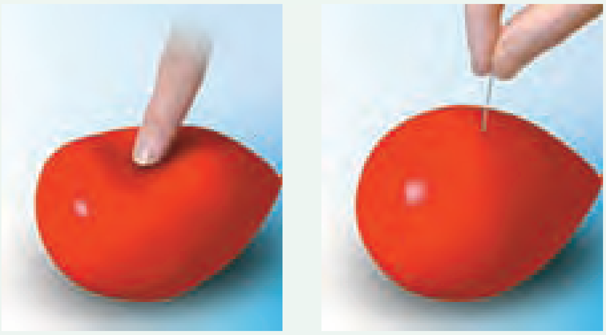
straight pin

Safety

- Be careful when using sharp objects such as straight pins.
- Notify your teacher of any latex allergies.

What to Do

1. Blow up both balloons to approximately the same size. Knot the end of each one.
2. Set one balloon on a table. Push your index finger into the balloon until it pops. (You may need to steady the balloon with your other hand.)
3. Repeat step 2 using the straight pin instead of your finger.



What Did You Find Out?

1. Which method required less force to pop the balloon? Which method was faster?
2. Which "popping tool" had the smaller surface area: your finger or the straight pin?
3. Which popping method required more pressure?
4. What relationship can you see between area and pressure?

The Relationship Among Force, Area, and Pressure

In Activity 9-2A, you examined how force, area, and pressure interact. When you applied pressure on the balloon with your finger, you exerted a force on the balloon over a surface area the size of your finger. However, when you pressed the straight pin into the balloon, you applied the same force over a much smaller area of the balloon. Therefore, the pressure on the balloon was much greater.

Consider another example to see the relationship among force, area, and pressure. Imagine two women, both of whom have the same weight. One woman is wearing flat shoes, while the other is wearing high heels. Since both women weigh the same amount, they exert the same force on the ground. For the woman in the flat shoes, this pressure is spread out over the whole area of the bottom of her shoes. For the woman in high heels, however, this same force is concentrated into two smaller surface areas for each foot. Therefore, the pressure is greater because the area is reduced.

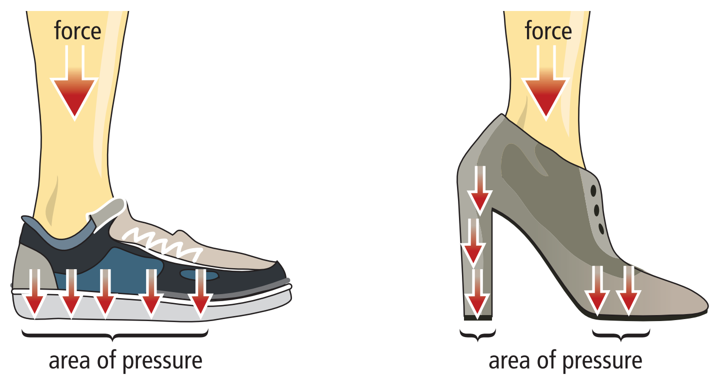


Figure 9.14A and 9.14B High heels exert more pressure on the ground because the pressure is concentrated into a smaller area than a flat shoe.

There are two general conclusions when discussing the relationship among force, area, and pressure: (1) *The larger the force, the greater the pressure, and* (2) *the smaller the area, the greater the pressure.*

Calculating Pressure

We can calculate the pressure on an object by measuring the force that is being exerted and dividing it by the area over which the force is being exerted. The formula for pressure is:

$$\text{Pressure } (P) = \frac{\text{Force } (F)}{\text{Area } (A)} \quad \text{or} \quad P = \frac{F}{A}$$

Force is measured in newtons (N) and area is often measured in square metres (m^2). The unit for pressure, therefore, is newtons per square metre (N/m^2). This unit is also called a **pascal** (Pa), named after the French scientist Blaise Pascal (1623–1662) who was one of the first scientists to study pressure. A kilopascal (kPa) is equal to 1000 Pa.

Sample Problem

An aquarium is filled with water that weighs 10 000 N. If the base of the aquarium has an area of 1.6 m^2, what pressure does the water exert on the base of the aquarium?

- Write the formula for pressure. $P = \frac{F}{A}$
- In place of *F* for force, write 10 000 N. $P = \frac{10\ 000\ \text{N}}{A}$
- In place of *A* for area, write 1.6 m^2. $P = \frac{10\ 000\ \text{N}}{1.6\ \text{m}^2}$
- Carry out the division. That is, divide 10 000 by 1.6. $P = 6250\ \frac{\text{N}}{\text{m}^2}$
- Write N/m^2 as Pa. $P = 6250$ Pa

The pressure of the water on the base of the aquarium is 6250 Pa.

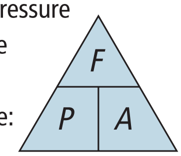
Practice Problems

1. Imagine that you are holding a lead weight on the palm of your hand. If the weight of the lead is 0.80 N and the bottom of the weight has an area of 0.016 m^2, what is the pressure on the palm of your hand?
2. Assume that the text book that is sitting on your desk weighs 14 N. If it has an area of 0.60 m^2, how much pressure is the book exerting on the desk?
3. A large water jug contains water weighing 185 N. If the bottom of the jug has an area of 0.12 m^2, how much pressure is the water exerting on the bottom of the jug?

If you know the pressure that an object or a substance is exerting on a surface, you can find the force acting on any specific area of that surface. To make this calculation, you use a different form of the formula. If you rearranged the formula, you would find that $F = PA$ or force equals the pressure times the area. Learn how to use this form of the formula by studying the Sample Problem on the next page. Then complete the Practice Problems.

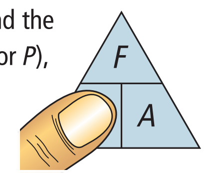
Did You Know?

You can place the pressure formula in a triangle graphic to make it easier to manipulate:



By using your thumb to cover up the variable for which you wish to solve, you will be able to see the formula required.

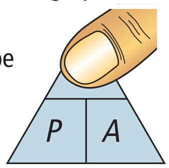
If you wish to find the pressure (solve for *P*), cover up the *P*.



The formula can be read as "*F* over *A*", or force divided by area.

Did You Know?

Use the triangle graphic technique to find the force (solve for *F*) by covering up the *F* in the triangle. The formula can be read as "*P* times *A*", or pressure multiplied by area.



Sample Problem

If the atmospheric pressure is 101 200 Pa and you are holding out your hand, the atmosphere is exerting a force on your hand. If the area of the palm of your hand is 0.006 m^2, how much force is the atmospheric pressure exerting on the palm of your hand?

- Write the formula for force when you know the pressure and area. $F = PA$
- In place of *P* for pressure, put 101 200 Pa. You know that Pa is the same as N/m^2, so use these units instead of Pa. $F = (101\ 200\ \text{Pa})A$
- In place of *A* for area, put 0.006 m^2. $F = \left(101\ 200\ \frac{\text{N}}{\text{m}^2}\right)(0.006\ \text{m}^2)$
- Carry out the multiplication. That is, multiply 101 200 times 0.006. $F = 607\ \text{N}$

The atmosphere is exerting a force of 607 N on the palm of your hand.

Practice Problems

1. The water in an aquarium exerts 2500 Pa of pressure on the bottom of the aquarium. If the area of the bottom of the aquarium is 0.15 m^2, what force is the water exerting on the bottom of the aquarium?
2. If the air pressure generated by a nail gun is 517 kPa (517 000 Pa) and the area of the head of the piston that drives the nail is 5×10^{-4} m^2 (0.0005 m^2), what force does the air in the nail gun exert on the piston?
3. If the pressure inside a tire is 241 000 Pa, what force is exerted on every square metre of the inside wall of the tire?

By rearranging the formula for pressure in another way, you can calculate the area over which a force is acting if you know the force and the pressure. The formula for calculating area is $A = \frac{F}{P}$ or area equals the force divided by the pressure. Study the following Sample Problem, and then complete the Practice Problems.

Sample Problem

The weight of water in a glass is 4.9 N. If the water is exerting a pressure of 1700 Pa on the bottom of the glass, what is the area of the bottom of the glass?

