UNIT

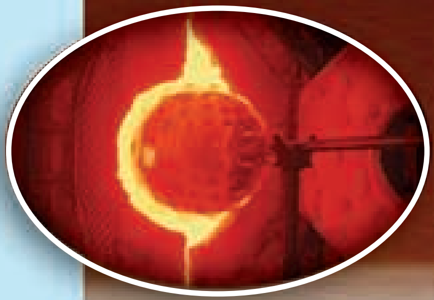
3 Fluids

Pure oxygen in liquid form.

Key Ideas

7 **Viscosity describes a fluid's resistance to flow.**

7.1 Describing Fluids
7.2 Viscosity and Flow Rate
7.3 Factors Affecting Viscosity



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

8.1 Defining Density
8.2 Determining Density
8.3 Changes in Density

9 **Forces influence the motion and properties of fluids.**

9.1 Forces and Buoyancy
9.2 Pressure, Hydraulics, and Pneumatics
9.3 Relationships among Pressure, Volume, and Temperature of Gases

Getting Started

Sitting in your kayak, an amazing scene takes place before you. A humpback whale breaches the surface of the water as he comes up for air. He seems to float effortlessly into the air and plunge back into the sea. In the silence that follows, you gaze at a towering iceberg in the distance. It feels as if you could not be more different than this giant of the sea, and the frozen giant of ice that floats off the shores of Newfoundland and Labrador. But perhaps you have more things in common with both the whale and iceberg than you might think.

You float on top of the ocean's surface in a kayak. The iceberg and whale also float within the ocean as they move. As the iceberg melts, it releases water vapour into the air – the same air that you and the whale breathe into your bodies. All of this, taking place in a giant ocean of liquid water. Liquids, such as water, and gases, such as oxygen, are both fluids. Fluids exist all around us, and many organisms move through the air, while thousands of species live in water environments. Humans have designed many different crafts and vessels to travel through these two environments, from kayaks to speedboats, and from hot air balloons to supersonic jets. Explore this unit to find out more about fluids – their viscosity, density, buoyancy, and pressure—and how we, and other organisms, make use of these properties.

Fluid or Non-fluid

Find Out ACTIVITY

How does a fluid differ from a non-fluid?

Safety

Materials

- Large sheet of paper for class chart
- Newspapers and magazines
- Scissors
- Masking tape

What to Do

1. Your teacher will make and display a large class chart with the headings: "Fluids" and "Non-fluids."
2. In your group, select and cut out three to five newspaper or magazine pictures that represent substances that are fluids. **Caution! Be careful when using sharp objects such as scissors.**
3. Cut out the same number of pictures that represent substances that are non-fluids.
4. Each group will take turns taping their pictures under the appropriate heading on the wall chart.

What Did You Find Out?

1. Look at the pictures that students have classified as fluids and as non-fluids. Do you agree with the classifications? Why or why not?
2. Compare and contrast a fluid and a non-fluid.

Extension

3. What is a simple test you could do to determine whether a substance is a fluid or a non-fluid?

Chapter 7

Viscosity describes a fluid's resistance to flow.

Glass is a marvellous substance. When it is cool and in solid form, it is rigid, clear, and breakable. But when it is heated to about 1000°C, glass becomes molten and flows—it becomes a fluid. When it is a fluid, artists can shape it to create beautiful works of art.

In this chapter, you will investigate fluids and learn how and why they flow and why solids do not. You will also learn what happens when energy is added or taken away from fluids.

What You Will Learn

In this chapter, you will
- **describe** how particles behave in solids, liquids, and gases
- **explain** how substances change states of matter
- **identify** factors that affect a fluid's flow rate
- **explain** why viscosity is useful

Why It Is Important

Exploring what affects a fluid's ability to flow is not only important in our own lives, but in the industries and business in our community. In understanding how energy can affect matter, we can learn how certain materials can be used.

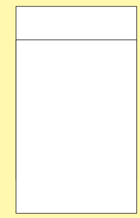
Skills You Will Use

In this chapter, you will
- **compare** and **contrast** fluids and non-fluids
- **measure** the flow rate of various liquids
- **assemble** apparatus according to a diagram
- **design** your own experiments

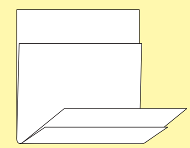
FOLDABLES™
Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 7.

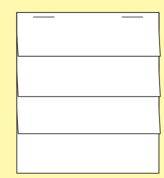
STEP 1 **Collect** 2 sheets of legal size paper and layer them about 2.5 cm apart vertically. Keep the edges level.



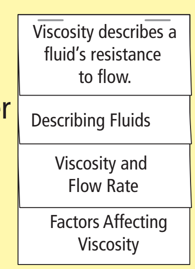
STEP 2 **Fold** up the bottom edges of the paper to form 4 tabs.



STEP 3 **Fold** the papers and crease well to hold the tabs in place. **Staple** along the fold.



STEP 4 **Label** the tabs as shown. (Note: the first tab will be larger than shown here.)



Show You Know As you read the chapter, take notes under the appropriate tab to *describe* the three states of matter and changes of state, *illustrate* how to determine a fluid's flow rate, and *explain* how temperature affects the viscosity of liquids and gases.

7.1 Describing Fluids

According to the particle theory of matter, all matter is made up of very small particles that are constantly moving. The more energy the particles have, the faster they can move and the farther apart they can get. Matter expands when its temperature is raised and contracts when its temperature is lowered. If enough energy is added to or removed from matter, the matter changes from one state to another.