- Write the formula for area when you know the force on the area and the pressure. $A = \frac{F}{P}$
- Weight is force so replace F with 4.9 N. $A = \frac{4.9\text{ N}}{P}$
- In place of P, write 1700 N/m². (Remember that Pa is the same as N/m².) $A = \frac{4.9\text{ N}}{1700\text{ N/m}^2}$
- Carry out the division. That is, divide 4.9 by 1700. $A = 0.0029\text{ m}^2$

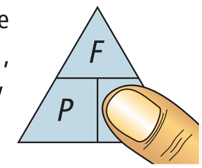
The area of the bottom of the glass is 0.0029 m^2 (which is 29 cm^2).

Practice Problems

1. A large stack of bricks is sitting at a building site. The total weight of the bricks is 102 000 N. If the bricks exert an average pressure of 153 000 Pa on the ground, what is the area of the ground where the bricks are stacked?
2. The water in a swimming pool weighs 24 525 000 N. If it exerts a pressure of 19 620 Pa on the bottom of the pool, what is the area of the bottom of the swimming pool?
3. A column of air from the ground to the top of the atmosphere weighs 50 662.5 N. The air exerts 101 325 Pa on the ground. What is the area of the base of the column of air?

Did You Know?

Use the triangle graphic technique to find the area (solve for *A*) by covering up the *A* in the triangle. The formula can be read as "*F* over *P*", or force divided by pressure.



Reading Check

1. Define pressure.
2. What is the relationship among force, area, and pressure?
3. What is the formula for calculating pressure?
4. What unit is used to measure pressure?
5. What is another way to express this unit?

Pressure and Liquids in Nature

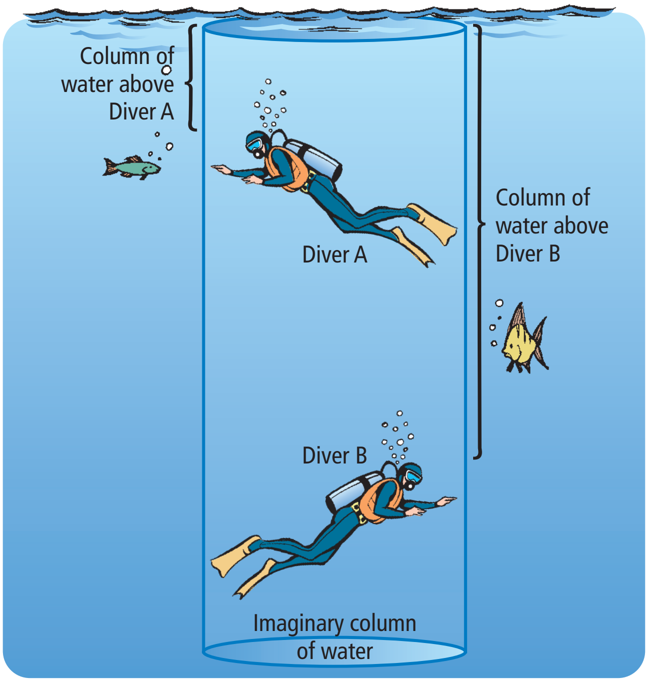


Figure 9.15 As you swim deeper in water, more pressure is exerted on you from the water above.

If you have swum down to the bottom of a pool, you may have noticed that you feel a pain in your ears. This discomfort is caused by water pressure on your eardrums. As you swim deeper, the weight of all that water—and air above it—pushes down on you and the water below. Imagine a column of water that has a cross-sectional area of 1 m^2. This section of water exerts pressure on anything that is below it. As you go deeper in the ocean, the amount of water in the column above you increases, and therefore, the weight of the water increases. The weight of the column of water is the same as the force it exerts on anything below it. Therefore, water pressure is greater the deeper you go underwater.

Figure 9.16 Have you felt pain in your ears when you swam underwater?

internet connect

Submersibles are underwater vehicles capable of allowing humans to go down 2000 m below the ocean's surface. Find out what scientists are finding at these depths. Go to **www.discoveringscience8.ca**

Compressibility of Solids, Liquids, and Gases

Can you remember the particle theory's description of solids, liquids, and gases? One reason that gases have different properties than liquids and solids is because of the large spaces between the particles of gas. An interesting property of gases, then, is **compressibility**—the ability to be squeezed into a smaller volume, or space. Gases are compressible because gas particles are so far apart. The particles remain far enough apart, however, that they still behave like a gas, even when compressed.

What if a liquid or a solid was compressed? The empty space between liquid and solid particles is already so small that when a force is applied to compress them, they cannot move much closer together. Because they cannot be squeezed into a smaller volume, liquids and solids are said to be **incompressible**.

Suggested Activity

Investigation 9-2D on page 360.

Atmospheric Pressure

Earth's atmosphere (the layer of gases surrounding Earth that are held by Earth's gravity) extends more than 160 km above Earth (see page 276 for details on Earth's atmosphere). Every layer of air exerts pressure on the layers below because all of the air particles are pulled toward Earth by the gravitational force. Imagine, when you extend your hand out, you are holding up the weight of a 160 km column of air. Close to Earth's surface, the entire atmosphere is pressing down on the air and compressing it. At higher levels, there is less air pressing down, and therefore, higher levels of air are not compressed as much as lower levels. As a result, air is less dense at higher altitudes.

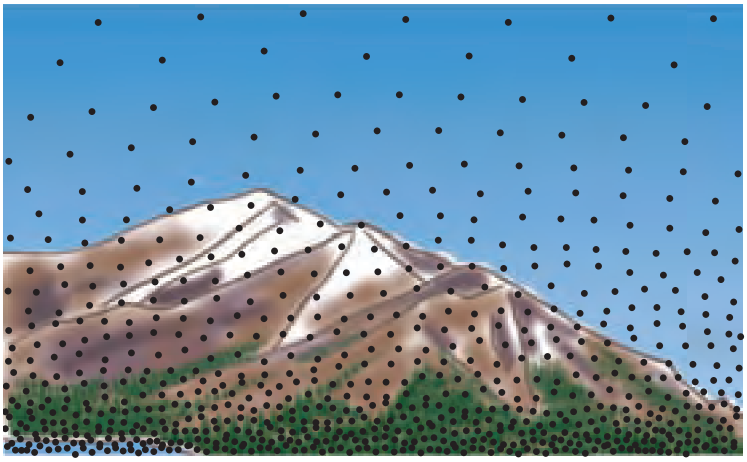


Figure 9.17 Because of Earth's gravitational pull, air particles (represented here by black dots) are most dense near the surface of Earth. The higher you go in altitude, the less dense the air particles, and therefore, the less atmospheric pressure (the amount of force that is exerted by the weight of the atmosphere) is exerted on you.

As you climb higher in the atmosphere, the amount of air above you decreases. Therefore, the air exerts less pressure on you. The air pressure inside your body, however, does not change as quickly. The pressure of any air that is trapped inside your body is still the same at the top of the mountain as it was when you were at the base of the mountain. How do you feel this difference in pressure between the inside and outside? Your eardrum is a very thin membrane that can move in response to a difference in air pressure. If the difference in pressure on either side of the eardrum becomes great, you experience a "pop" inside your ear as the pressure equalizes.

Reading Check

1. Why is water pressure greater the deeper you go?
2. Define compressibility.
3. Why are gases compressible?
4. Why are solids and liquids incompressible?
5. Why do your ears "pop" as your altitude increases?

Figure 9.18 When you squeeze a tube of toothpaste, you are demonstrating Pascal's law.

Pascal's Law

You learned that Blaise Pascal was a 17th century scientist who studied pressure. One of his important findings has become known as Pascal's law. This law states that pressure applied to an enclosed fluid is transmitted with equal force throughout the entire container. Every time you squeeze a tube of toothpaste you demonstrate Pascal's law. The pressure that your fingers exert at the bottom of the tube is transmitted through the toothpaste and forces the paste out at the top. Likewise, if you squeeze one end of an inflated balloon, the other end of the balloon expands.