Key Terms

boiling
boiling point
change of state
condensation
deposition
evaporation
fluid
freezing point
gas
liquid
melting
melting point
particle theory of matter
solid
solidification
sublimation

Go With the Flow

Chances are you have seen many types of flowing fluids. Water flowing out of a fountain, juice being poured into a glass, and maple syrup being squeezed from a bottle are all examples of flowing fluids. A **fluid** is defined as anything that flows. Although you usually cannot see them, gases also flow. To demonstrate that gases flow, imagine blowing up a balloon. As you inflate the balloon, air from your lungs flows into the balloon. If you let the balloon go, that same air travels out of the balloon and into the room. Since gases and liquids both flow, they are classified as fluids.

But what about other substances which seem to flow? You pour sugar into a bowl, so is sugar considered a fluid? Breakfast cereals seem to flow when you pour them out of the box into a bowl, so are cereals fluids? To answer these questions, we first must review the states of matter and the particle theory.

Figure 7.1 Just because a substance can be poured, does it mean it is a fluid?

7-1A Magic Mud

Find Out ACTIVITY

How thick is too thick? Can a liquid become so thick that it can no longer flow?

Safety

Materials

- lab coat
- 75 mL cornstarch
- 45 mL water
- food colouring
- mug
- sturdy spoon

What to Do

1. Spoon the cornstarch into the mug.
2. Add the water and stir. When the water and the cornstarch are completely mixed, the mud mixture should be difficult to stir.
3. Mix in a few drops of food colouring and stir. (If the mixture becomes runny, add a little more cornstarch.)
4. Squeeze some of the Magic Mud between your fingers. Describe what happens when you stop squeezing? Try rolling the Magic Mud into a ball. What happens to the shape?
5. Wash your hands thoroughly after cleaning up this lab.

What Did You Find Out?

1. Is Magic Mud a liquid or a solid? Decide how to classify it, and record your answer in your notebook. What makes it more like one than the other?

States of Matter and the Particle Theory

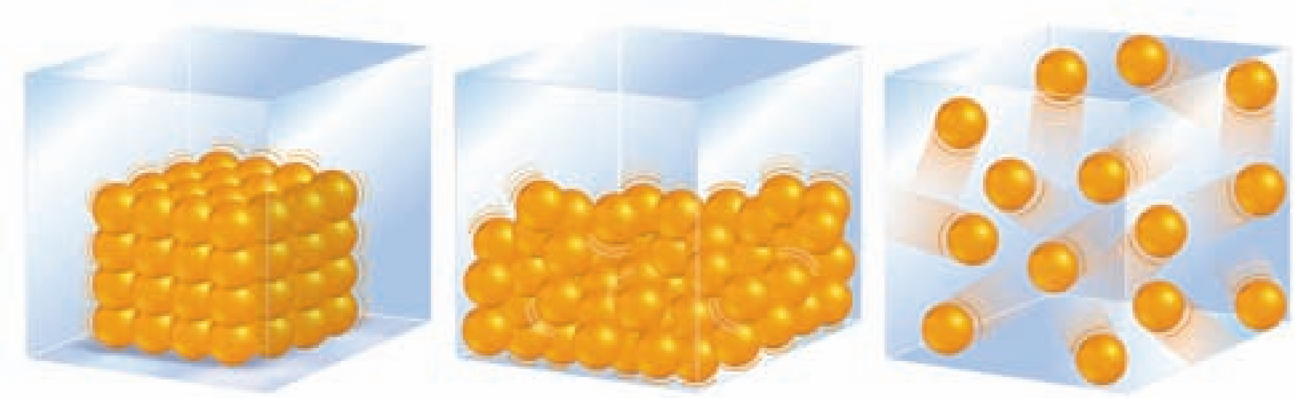
Oxygen, glass, and water are all examples of matter. There are three different states of matter: solid, liquid, and gas. As you have learned,

- **Solid** is the state of matter that has a definite shape and volume (for example, a bowling ball, a piece of paper, or a cell phone).
- **Liquid** is the state of matter that has a definite volume, but its shape is determined by its surroundings (for example, water in a beaker, coffee in a cup, or juice in a pitcher).
- **Gas** is the state of matter that has its volume and shape determined by its surroundings (for example, helium in a balloon, air in bicycle tires, or oxygen in a tank).

All matter is made of particles. The five major points of the **particle theory of matter** are:

1. All matter is made up of very small particles.
2. All particles in a pure substance are the same. Different substances are made of different particles.
3. There is space between the particles.
4. The particles are always moving. As the particles gain energy, they move faster.
5. The particles in a substance are attracted to one another. The strength of the attractive force depends on the type of particle.

Although all particles follow this theory, the way the particles behave in each of the three states of matter is very different. Look at Figure 7.2 and examine how the particles are different for each example of matter.



Solid

Figure 7.2A The particles in a solid are packed together tightly. This means that solids will hold a definite shape. Even though a solid does not appear to move, the particles are constantly vibrating in place.

Liquid

Figure 7.2B The particles in a liquid are in contact with each other, but they can slip and slide past one another, changing their position. This slipping and sliding means liquids take the shape of their container.

Gas

Figure 7.2C Gas particles have very large spaces between them. In fact, gases are mostly empty space. Gases are quite different from liquids and solids because the particles in a gas can move freely in all directions. This is why gases always spread out or diffuse in their container.

7-1B Can Solids Flow, Too?

Find Out ACTIVITY

Sand and sugar are both solids. They can be poured, but can they flow like a fluid such as water? Pour one of them and find out.

What You Need

sand or sugar (about 250 mL)
water
2 large plates

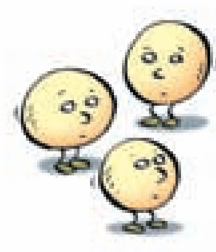
What to Do

1. Place two large plates on a level surface. While holding your hands steady, slowly pour sand or sugar onto one of the plates. Draw the results in your notebook.
2. Again, hold your hand steady as you slowly pour 250 mL of water onto the second plate. Draw the results again.
3. Wipe up any spills and wash your hands after this activity.

What Did You Find Out?

1. Describe any differences in the behaviour or the appearance of the substances when you poured them.
2. What characteristic is necessary in order for a substance to be classified as a fluid?

Particles in Solids



According to the particle theory of matter, you can think of solids being made up of particles that are tightly packed together. Each particle is attracted to the particles on each side by a strong force. While the particles can move with small vibrations, they do not separate from their neighbouring particles.

Many solids can be ground into such small pieces that they can slip past each other when they are poured out of their containers. Sugar, salt, flour, powdered cleansers and detergents, and many other crystals and powders that we use every day are examples of solids that can be poured. When you pour sugar, salt, or an other granulated substance, however, it forms a cone-shaped pile. It does not flow until it forms a flat, even layer, like water. Although each grain of salt or sugar is very small, it is still large compared to the individual particles that make it up. Each grain or fragment is a miniature solid that contains billions of small, tightly packed particles that are strongly attracted to one another.

Particles in Liquids

The particle theory states that particles in a liquid have just enough energy to pull away from one neighbouring particle, only to be attracted to the next particle. Unlike the particles in solids, particles in a liquid do not form rigid clumps. Because the particles can slide past one another, constantly "changing partners," a liquid cannot hold its shape; instead, a liquid takes the shape of the container it has been poured into.

Although they can slide past one another, particles in a liquid do not have enough energy to break away from all other particles. As well, they do not have enough energy to overcome the attractive force of gravity. Gravity pulls particles of a liquid down. Therefore, liquids always flow to the lowest possible level, like the water flowing over a waterfall (see Figure 7.3). Liquids also form a level surface when they are at rest.

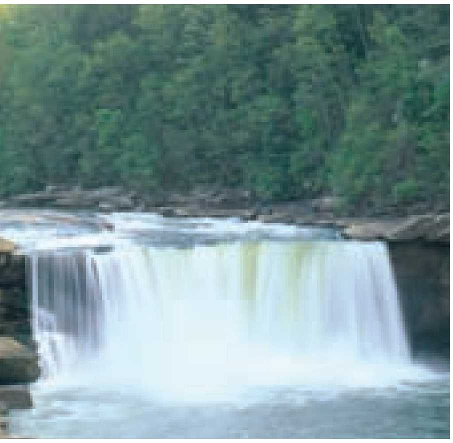
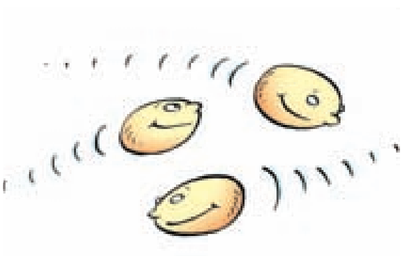


Figure 7.3 Liquid particles, such as the water in this waterfall, always flow to the lowest possible point.



Particles in Gases

According to the particle theory, gas particles are so far apart from each other that there is an enormous amount of empty space between them. This theory explains why most gases seem invisible to you: because you are observing mostly empty space. It also explains why gas particles can easily move past each other, making gases flow with little difficulty.

Gases, like liquids, spread out and take on the shape of the container in which they are sealed. Gas particles are so free to move that they travel in every direction, and they have a great deal of energy to move extremely far apart very quickly. Gas particles have enough energy to collide with other particles and move upward against gravity. Gas particles have so much energy that they continually bounce off other particles and stay suspended in mid-air. For example, if a lid is taken off a container of oxygen in a room, the gas particles will travel out of the container and start to spread apart again, until they have filled the entire room. Gas particles always occupy all the space in which they are contained.

Particles move from an area of high concentration to an area of low concentration of the same substance. For example, if you spray an air freshener, the particles in the freshener vapour begin to move away from the air freshener bottle (where there is a high concentration of air freshener particles) until you can smell it across the room (where there is a low concentration of air freshener particles).

Did You Know?

There has been some question as to the physical state of glass. It has been argued that glass is a very stiff liquid. Glass is now known to be a type of solid called an *amorphous* solid.

Reading Check

1. What is a fluid?
2. What are the five points of the Particle Theory of Matter?
3. Why do solids form a pile when they are poured?
4. Explain why particles in a liquid cannot hold their shape.
5. Why can gas particles sometimes travel against gravity?

Changes of State

Although it may seem like solids, liquids, and gases are very different, there is a close relationship that exists among them. When heat is added or taken away, a substance can undergo a change of state. A **change of state** occurs when the physical state of a substance is transformed into another state. Figure 7.4 shows changes of state. The change from solid to liquid is called **melting**, and the change from liquid to gas is called **evaporation**. These changes of state occur when the substance is heated and the particles of the substance gain energy. If you were to cool the substance, the reverse changes of state would occur because the particles would lose energy. The change from gas to liquid is called **condensation**, and the change from liquid to solid is called **solidification**.

An unusual change of state occurs when a solid turns into a gaseous state without going through a liquid stage. You might recall that this change of state is known as **sublimation**. An example of sublimation is the use of dry ice at a rock concert. A block or chunk of frozen carbon dioxide (a solid) gains energy when exposed to heat and gives off a thick cloud of fog. This "fog" is really condensation of water in the air due to the cold temperature caused by the carbon dioxide. If a gas changes directly to a solid, without going through a liquid state, it is called **deposition**. An example of deposition occurs when frost forms on windows on cold days. Water vapour in the air rapidly loses energy, and forms snowy ice on a window.