Squeezing an enclosed fluid creates **static pressure**, meaning the fluid is not moving. The fluid, however, is still capable of carrying a force, even though it is static. For example, pressing the brakes in a car compresses the fluid in the brake lines that causes the brake pads to push against the wheels, stopping the car. Pascal's law is the principle behind hydraulic systems, which you will learn about next.

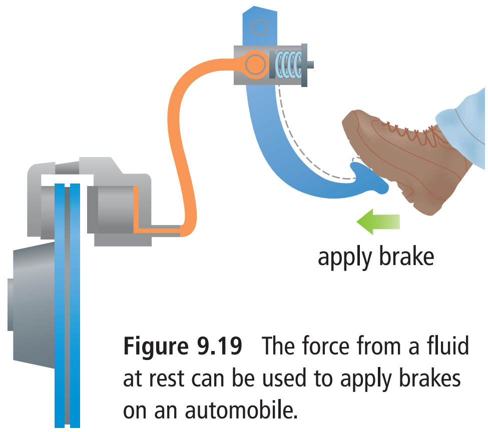


Figure 9.19 The force from a fluid at rest can be used to apply brakes on an automobile.

Figure 9.20 This dentist's chair uses hydraulic systems to adjust the height and position of the chair.

Liquid Pressure and Hydraulic Systems

If you try to compress a sealed liquid by squeezing the walls of its container, you cannot do it. Liquids are incompressible. What happens to the force you exert on the container and the liquid inside? As long as the liquid is enclosed in a tube or a pipe, the force will be transmitted along the liquid until something moves or bulges. The pressure produced in this way is the same throughout the liquid and is exerted in all directions equally.

Hydraulics is the study of pressure in liquids. Devices that transmit applied force through a liquid to move something else are called **hydraulic systems**. In most hydraulic systems, a force is exerted on a continuous, enclosed liquid. This applied force creates pressure that moves the liquid through a series of tubes, pipes, or hoses, which causes a motion at the other end of a hydraulic system. Examples of hydraulic systems are everywhere, including a dentist's or a hairdresser's chair, the Jaws of Life that are used by fire departments, dump trucks, and many types of machines.

9-2B Simple Hydraulics

Find Out ACTIVITY

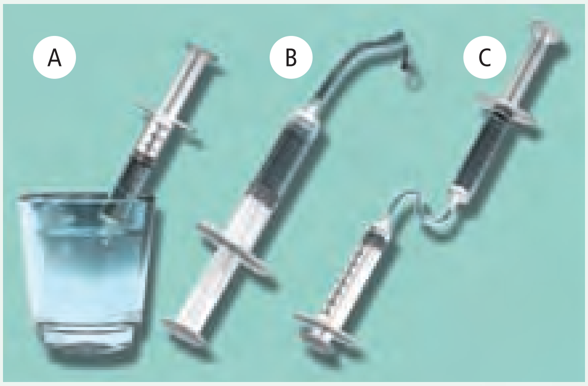
Modified syringes filled with water and joined with plastic tubing provide a simple model of a hydraulic system.

What You Need

2 modified syringes
short piece of plastic tubing
glass of water

What to Do

1. Fill the cylinder of one syringe (the "main cylinder") with water by inserting the cylinder tip into a glass filled with water and pulling back the plunger (see Diagram A).
2. Attach a piece of tubing to this syringe. Push the plunger until the tubing is filled with water (see Diagram B).
3. Attach the cylinder of the other syringe (the "reacting cylinder") to the other end of the plastic tubing (see Diagram C). Make sure that the plunger of the reacting cylinder is completely pushed in before connecting the tubing.
4. Push the plunger of the main cylinder in all the way. **Caution: Never point the tubing or syringe toward anyone when expelling excess fluid.**



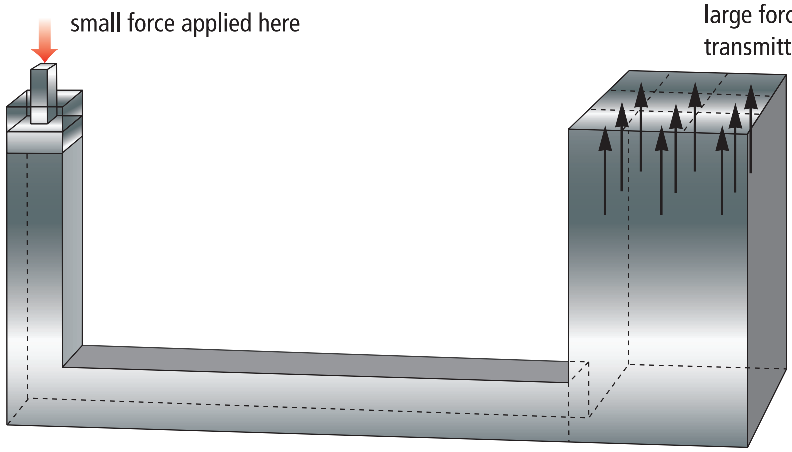
What Did You Find Out?

1. What happens when you apply a force on the plunger of the main cylinder?
2. Explain your observation using the term *hydraulic system.*

Hydraulic Multiplication

Pascal's law can also be used to show how a car lift in a mechanic's shop works. Hydraulic systems can greatly multiply the force exerted by a liquid. In **hydraulic multiplication**, liquid increases and transmits a force from one point to another. Figure 9.21 on the following page shows you how you can multiply the force. Examine the diagram and notice that a small force, such as 10 N, is applied to a small area on the left side. According to Pascal's law, the pressure created on the left is transmitted to all parts of the liquid. As the liquid is pushed up on the right, the same pressure is acting on an area that is nine times as large as the area on the left. Therefore, the total force on the right is nine times as large as the force exerted on the left. If the force on the left is 10 N, then the force pushing up on the right is 9×10 N, or 90 N.

Figure 9.21 This simplified diagram of a hydraulic lift shows how a small force can be transmitted into a large force.



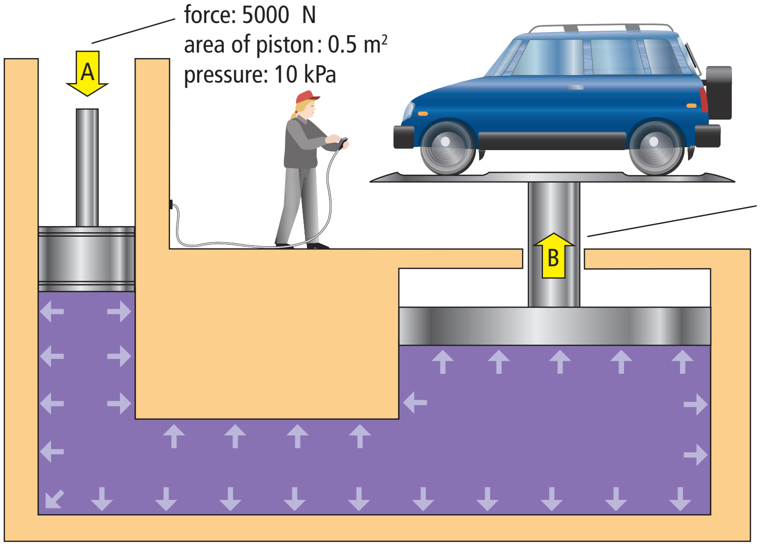


Figure 9.22 Hydraulic multiplication greatly increases force over a relatively small distance.

As shown in Figure 9.22, this method is used to hoist vehicles for repair. Only a small electric motor is needed to push a small piston, or metal cylinder, and it lifts a whole car.

Air Pressure and Pneumatic Systems

Just like other fluids, air exerts pressure on everything that surrounds it. The study of pressure in gases is called pneumatics [pronounced new-MA-tics]. Pneumatic systems are similar to hydraulic systems, except that gases are used instead of liquids. In **pneumatic systems**, a gas transmits a force exerted on the gas in an enclosed space.

The operation of most pneumatic systems is based on the fact that gases can be compressed. Therefore, compressors—devices that compress air—are needed for pneumatic devices to operate. The compressor builds up the air pressure, and then when the pressure is released, the air particles start to move apart suddenly, creating a strong, steady force that can perform powerful tasks. Many tools use pneumatics, from large tampers, which are used to pack down dirt and gravel when building a road, to jackhammers, as seen in Figure 9.23, to tiny precision drills used by dentists. Heavy trucks and buses also rely on pneumatic braking systems (also called air brakes) to stop quickly and smoothly.