Did You Know?

Because the term "deposition" can have several different meanings, some people prefer to use the term "sublimation" for both transformations from a solid to a gas and from a gas to a solid.

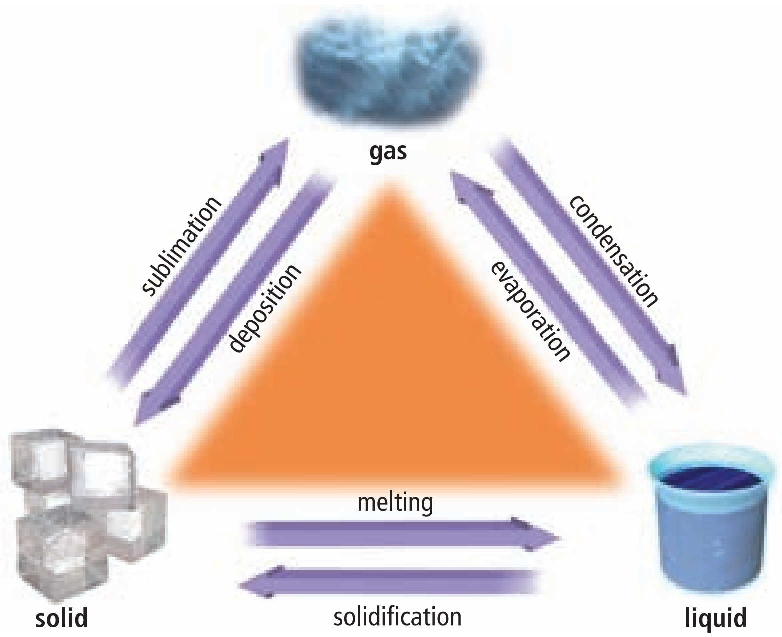


Figure 7.4 Changes of state.

Did You Know?

The white cloudy material that you see coming from a boiling tea kettle is not steam. Steam is a gas and is invisible. The cloudy material is made up of water droplets that condensed when the steam began to cool.

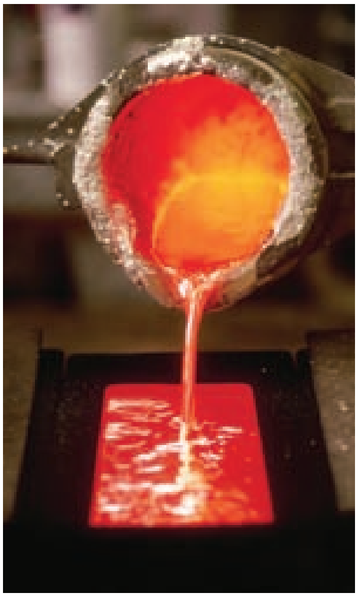


Figure 7.5 Gold melts at 1064°C. Once it is melted, it can be formed into objects such as necklaces or gold coins.

Freezing, Melting, and Boiling Points

Evaporation is slow vaporization. It occurs over a wide range of temperatures. A wet towel will dry even if the air temperature is not high. On a cool day, it will simply take longer for the water to evaporate from the towel.

Boiling is rapid vaporization. It occurs at a specific temperature, called the **boiling point**. The boiling point of water is 100°C (at sea level). Similarly, every substance has its own **melting point** and **freezing point**. The melting point is the temperature at which a substance changes state from a solid to a liquid. The freezing point is the temperature at which a substance changes state from a liquid to a solid. For example, the freezing point of water is 0°C (at sea level). It is also at this temperature that ice melts—its melting point.

Knowing the melting point of a substance can be very useful. When solid substances are melted, the liquid can be poured into moulds of various shapes. When the liquid cools, it changes back into a solid, but keeps the shape of the mould. Figure 7.5 shows melted gold and the products that can be made from it once it solidifies into moulds.

Reading Check

1. What is a change of state?
2. Provide one example of the process of sublimation.
3. When water changes from a liquid to a solid (ice) we often say that it freezes. What is another term for the change of state from a liquid to a solid?
4. What is the difference between evaporation and condensation?
5. Why is it valuable for some industries to know the melting point of certain substances?

Wild, Weird, Wonderful

www Science

Spooky Change of State

Sitting five rows from the front at a rock concert, you watch eagerly as the lights slowly begin to glow on stage. An eerie fog crawls along the stage floor. Through the fog, the band bursts into their first song and the concert begins. Would you have any idea that one aspect of this show had to do with a substance's change of state? The fog was created by dry ice as the solid sublimated into gas.

Dry ice is frozen carbon dioxide. What is interesting about dry ice is that it sublimates directly into a gas instead of melting into a liquid. Because it leaves no liquid residue, it is often used to create the effect of fog for theatres, concerts, theme park haunted houses, and other venues.

Dry ice sublimates directly into carbon dioxide gas, allowing for an eerie fog effect.

Dry ice has many other uses, too. Because its sublimation point is –78.5°C, it can be used to keep objects cool or frozen. For example, medical labs and hospitals use dry ice to transport objects that are sensitive to warm temperatures. They can pack the object in dry ice, send it across the country, and it will still be frozen or cool when it is opened by the receiver.

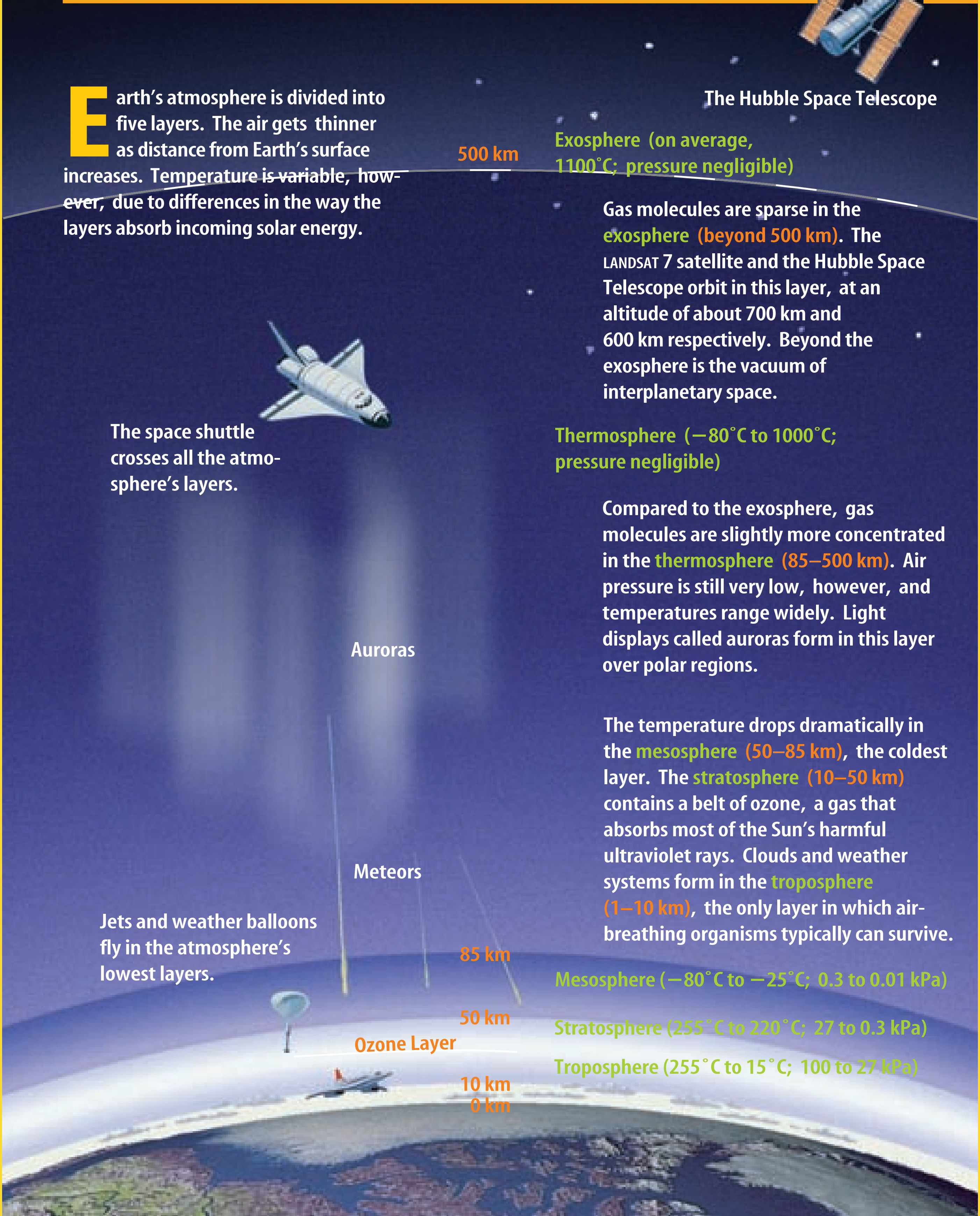
Other industries have made use of the qualities of dry ice. Construction companies may use it if they have to remove floor tiles. When dry ice is placed on the floor tiles, they shrink and crack, making them easier to remove. Another use for dry ice is a cleaning method called dry ice blasting. When industrial equipment becomes dirty with ink, paint, glue, or other substances, dry ice pellets can be blasted at the equipment using a compressed-air nozzle. It is believed that this process is better for the environment than using solvents to clean equipment.

Be Careful Around Dry Ice!

Although we often think of ice as being harmless, dry ice can be dangerous. You must wear gloves if you are handling dry ice because its extremely low temperature can damage your skin. Dry ice must also be used in a well ventilated room. As the ice sublimates into gas, the vapours of carbon dioxide can become concentrated in the air if the room is not ventilated. This can result in carbon dioxide poisoning. Dry ice should only be used by people who know how to handle this substance safely.

VISUALIZING ATMOSPHERIC LAYERS

NATIONAL GEOGRAPHIC



Earth's atmosphere is divided into five layers. The air gets thinner as distance from Earth's surface increases. Temperature is variable, however, due to differences in the way the layers absorb incoming solar energy.

Exosphere (on average, 1100°C; pressure negligible)

Gas molecules are sparse in the exosphere (beyond 500 km). The LANDSAT 7 satellite and the Hubble Space Telescope orbit in this layer, at an altitude of about 700 km and 600 km respectively. Beyond the exosphere is the vacuum of interplanetary space.

Thermosphere (−80°C to 1000°C; pressure negligible)

Compared to the exosphere, gas molecules are slightly more concentrated in the thermosphere (85–500 km). Air pressure is still very low, however, and temperatures range widely. Light displays called auroras form in this layer over polar regions.

The temperature drops dramatically in the mesosphere (50–85 km), the coldest layer. The stratosphere (10–50 km) contains a belt of ozone, a gas that absorbs most of the Sun's harmful ultraviolet rays. Clouds and weather systems form in the troposphere (1–10 km), the only layer in which air-breathing organisms typically can survive.