Figure 9.23 Many construction tools, such as this jackhammer, work on pneumatic systems.

Reading Check

1. Define Pascal's law.
2. What is a hydraulic system?
3. What is a pneumatic system?
4. Provide an example of a hydraulic system and a pneumatic system.
5. What is hydraulic multiplication?

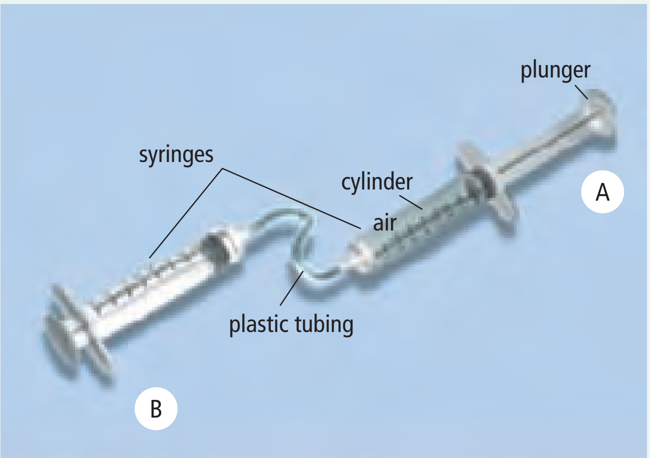
9-2C Exploring Pneumatics

Find Out ACTIVITY

Observe how pressure is transmitted in a simple pneumatic system.

What You Need

modified syringes (various sizes)
short piece of plastic tubing



What to Do

1. Connect two identical syringes together with a piece of plastic tubing.
2. Before you make the final connection, make sure that the syringe you will push on has its plunger pulled completely out. Make sure that the plunger that will react is pushed completely in.
3. Press on A. What happens at B?
4. Press on A while your other thumb is on B. What can you feel? Why don't you feel the pressure immediately?
5. Try different-sized syringes at each end. How far does the plunger at B move compared to the distance A moves?

What Did You Find Out?

1. Is the force exerted at B always the same?
2. Do you think this simple pneumatic system could be used to make work easier? How?

9-2D Bottle Squeeze

SkillCheck

- Observing
- Recording
- Analyzing
- Explaining systems

Safety

- Dispose of materials as instructed by your teacher

Materials

- 500 mL beaker (or measuring cup)
- rubber gloves
- 3 empty plastic pop or water bottles with twist-off caps (500 mL each)
- water
- sand

In this investigation, you will test the compressibility of solids, liquids, and gases.

Problem

How do the compressibilities of solids, liquids, and gases compare?

Procedure

1. Twist the cap tightly on an empty water bottle.
2. Squeeze the bottle as hard as you can. Estimate how much of the original volume you could compress—one quarter, one third, one half, more? Record your estimate.
3. Find the precise volume of the bottles. Although these bottles are meant to hold 500 mL of water or pop, the bottle might actually have a larger capacity. Fill the bottle right to the top with water. Then, use the beaker or the measuring cup to measure the total actual volume of the bottle. Record the total capacity of the bottle.
4. Half-fill the other two bottles, one with water and one with sand. Repeat step 2 for each of these bottles.
5. Completely fill each bottle: the water bottle with more water, the sand bottle with more sand. *Make sure that no air is left inside the bottles.*
   (a) Fill the water bottle until the water rises to mid-neck. Wait about 5 minutes.
   (b) Then, very carefully, pour more water into the bottle until the water bulges at the top.

Step 2

Step 3

Step 4

Step 5

Inquiry Focus

6. Twist the cap tightly on the bottle of sand, and then on the water bottle. You should see some water leaking out as you do this. Be careful not to squeeze the bottle while you are twisting the cap shut.
   (a) Repeat step 2 for each bottle.
   (b) Organize all the data you have collected in a table and give your table a title.


Step 6

Analyze

1. (a) How did your ability to compress the bottle containing water change as the amount of water increased?
   (b) How did your ability to compress the bottle containing sand change as the amount of sand increased?

Conclude and Apply

2. (a) How does the compressibility of a gas compare to the compressibility of a solid?
   (b) How does the compressibility of a gas compare to the compressibility of a liquid?
3. How does the compressibility of a liquid compare to the compressibility of a solid?
4. If a car ran over the water-filled bottle, what do you think would happen? Would the water inside the bottle compress as the bottle flattened, or would the bottle burst as the plastic gave way? Explain your answer.

Extend Your Knowledge

5. Would a force greater than the force exerted by your two hands be able to compress the water-filled bottle and the sand-filled bottle? Find or design a device that could exert a greater, controlled force on your sample bottles.

Science Watch

Body Hydraulics

Hydraulic systems can be used to transport fluids over large distances. Pumps provide the force that pushes the fluid through the pipes and allows it to get to its destination. It is through the use of hydraulics that water can reach homes in highrise apartment buildings and other high areas.

One of the most efficient hydraulic transport mechanisms is the human circulatory system. In humans, blood must be kept under pressure so that it can reach all parts of the body. The constant beating of the heart, which is the pump, keeps the blood moving throughout the arteries and capillaries, which are like pipelines.

In most hydraulic transport systems, it is important that the fluid keep travelling away from the pump. In order to do this, many pumps have valves, which are devices used to regulate the flow of a liquid in hydraulic systems. The human pump also has valves. Valves in the heart keep the blood moving in one direction. This is important because once carbon dioxide has been removed from the blood and oxygen has been added by the lungs, the heart needs to send this out to all parts of the body. Re-oxygenated blood cannot mix with blood that has carbon dioxide in it.

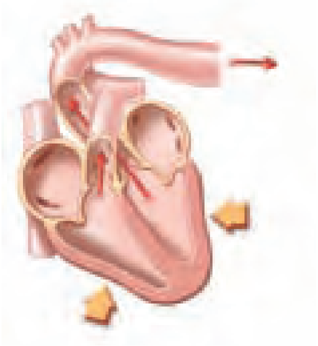


Figure A Heart during contraction. Which valves are open and which valves are closed?

Figure B Relaxed heart, between contractions. Which valves are open and which valves are closed?

Did you know that the human heart...

- creates enough pressure to squirt blood over nine metres away?
- beats about 100 000 times a day?
- pumps about 1 million barrels of blood over the course of an average lifetime?
- circulates the blood in your body three times every minute?

Check Your Understanding

Checking Concepts

1. Michelle weighs 500 N. How much pressure does she apply when she stands on her head, if the circular part of her head that is touching the floor has a radius of 2 cm?
2. Amy's friends got her a helium balloon for her birthday. By accident, it slipped out of her grasp and rose higher and higher into the air until she could not see it anymore. A few days later, she and her friends found it in the park. It had burst. Why do helium balloons eventually burst, or explode, as they rise higher and higher in the atmosphere?
3. Describe how the body's circulatory system is similar to a hydraulic system.
4. Explain why the leak in the bottom of a water barrel will spray water farther than a leak at the top of the barrel.
5. If an airplane door were to open at a high altitude, in which direction would the air move—into or out of the airplane? Why?

Understanding Key Ideas

6. Explain, using the particle theory of matter, why gases can be compressed, but liquids and solids cannot.
7. Explain why your body is sensitive to 30 kPa of water pressure at the bottom of a swimming pool, but not sensitive to 101.3 kPA of normal atmospheric pressure.
8. (a) Pneumatic systems are based on what property of gases?
   (b) How does this property help pneumatic systems do work?
9. Why are pumps and valves necessary in hydraulic systems? Explain.

Pause and Reflect

Think about equipment used in your home, at school, in grocery stores, and in hospitals, and make a list of devices, mechanisms, or situations in which compression can occur. In each case, decide whether the compression is desirable or undesirable. How might compression be prevented when it is not needed? Record your answers in your notebook.

9.3 Relationships among Pressure, Volume, and Temperature of Gases

When studying the characteristics of gases, you find three factors that that can influence one another. These factors are temperature, pressure, and volume of the gas. To find a relationship between any two of the factors, or variables, you must ensure that the third remains constant throughout the experiment. When the temperature of a gas is constant, or unchanging, and you increase the pressure on a gas, its volume will decrease. When the pressure on a gas is constant, and you increase the temperature, the volume of the gas increases. When the volume is constant and you increase the temperature of a gas, the pressure increases. An understanding of these relationships allows scientists and engineers to develop practical technologies.

Key Terms

controlled variable

Figure 9.24 Portable oxygen tanks allow people with breathing problems to leave a hospital or home and participate in outings with family and friends.

The woman in the photograph in Figure 9.24 is breathing oxygen from a portable oxygen tank that she carries on her scooter. Without the portable oxygen tank, she would probably have to remain in a hospital or at home. Although the portable oxygen tank gives her a lot of freedom, it is very important to know how much oxygen the tank can hold and how long it will last.

You learned in Section 9.2 that gases are compressible. By exerting pressure on a gas, you can reduce its volume. To design tanks, such as the oxygen tank in Figure 9.24, you need to know how much pressure the tank can withstand with no danger of leaking or breaking. Scientists have found relationships that they can use to predict the amount of pressure needed to compress a gas to a desired volume. They have also determined how the temperature of the gas affects its volume and pressure. In this section, you will learn about the relationships among pressure, volume, and temperature of gases.

9-3A Hot and Cold Gases

Find Out ACTIVITY

How does the temperature of a gas affect its volume? You can find out by trapping air inside a flexible container such as a balloon and changing the temperature of the gas.

What You Will Need

bottle with narrow neck
balloon
elastic band
large bowl
ice water
hot water

What to Do

1. Stretch the opening of the balloon over the neck of the bottle.
2. Secure the balloon on the bottle with the elastic band as shown in the diagram.

3. Place the bottle in the large bowl. Hold the bottle in place while you fill the bowl with hot water.
4. Hold the bottle in the hot water for one minute. Observe and record what happens to the balloon while the bottle is in the hot water.
5. Remove the bottle and empty the bowl.
6. Put the bottle back into the bowl and hold it in place while you fill the bowl with ice water.
7. Hold the bottle in the ice water for one minute. Observe and record what happens to the balloon while the bottle is in the ice water.

What Did You Find Out?

1. Describe any changes in the balloon when the bottle was sitting in the hot water.
2. Describe any changes in the balloon when the bottle was sitting in the ice water.
3. Provide possible explanations for the changes that you observed in the balloon while the bottle was in the hot water and while it was in the ice water.

Suggested Activity

Investigation 9-3D, page 371.

Did You Know?

Robert Boyle used a "J" tube like the one shown here to study the relationship between the pressure on a gas and its volume. The short end of the tube was sealed and the long end was open. As Boyle poured mercury, a very heavy liquid, into the long side of the tube, it exerted pressure on the air trapped in the short side. He then compared the pressure exerted by the mercury to the volume of the trapped air.

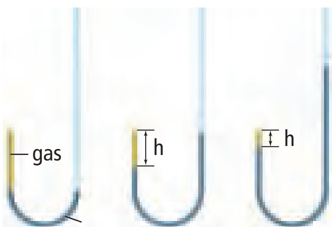


Figure 9.25A Propane gas is compressed into a liquid form that can be stored in special cylinders. The high pressure in the cylinder reduces the volume of the gas so much that the propane enters the liquid state. Why is it important to avoid heating a propane cylinder?

Pressure and Volume of a Gas

To study the relationship between pressure and volume of a gas, scientists knew that they had to make sure that there were no other factors affecting the pressure or volume. As you know, temperature affects the volume of a gas. Therefore, the temperature of a gas must remain the same when making observations involving the pressure and volume. You would say that temperature is the **controlled variable** because the temperature is being held constant during the experiment.

In 1662, Irish scientist Robert Boyle (1627–1691) developed a method to predict how much the volume would change when he exerted a certain amount of pressure. For example, if he doubled the pressure on a gas, its volume would decrease to half its original volume. If he increased the pressure on a gas to ten times the original pressure, its volume would decrease to one tenth of the original volume. This relationship is now known as Boyle's law. It allows you to determine the final volume of a known amount of gas when you exert a certain amount of pressure on the gas. It also allows you to determine how much gas can be compressed into a tank when you know how much pressure the tank can withstand (Figure 9.25A).

Rescue workers use practical applications of the relationship between pressure and volume of gases to help save lives. If someone is trapped under a car or truck after an accident, the rescue workers use airbags to lift the car or truck as shown in Figure 9.25B. They place the flat airbag under the vehicle and attach an air hose. As air is pumped into the bag, the pressure increases greatly, thereby increasing the volume of the bag. As the bag inflates, the vehicle is lifted off the trapped person.

Figure 9.25B Flat air bags can be inserted under a car and then inflated to lift the car off the ground.

9-3B Lifting with Air

Find Out ACTIVITY

How many books can you lift with air?

What You Will Need

straw
balloon
strong tape
textbooks
strong elastic band

What to Do

1. Insert a straw into the mouth of a balloon. Seal the straw to the balloon with tape. Reinforce the seal by winding the elastic band around the balloon seal.
2. Place a book on the balloon as shown in the picture. Blow steadily into the straw and observe what happens.

3. Place more books on top of the first one, one book at a time. Record how many books you can lift by blowing into the straw.

What Did You Find Out?

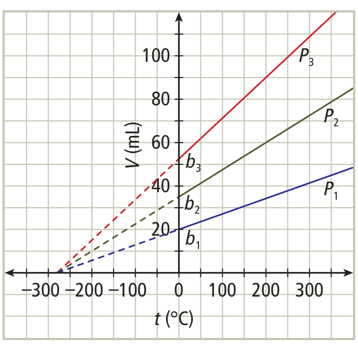
1. What happened to the balloon as you blew into the straw? Which part of the balloon inflated first?
2. Was it harder to blow up the balloon with two books on top of it rather than one? If so, why?
3. How many books were you able to lift by blowing up the balloon?

Reading Check

1. Why must the temperature be held constant when you are doing an experiment to determine the relationship between the pressure on a gas and the volume of the gas?
2. What happens to the volume of a gas when you exert pressure on it? Assume that the temperature of the gas remains constant while you are exerting the pressure on it.
3. Describe one practical application of the relationship between the pressure and the volume of a gas.

Did You Know?

French scientist, Jacques Charles (1746–1823), measured the the volume of a gas when he increased its temperature. He discovered that when he held the pressure constant, a plot of temperature versus volume of a gas always made a straight line. This relationship is now known as Charles' law. An example of the graph is shown here. You will notice that when the lines are extended backwards to the temperature axis, they all meet at the same temperature, –273.15°C. You might recall that this temperature is called *absolute zero* because the temperature of any substance cannot go below this temperature.



Temperature and Volume of a Gas

In Chapter 8, you read that as the temperature of a gas increases, its particles move faster. When the particles collide, they hit each other with a greater force. They push each other farther apart. As the particles spread out, they take up a larger volume. You saw evidence of this if you completed the Find Out Activity 9-3A, Hot and Cold Gases, on page 365. When you placed the bottle in hot water, the temperature of the air inside the bottle increased. The volume of the bottle could not increase, so the gas increased its volume by expanding the balloon. When you then placed the bottle in cold water, the temperature of the air inside the bottle decreased. The volume of the bottle could not decrease, so the volume of the balloon decreased. You can conclude that the volume of a gas increases when its temperature is increased if the pressure is kept constant.

Temperature and Pressure of a Gas

To determine the relationship between the temperature and pressure of a gas, you must hold the volume constant throughout the experiment. You can do this by trapping gas in a rigid container with very strong walls. When heating the gas inside and measuring the pressure, you will discover a relationship. As the temperature rises, the pressure rises if the volume is held constant.

Explore More

Blow up three identical balloons to the same size. Tie the necks of the balloons very tightly so that no air will escape. Place one balloon in the freezer. Place one balloon in direct sunlight or under a very bright light. Place the third balloon in a shaded corner. After about 30 min, compare the sizes of the balloons. Explain any differences in the size of the balloons.