Mesosphere (−80°C to −25°C; 0.3 to 0.01 kPa)

Stratosphere (255°C to 220°C; 27 to 0.3 kPa)

Troposphere (255°C to 15°C; 100 to 27 kPa)

Check Your Understanding

Checking Concepts

1. When you fill up an ice cube tray and place it in the freezer, the water turns into ice a few hours later. Use the particle theory of matter to explain why the water changes to ice.
2. If you break a solid into a thousand pieces and "pour" it onto a table, it forms a pile instead of a level surface. How does the particle theory of matter help explain why even solids that appear to be pourable, are not considered fluids.
3. At the lowest point in many basements or work areas, there is a drain in case of a flood or spill. How can people be sure that a fluid will go down the drain? Use the particle theory of matter to help explain your answer.
4. Someone at the far end of a hallway sprays some perfume. Two minutes later, the perfume can be smelled throughout the entire hall. Explain how this happens.
5. Explain how the frost that appears on a car window on a cold winter's morning is an example of deposition (also known as sublimation).
6. In order to turn mercury from a liquid into a solid, you must lower its temperature to approximately –39°C. Draw a diagram to represent what happens to the particles of mercury as it turns from liquid to solid.

Understanding Key Ideas

7. Are evaporation and boiling the same thing? Use the particle theory to explain.
8. Draw and label a diagram showing the relationships between changes of state in matter.

Pause and Reflect

How do raindrops form? If clouds contain water vapour and remain suspended in the sky, try to explain what you think happens inside the clouds to form rain.

7.2 Viscosity and Flow Rate

Does your mouth water at the thought of gooey caramel topping or pancakes drizzled with syrup? Some of the most delicious treats are liquids that flow thickly and smoothly. The property of thickness or thinness in a fluid is called viscosity.

Key Terms

flow rate
viscosity

Word Connect

The word *viscous* comes from the Latin word *viscum*, which is a sticky substance taken from mistletoe. In the past, it was spread on twigs to catch birds.

Figure 7.6 Imagine if manufacturers did not worry about the viscosity of their products. Your milkshake might end up being thin and runny instead of the thick and creamy drink you enjoy.

Viscosity

Have you ever wondered why a liquid like molasses takes a long time to flow out of its container, while another liquid such as water flows so quickly? It is because of a property called viscosity. **Viscosity** describes a liquid's "thickness" or "thinness." Liquids like molasses and maple syrup have a high viscosity, while other liquids like water and milk have a low viscosity. But what makes one fluid run faster or slower than another? Even though all fluids flow smoothly, they flow at different rates because they have different viscosities. Another way to define viscosity is resistance to flow. Resistance to flow means that the particles can move around, but it may be difficult for them to pass by each other. As you know, particles in a liquid can move past each other. However, the ease with which they move depends on the type of particle. It is much more difficult for some particles to slide past one another than for other types of particles. You might say that some types of particles hold on to each other more tightly than others.

Why Is Viscosity Important to Us?

Why do you think it might be important to know the viscosity of a liquid? The viscosity of liquids is an important property that must be measured very carefully in some industries. Take a look at how viscosity affects the food we eat and the products we use every day.

Viscosity: A Taste Sensation?

Think about all the foods you eat in a day. You may be surprised to realize how much we depend on the viscosity of certain food products to make them taste good. Your mouth is highly sensitive to viscosity, so food manufacturers ensure that ice-cream toppings, pasta sauces, soups, salad dressings, milkshakes, and other products are just the right consistency (thickness) to suit consumers' tastes.

Food manufacturers also need to know how to regulate the effect of heat on the viscosity of their products. For example, chocolate coating for candy bars must be heated exactly to the right viscosity in order to completely cover the bar with the same amount of chocolate each time. Another product that is affected by heat is maple syrup. Canada's maple syrup industry depends on controlling the viscosity of a liquid. Maple syrup comes from the sap of sugar maple trees. The sap itself is thin, runny, and not sweet to the taste. When the sap is heated, however, a large amount of water evaporates, leaving a thick, sweet syrup that is highly viscous.

Figure 7.7 Heating the sap from sugar maple trees changes its viscosity.

Viscosity in Everyday Products

What would it be like to paint the walls of a room with paint that was too thin and runny? What about if the paint was too thick? Just as in foods, manufacturers of various household and other products need to closely regulate the viscosity of their materials. Everything from dish soap to shampoo to shoe polish need to have just the right viscosity, or they would be messy or impossible to use. Some medicines need to have the proper viscosity as well. For example, manufacturers of cough syrup have to create a medicine that has a high viscosity, yet is still easy to swallow in order to coat and soothe the throat.

Figure 7.8 Why must paint, varnishes and such liquids have just the right viscosity?

Explore More

Viscosity at Work

As a class, brainstorm how a knowledge of fluid viscosity might be useful in each of these occupations: candy maker, baker, beekeeper, mason, painter. Contact someone in your community who works in one of these occupations, and ask if you might job shadow him or her for half a day. (When you job shadow someone, you observe and assist the person at work.) Take notes on what you learn about the role of viscosity in the job. Present an in-class report describing your experience, and write a letter to thank the person you visited.

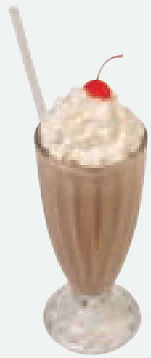
internet connect

The art of glass blowing has been around for over 2000 years. See how artists use the different changes of state in glass to create works of art. Go to **www.discoveringscience8.ca.**

7-2A The Value of Viscosity

Find Out ACTIVITY

Have you ever bought a product such as a milkshake and wished it were thicker? Did you ever buy a product such as Liquid Paper® that, over time, became too thick to be useful? Can the viscosity of a product make it more valuable to you? Would you pay more for just the right viscosity in a product?



What to Do

1. With a group of classmates, choose one product from the following list:
   - hair conditioner
   - shampoo
   - water-based paint
   - yogurt
   - salad dressing
   - nail polish
   - ice-cream topping
   - hand lotion
   - liquid detergent
   - ketchup
   - liquid bubble bath

   Then obtain three or four different brands of this product, making sure that the viscosities are obviously different (for example, runny salad dressings versus thick salad dressings).
2. Make a table for the different brands of your product. Write the following headings:

Name Brand of Product	Cost ($)	Volume (mL)	Cost per Volume (¢/mL)	Relative Viscosity (high, medium, low)

3. Give your table a suitable title. Complete the table, filling in the information for each product that you examine. Wash your hands after this activity.

What Did You Find Out?

1. Is there a relationship between cost per volume and viscosity? If so, describe it. How is viscosity related to the product's usefulness?
2. As a class, list three products that are more useful because their viscosity is high, and three products that are more useful because their viscosity is low.

Did You Know?

People in many occupations need to know how to adjust the viscosities of the products they work with. Chefs need to know how to make sauces and frostings either thinner or thicker; mechanics must choose an engine oil that has the right viscosity for the season; artists need to know how to thin or thicken oil paints or acrylics. In your notebook, list three other careers where people need to know how to adjust the viscosity of products.

Reading Check

1. What is viscosity?
2. How does the ability of a substance's particles to slip past each other relate to a fluid's resistance to flow?
3. Why is viscosity important to many industries?
4. Name three careers where knowing viscosity is a part of the job.

Flow Rate

As you have read, some liquids flow faster than others. Water flows freely from a pitcher, but how would you describe the flow of honey from a jar? Look at the fluids shown in Figure 7.9. Predict which fluid will flow to the end of the pan first. Then predict in which order the other fluids will flow to the end of the pan.

Figure 7.9 Which fluid will reach the end of the pan first?

When we want to determine how fast something is moving, we often measure the time it takes to get from one place (point A) to another (point B). To determine how fast a fluid "runs," we can measure it in a similar way. By measuring the time it takes a fluid to flow from one point to another (its distance), we can determine its **flow rate**.

You might think of cars travelling along a road as a model for the motion of particles in a fluid. What types of things affect the rate at which cars travel? Road construction might allow only one lane of traffic. Cars must slow down and make one row instead of two rows travelling down a highway. Also, a muddy road will slow a car down because the mud is sticky and it pulls on the tires. Steep hills and sharp curves cause cars to slow down. What property of fluids might cause a liquid to slow down?

Suggested Activity

Conduct an Investigation 7-2B on page 282.

Reading Check

1. What is meant by the flow rate of a substance?
2. What is the relationship between the viscosity of a liquid and its flow rate?
3. How can you test the viscosity of a liquid?
4. List two substances that have a low viscosity and two substances that have a high viscosity.

The Flow Rate of Liquids

Core Lab

SkillCheck

- Observing
- Recording data
- Calculating data
- Graphing data

Materials

- ramp made of smooth plastic or glass (minimum 0.5 m × 0.3 m)
- stack of books (0.25 m – 0.3 m high)
- thermometer
- measuring spoon (15 mL), with rounded bottom
- stopwatch or watch with second hand
- rubber gloves
- waterproof marker or wax pencil
- tape
- paper towels
- soap for cleaning ramp surface
- water
- 15 mL of any two of the following liquids (at room temperature):
    - cooking oil
    - molasses
    - corn syrup
    - honey
    - liquid detergent
    - apple juice or vinegar

Viscosity is a difficult property to measure directly. The flow rate of a liquid, however, is a good indicator of viscosity. You can determine how fast a fluid flows by measuring the amount of time it takes for a certain amount of the fluid to flow past a specific point.

Question

How can you compare the flow rates of various liquids?

Safety

- Keep your hands away from your face and mouth. Do not eat or drink any substances in the science laboratory.
- Wipe any spills immediately. Do not leave floors wet.
- Dispose of materials properly, according to your teacher's instructions.

Procedure

1. Draw a line across the width of the ramp, approximately 10 cm from the top. Draw a dot in the centre of the line and just above it. When you place the measuring spoon on the dot and rock the spoon forward, the lip of the spoon will touch the top line. This is the start mark.

2. Draw a finish line 10 cm below the top line. Then assemble the apparatus as shown here.
   (a) Measure the temperature of the room and record it in your notebook.
   (b) Make a data table that looks like the following:

Liquid	Time (s)	Flow Rate (cm/s)	Ranked Flow Rate	Ranked Viscosity
Water				
Substance 2				
Substance 3				

   (c) With your group members, hypothesize which of the three liquids will flow fastest.

3. Test one liquid at a time, starting with water. The "spoon student" will pour enough water into the clean, dry measuring spoon so that it is level, then place the spoon at the start mark on the ramp.

(a) another group member, the timer, will work the stopwatch
(b) A third group member, the marshall, will say "go" and will call "stop" when the liquid reaches the finish line.

4. When the marshall says "go," the spoon student rocks the spoon quickly but gently to pour its contents down the ramp. At the same time, the timer starts timing.
5. When the marshall says "stop," the timer stops timing and records the time in the data table. Students clean and dry the ramp and measuring spoon to get ready for the next liquid.