9-3C The Pressure is Rising

Think About It

In an investigation, 1.0 g of water was boiled into steam in a sealed container that could not expand. The container was fitted with a thermometer and a pressure gauge that could measure the temperature and pressure of the gas inside the container. As the container was heated, the data in the following table were collected.

Pressure vs. Temperature of 1.0 g of Steam

Temperature (°C)	Pressure (kPa)
100	172
125	184
150	195
175	207
200	218
225	230
250	242
275	253
300	265

What To Do

1. Using graph paper, prepare a graph of pressure versus temperature of steam. Put pressure on the vertical axis (*y*-axis) and temperature on the horizontal axis (*x*-axis). Give your graph a title and put labels and units on the axes.
2. On the graph, plot the points given in the data table.
3. Do not connect the dots precisely but draw a smooth line that is as close to all of the dots as possible.

What Did You Find Out?

1. Write a statement that describes the relationship between the temperature and pressure of a gas when the volume is held constant. **Hint:** What happens to the pressure when the temperature increases? Is the line straight or curved?
2. Use the particle theory to explain the relationship that you found between pressure and temperature of a gas when the volume is held constant.

Understanding the relationship between temperature and pressure of a gas is very important in both designing equipment and safe handling of equipment and household items. For example, a cooking device called a pressure cooker uses steam at very high temperatures and pressure to cook food more quickly. Because the steam from the boiling water cannot escape, it rises in temperature and pressure, and is able to cook food in a quick and safe manner.

Figure 9.26 A pressure cooker uses the relationship between temperature and pressure of a gas to cook foods more quickly.

Have you ever used an aerosol can like the one in Figure 9.27? Aerosol cans contain gases at high pressure that push the ingredients out of the can in the form of a spray. The safety warning on the label nearly always says, "Do not incinerate." You might have wondered why incinerating, or burning, could be dangerous if the ingredients in the can have been used up. If the can will not spray any more, the pressure has been reduced. The pressure inside and outside the can is the same. However, the can is still sealed. What happens to a gas in a sealed container (constant volume) when it is heated? The pressure goes up. As the pressure increases and has nowhere to go, a heated aerosol can might explode.

Figure 9.27 Gas pressure inside an aerosol causes liquid to spray out rapidly.

Reading Check

1. When you increase the temperature of a gas and hold the pressure constant, what happens to the volume of the gas?
2. When you are doing an experiment to measure the effect of increasing temperature on the pressure of a gas, what variable must be held constant?
3. What happens to the pressure of a gas when you increase the temperature of the gas?

9-3D Putting on the Pressure

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Observing
- Measuring
- Controlling variables
- Graphing

Be sure to clamp your syringe securely with its tip against the bottom of the lab stand or the desk.

Safety

- Clean up any spills.

Materials

- plastic syringe with covered tip
- lab stand
- clamp
- 100 mL beaker
- water
- vegetable oil
- 0.5 kg, 1 kg, 2 kg masses

Science Skills

Refer to Science Skill 1 for instructions on drawing a graph.

Design your own investigation using a syringe to apply pressure to a liquid and a gas.

Question

How do gases and liquids under pressure compare?

Hypothesis

Formulate a hypothesis about how the results will differ when you apply pressure to a liquid and a gas.

Procedure

1. Copy the following table into your notebook. Give your table a title.

Fluid	Mass Applied (kg)	Force Applied (N)	Syringe Start Position (mL)	Syringe Finish Position (mL)	Change in Volume (mL)

2. Attach a clamp to the lab stand, and test-fit a syringe in the clamp so that the syringe is in a secure vertical position with the covered tip resting against the bottom of the lab stand.
3. Plan how you will measure the change in volume of a fluid in the syringe when you add various masses. Your plan should include testing masses on three different fluids in the syringe: air, water, and vegetable oil. Have your teacher approve your plan.
4. Perform your investigation. Remember that you convert mass to force by multiplying by 9.8.
5. Create a line graph of your results by plotting change in volume vs. the force applied for each of the fluids.
6. Clean up and put away the equipment you have used.

Analyze

1. What were the independent, dependent, and controlled variables in your investigation?
2. How did your experimental results compare with your hypothesis?

Conclude and Apply

1. Use your line graph to answer the following questions.
   (a) If you increased the amount of pressure, how would you expect the volume to change for each of the fluids? Explain.
   (b) Could you reduce the volume of any of the substances to zero? Explain.

Career Connect

Professional Diver

Rick Stanley at the propeller of one of the Bell Island Shipwrecks in Conception Bay.

Rick Stanley is the owner and President of Ocean Quest Adventure Resort in Conception Bay South, Newfoundland and Labrador. He is an open water and speciality instructor and is a SCUBA diving advisor to Parks Canada.

Q. How long have you been diving?

A. I did my first dives in winter of 1992 on the Conception Harbour whaling shipwrecks. Now, to my credit, I have over 500 dives on the Bell Island shipwrecks, and more than 1000 dives in total.

Q. What training do you have to complete to become a scuba diver?

A. Learning to scuba dive consists of two parts: classroom work where you learn the theory and science of your equipment and safety, and practice, where you apply your lessons in a pool and then out in the open water. When you're out in the lakes or oceans, you can practice your buoyancy and all the safety drills you learned in class.

Q. What can divers see in the waters around Newfoundland and Labrador?

A. Shipwrecks…of course I would say that because I am a shipwreck fanatic! But because of the collide of the Gulf Stream and Labrador Current just off the coast of Newfoundland and Labrador there is an abundance of nutrients for all kinds of marine life, fish, and whales to feed on, which means there is a lot for divers to see.

Q. Do you need special training to dive among the wrecks and in caves?

A. Special technical training is needed to dive into wrecks and caves, as your mind and equipment have to be properly prepared for such dives. There are many more safety issues that you must be ready for when you dive into wrecks and caves.

Q. How do divers protect themselves from the cold waters around Newfoundland and Labrador?

A. Because of the cold waters around this province, thermal suits are required. First, there is the wetsuit that preserves your body heat by trapping a thin layer of water against your skin. Dry suits are also used. They do not let water enter, and have seals around the neck and wrists.

Q. Why is science an important part of being a professional scuba diver?

A. You need to know about your body and how it reacts to pressure and gases. Diving means entering into an environment that is not natural for humans, and that makes studying science as it relates to being underwater necessary. Before anyone goes diving, you need to know how being underwater affects your body. You also need to understand how gases behave under pressure. Buoyancy is also a critical part of diving. If you understand the science pertaining to diving, it will keep you out of trouble.

Q. What is the best aspect of being a professional scuba diver?

A. By being a professional diver, you have completed extensive training. This enables you to understand what you are experiencing and allows you to be more comfortable in the ocean. Also to be able to help people achieve their goals is very rewarding—not to mention the possibilities to make money! But that's for business class.

Check Your Understanding

Checking Concepts

1. What could you do if you wanted to reduce the volume of a gas without changing the temperature?
2. Describe the experiment that Robert Boyle used when he studied the relationship between the volume of a gas and the pressure on the gas.
3. What could you do if you wanted to reduce the volume of a gas without changing the pressure on the gas?
4. Describe or sketch the appearance of a graph of volume versus temperature of a gas. Volume should be on the vertical axis (y-axis) and temperature should be on the horizontal axis (x-axis).
5. Explain why you should never incinerate (burn) a used aerosol can.
6. How can you ensure that the volume of a gas does not change when you are measuring the pressure of a gas while you are increasing the temperature of the gas?

Understanding Key Ideas

7. Imagine that you were doing an experiment in which you were measuring the volume of a gas in a syringe while exerting pressure on the plunger of the syringe. Suppose you wanted to keep the gas in the syringe at a temperature of 50°C. Suggest a method by which you could carry out the experiment.
8. On extremely cold days, automobile tires often look slightly flat even when they have not lost any air. Explain why they may appear like this.
9. A classmate shows you a graph of temperature versus pressure of a gas. The graph shows a slightly curved line instead of a straight line. What might have happened during the experiment that caused the line to be curved?
10. Imagine that you went hiking at a high altitude in the mountains. While you were resting at the highest point of your hike, you drank some water from a plastic water jug. You sealed the cap tightly and hiked back down. When you were back at a low altitude, you took the water jug out of your backpack. The sides of the jug were pulled inward. What might have caused the change in the shape of the jug?

Pause and Reflect

The airbags shown in the photograph can be used to lift objects with masses of hundreds of kilograms. Describe some characteristics of the bag that would be necessary in order for it to carry out the tasks.

Chapter Review

Prepare Your Own Summary

In this chapter, you have learned how fluids react to different forces. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. Use the following headings to organize your notes:

1. Buoyancy and Fluids
2. Pressure and Fluids
3. Relationship among Pressure, Temperature, and Volume of Gas

Checking Concepts

1. Draw a diagram of a closed container of air and water, and use it to explain what happens to each when pressure is applied to the container.
2. Draw a cross section of a swimming pool and use it to describe how water pressure changes with depth.
3. (a) What are the differences between hydraulics and pneumatics?
   (b) How are the terms related?
4. How does the concept of hydraulic multiplication apply to lifesaving tools used by fire departments?
5. Why are pumps needed in municipal water systems?
6. What would happen to the volume of a gas if you decreased the pressure on the gas while holding the temperature constant?
7. What variable must be controlled when you are doing an experiment to determine the relationship between the temperature and volume of a gas?
8. If you first increased the temperature of a gas while all other variables were constant, what would happen to the volume of the gas? If you then kept the temperature constant and increased the pressure on the gas, what would happen to the volume?

Understanding Key Ideas

9. An inflation needle on the end of a bicycle pump is commonly used to inflate sports balls.
   (a) Describe how a bicycle pump produces compressed air.
   (b) Why is it much harder to press the pump if there is an inflation needle added to the end of the hose?
10. Building contractors sometimes use powerful hydraulics to lift up a house so that repairs can be made to the foundation. Using a diagram, explain how hydraulic multiplication can be used to lift a house.
11. (a) In an investigation, you are told to increase the volume of a gas without changing the temperature. How would you accomplish this?
   (b) In the next step of the investigation, you are told to bring the pressure back to the original value without changing the volume. How would you accomplish this?
12. If you were to blow up a balloon and then leave it in direct light from the Sun, what would happen to the balloon? Explain why this would happen.

Unit Summary

7 Viscosity describes fluid's resistance to flow.

- The particle theory of matter states that solid particles, liquid particles, and gas particles behave differently. (7.1)
- Viscosity is a fluid's resistance to flow. (7.2)
- The viscosity of a fluid is affected by temperature. (7.3)

8 Density describes the amount of mass in a given volume of substance.

- Density is a measure of the mass contained in a given volume. (8.1)
- Substances with a lower density will float on substances with a higher density. (8.1)
- The density of a substance can be determined by dividing the object's mass by its volume. (8.2)
- Changes in temperature affect the density of a substance. (8.3)

9 Forces influence the motion and properties of fluids.

- Fluids exert forces on objects in their environments. (9.1)
- The density of fluids determines how they will react with other fluids or solids. (9.1)
- Compression of fluids and gases can be used to produce force. (9.2)
- Temperature, pressure, and volume of a gas influence one another. (9.3)

Key Terms

- boiling
- boiling point
- change of state
- concentration
- condensation
- deposition
- evaporation
- flow rate
- fluid
- freezing point
- gas
- kinetic energy
- liquid
- melting
- melting point
- particle theory of matter
- solid
- solidification
- sublimation
- viscosity

Key Terms

- density
- displacement
- mass
- mass-to-volume ratio
- volume

Key Terms

- Archimedes' principle
- average density
- balanced forces
- buoyancy
- buoyant force
- compressibility
- controlled variable
- force
- hydraulics
- hydraulic multiplication
- hydraulic systems
- incompressible
- mass
- neutral buoyancy
- pascal
- pneumatic systems
- pressure
- static pressure
- unbalanced forces
- weight

Project

Emergency Hovercraft

Hovercraft are fast-response vehicles that can travel over land and water, bringing vital aid and supplies to victims of emergencies. Powerful pumps in the hovercraft draw in air and pump it out through holes in the bottom of the hovercraft. Given enough air pressure, a hovercraft can support extremely heavy loads. Propellers drive the hovercraft forward, and rudders are used to steer.

Problem

In this project, you will use your knowledge of fluids and pressure to design a hovercraft with a propulsion system that allows it to move from place to place in the classroom.

Saftey

Suggested Materials

- plastic soft drink bottle with screw cap
- electric drill
- square piece of cardboard
- pencil
- scissors
- hot glue gun or tape
- balloon

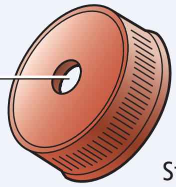
Criteria

- You may use your own design to construct a model hovercraft, or use the procedure steps below to construct a basic model without a propulsion system.
- Your hovercraft should be able to propel itself. The basic model provided below will float, but it will not propel itself. This feature must be designed and added by you.
- Whatever materials you choose to build with, always remember—safety first.
- Prepare a complete and detailed diagram of your model. The diagram should clearly show how all of your materials were used to construct your hovercraft. Your diagram should be accompanied by a detailed explanation of how your hovercraft works. Make sure that you use the knowledge you have gained about pressure in this unit in your explanation.
- Keep a "design log"—a record of your steps of construction, including any problems you experienced and what you did to overcome them.

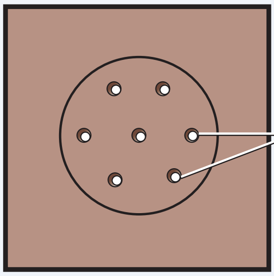
Procedure

1. Meet with your partner or group and plan your design for your hovercraft with a propulsion system. Keep all of your sketches to attach to your final diagram. Have your teacher approve your plan.
2. Build your model hovercraft. Be sure to record your steps of construction in your design log. Whenever you run into a problem, note that in your log as well, along with the troubleshooting steps you took to solve the problem. If you decide to build your own model, skip to step 10. If you decide to use the plans for the basic model, proceed to step 3.

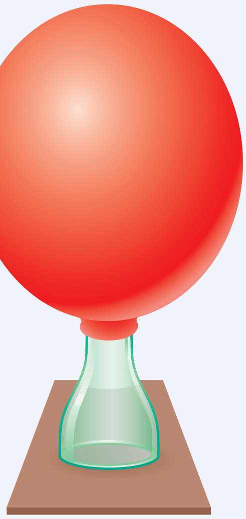
3. Drill a 5–6 mm hole in the screw cap of a plastic soft drink bottle. Make sure that the edges of the hole are clean; you should be able to blow air though it easily. **Caution: Be careful when using a power drill. If you are not familiar with the safe use of this hand tool, have your teacher drill the hole for you.**



4. Cut off the top one third of the soft drink bottle. Try to make your cut as straight across the bottle as possible.
5. Cut a square piece of cardboard that is just slightly larger than the large end of the bottle you cut in step 4. Do not bend the cardboard. It should remain perfectly flat.
6. Put the bottle on the cardboard and trace the edge of the bottle onto the cardboard. Use a pencil to punch seven holes in an even pattern within the circle on the cardboard. Punch through the cardboard the same way for each hole. One side of the cardboard must remain perfectly smooth.



7. Place the cardboard smooth-side down. Centre the plastic bottle on the cardboard and use hot glue around the entire edge to seal it onto the cardboard. Tape can be used if you do not have a hot glue gun.
8. Put the mouth of the balloon onto the screw cap. Leave just enough screw cap exposed so that you can tape the balloon securely to the cap.
9. Blow up the balloon through the screw cap. Pinch the neck of the balloon to keep the air in it while you screw the cap onto the bottle. Your basic hovercraft model is now complete.
10. Your model hovercraft must be equipped with a propulsion system. A successful hovercraft model will rapidly move across the test surface without being pushed. If you have not already done so, add a propulsion system of your own design to your hovercraft model.


A basic hovercraft model

Report Out

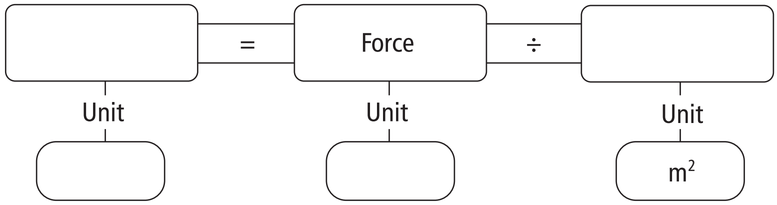
1. Present your design and model to the class or to other groups.
2. Respond to each of the following points with a brief paragraph in your notebook:
   (a) How well does your hovercraft float and propel itself?
   (b) Observe other students' hovercraft in action. How well do they work? What design elements do you think are particularly effective?
   (c) If you could improve your hovercraft model, what changes would you make?

UNIT 3

Unit Review

Visualizing Key Ideas

1. Copy and complete the following concept map.



Using Key Terms

2. In your notebook, state whether the following statements are true or false. If a statement is false, rewrite it to make it true.
   (a) A fluid is defined as anything that flows.
   (b) The particle theory of matter does not apply to all particles.
   (c) The volume of a solid is often measured in cubic centimetres.
   (d) The density of a substance is not related to its physical state.
   (e) Gases are less dense than solids or liquids.
   (f) A balanced force causes a change in the speed of an object.
   (g) The buoyant force depends on the weight of the displaced fluid.
   (h) Pneumatics is the use of a liquid in an enclosed system under pressure.
   (i) The other name for a N/m^2 is a pascal.
   (j) The controlled variable is the variable that you adjust so you can observe its effect on a second variable.
   (k) Boyle's law states that when the pressure on a gas is decreased, the volume decreases.

Checking Concepts

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3. Why do liquids take the shape of the container they are in?
4. Explain why gas particles always occupy all of the space in which they are contained.
5. What is the difference between viscosity and flow rate?
6. How does temperature affect the viscosity of a liquid and a gas?
7. How does concentration affect the viscosity of a fluid?

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8. Explain why, in general, gases are less dense than liquids.
9. How is density calculated?
10. What are the differences among mass, volume, and density?
11. Why is it possible to layer fresh water on top of salt water?
12. How does temperature affect density?

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13. Why does air pressure change with altitude?
14. What is buoyant force?
15. What is static pressure?
16. What is the purpose of hydraulic multiplication?

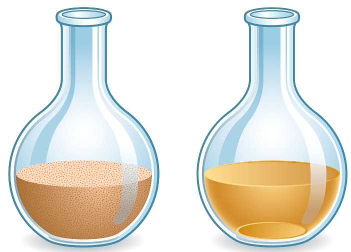
17. How does a hydraulic system differ from a pneumatic system?
18. What change can cause the volume of a gas to increase if the temperature of a gas remains constant?
19. If you increase the temperature of a gas while keeping the pressure on it constant, what change will take place?
20. What can cause the pressure of a gas inside a sealed container to increase if the volume of the container cannot change?

Understanding Key Ideas

21. What are the five rules of the particle theory of matter?
22. Use the particle theory of matter to explain the difference between solid wax at 40°C and liquid wax at 80°C.
23. Explain why the density of pancake syrup is greater than the density of water.
24. Explain how weight is different than mass.
25. Explain why falling and hitting the ground with the point of your elbow would exert more pressure than falling and hitting the ground with your back.
26. What causes one substance to have a greater viscosity than another substance?
27. Explain why you must first compress a gas in order to transmit a force in a pneumatic system.
28. What two forces act upon an object in water?
29. What is Archimedes' principle?
30. Why are liquids and solids incompressible?
31. What changes are taking place in a bicycle tire when you are adding air to the tire, assuming that the temperature of the air is not changing?
32. Use the particle theory to explain why the volume of a gas increases when the gas is heated at a constant pressure.
33. A label on a can of spray paint says that the can should be kept at room temperature or below. Does the warning apply only to a full can or does it apply even if the can is empty? Explain why the label applies to the condition that you stated in your answer.

Thinking Critically

34. One of the characteristics of a liquid is that it takes the shape of its container. However, the illustration below shows sand, a solid, taking the shape of its container.
    (a) Does that mean that sand is a liquid?
    (b) Explain why or why not in terms of the particle theory of matter.



35. Deep-sea exploration vehicles must be built with very thick steel.
    (a) Why?
    (b) What would happen if the structure of the deep-sea vehicle were not strong enough?
36. Aerosol spray cans often have a warning on their label to avoid heating them. Explain, in terms of pressure, what would happen if an aerosol spray can was heated.
37. You wish to open a motorcycle service centre and you need a hoist in the centre to raise the motorcycles to make them easier to work on. Would a pneumatic or hydraulic system be more appropriate to use in the design of the hoist? Explain your choice.

38. Your eye is a bit like a beach ball in the sense that it would have no shape without internal pressure. The internal pressure is due to fluid that is created in the eye, and which slowly and naturally drains and is refilled. What would happen if:
(a) the drainage for the eye was blocked?
(b) production of the internal fluid was interrupted?

39. Discuss what would happen to the human circulatory system if it had no valves.

40. Muscles in your chest can cause your lungs to expand. If you close your mouth and hold your nose and try to expand your lungs, it is very difficult. Explain why this is true.

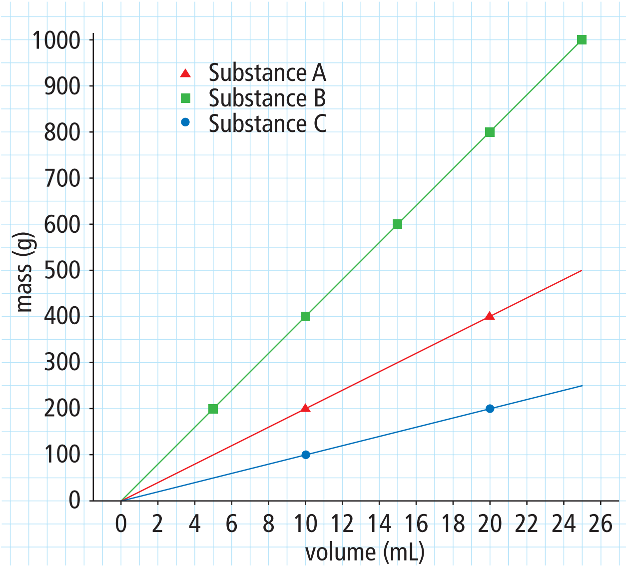
41. How are the tires on a car similar to lifting airbags that are used to lift heavy objects in rescues?

Developing Skills

42. A student samples an unknown material and finds that 1200 mL of the material has a mass of 1080 g.
(a) What is the density of the material?
(b) Would this material sink or float in water?

43. An unknown material with a volume of 460 cm^3 has a mass of 3620 g. With the help of the Table 8.1 on page 312, determine what the unknown substance is.

44. Examine the mass versus volume graph.
(a) Rank the substances from least to greatest density.
(b) Draw a labelled diagram that shows how the substances would layer in a beaker if they were all liquids.



45. The area of an elephant's four feet is about 1.17 m^2. If an elephant weighs 140 000 N, what pressure is the elephant exerting on the ground where it is standing?

46. A television stand that weighs 350 N has a flat base that measures 0.75 m by 0.50 m. If a television with a weight of 800 N is placed on the stand, how much pressure does the stand exert on the floor?

47. Design an experiment in which you could determine the relationship between the temperature and volume of a gas. Include the materials and apparatus that you would need. Include safety precautions. Explain how you would ensure that the proper variable remains constant. Explain what type of measurements you would take.

48. Make a graph of pressure versus volume of a gas using the data in the table below. Put volume on the vertical axis (*y*-axis) and pressure on the horizontal axis (*x*-axis). Label the axes and include units. Give your graph a title. Explain the meaning of the graph.

Pressure (kPa)	Volume (mL)
100	96
200	48
300	32
400	24
500	19
600	16

Pause and Reflect

Imagine a large hollow steel ball that has a small amount of water in it. Now imagine that the ball is slowly and steadily heated. Discuss what you would expect to happen to the water and the ball in terms of the particle model of matter, force, and pressure.