6. Repeat steps 3 to 5 for the other two liquids. (Do this at least twice for each liquid.)
   (a) Wash your hands after this investigation.
   (b) Keep the flow rate ramp assembled so you can complete Activity 7-3A on page 287.

Analyze

1. Determine the flow rate (in cm/s) for each substance. Do this by dividing the distance travelled (10 cm) by the time recorded for each substance (in seconds). Record each result in your data table.
2. Rank the liquids from fastest flow rate (1) to slowest flow rate (3). Record these rankings in the fourth column of your data table ("Ranked Flow Rate"). Was your hypothesis correct?
3. Rank the viscosities in the table from lowest (1) to highest (3). Record these values in your data table under "Ranked Viscosity."
4. Describe two sources of error that might affect your results. Are these errors due to the equipment or to human factors? How could you reduce or eliminate these errors?

Conclude and Apply

5. Collect and record the class data. Determine the median flow rate of all the liquids. Compare the median value with the mean (average) value.
6. How is the flow rate of a liquid related to its viscosity?
7. Which liquids were more difficult to measure with the viscosity ramp? What could you have done to the ramp to make it easier to measure these liquids?
8. Make a bar graph showing flow rate (in cm/s) along the vertical axis (y-axis), and the various liquids along the horizontal axis (x-axis). Plot the data for each liquid on this graph, using a different colour for each liquid. Include a legend on your graph.

Wild, Weird, Wonderful

www Science

Superfluids

Can you imagine a liquid with no viscosity at all? Imagine diving into a swimming pool filled with a zero viscosity fluid—you would go straight through to the bottom with no resistance at all. Ouch!

A superfluid offers no resistance to flow.

Superfluids have some amazing properties:

- Superfluids have no viscosity—this means they can flow at a high rate though the narrowest of tubes. They can flow through microscopic pores that other liquids could never get through.
- Superfluids cannot be moved by friction—have you ever spun a cup full of juice? After a few spins, the juice begins to move in a circular fashion inside the cup. If the cup were filled with superfluid, you could spin the cup for as long and as fast as you want, and the superfluid would never move.
- Superfluids have no resistance to flow—this means if you put a superfluid into a loop-shaped tube and started it flowing, it would never stop. As long as it remained a superfluid, it would flow in the loop forever.

You will not encounter superfluids in everyday life. Superfluids have only been observed in substances such as helium and hydrogen that have cooled to extremely low temperatures, near absolute zero (–273.15°C). Unfortunately, there are not yet many practical uses for superfluids, but scientists hope to learn more about the nature of matter by studying superfluids.

This device is a cryostat. A cryostat contains superfluid helium and is used to keep sensitive detectors at a stable low temperature.

Vitaly L. Ginzburg (left) received the Nobel Prize in Physics in 2003 for his contributions to the theory of superfluids.

Check Your Understanding

Checking Concepts

1. Two different house paint companies each have a 3.8 L can of white paint in their weekly flyer. Company A is selling their can of paint for $34.99. Company B is selling their can of white paint for $45.99. Using your knowledge about viscosity, what possible explanations could there be for the difference in price?
2. A group of students is testing the flow rate of vegetable oil. Each time they retest, the group gets a different flow rate. Suggest explanations why this group is getting inconsistent data.
3. Imagine that you were sent into a grocery store and told to group all the liquids according to viscosity. Explain how you would classify the liquids. List three items that you would place in each of the categories.
4. Many products, such as paint, nail polish, and glue, can only work effectively when they have a certain viscosity. What do manufacturers do to the products' containers to help prevent any changes in viscosity? What are three things you can do once you have opened a product to keep its viscosity the same over time?

Understanding Key Ideas

5. Explain how to determine the flow rate of a liquid.
6. Design a simple test that someone (for example, a chef, or a mechanic) could use to provide an estimate of the viscosity of a substance, without testing the flow rate. Prepare a step-by-step procedure to explain how this test might be done and how the viscosity of a substance can be estimated as high, medium, or low.
7. A student performs a flow rate experiment on an inclined ramp with three mystery substances and obtains the following results:

Substance	Length of Ramp (cm)	Time to Reach End of Ramp (s)
A	20	2
B	20	10
C	20	5

(a) Calculate the flow rate of each of the substances in cm/s.
(b) Rank the substances from highest to lowest viscosity.

Pause and Reflect

Imagine that you have been asked to create a milkshake for a well-known ice-cream store. How would you design a straw to match the viscosity of your new milkshake? What factors would you take into account? Draw your straw and explain your design in your notebook.

7.3 Factors Affecting Viscosity

Although all fluids can flow, viscosity plays a much bigger role in liquids than in gases because of the distance between the particles. Gases have much more space between particles, so the interaction between particles cannot cause much resistance to flow. The particles in liquids, however, are close together. The size and shape of liquid particles and the attraction between particles contribute to friction. Friction slows the rate at which the liquid can flow. What happens to viscosity and flow rate when a fluid is cooled? The answer depends on whether the fluid is a liquid or a gas.

Key Terms

concentration
kinetic energy

Word Connect

The word "kinetic" comes from the Greek word *kinetikos*, meaning moving, or putting into motion. The same Greek word is the basis of the word "cinema," meaning moving picture.

internet connect

Motor oils can be purchased in different viscosities. Find out what the viscosity label ratings on motor oil mean. Start your search at **www.discoveringscience8.ca.**

According to the particle theory of matter, all particles are constantly moving. You probably recall, from previous science courses, that the energy of motion is called **kinetic energy**. Any object or particle that is moving has kinetic energy. You might also recall that the average kinetic energy of the particles in an object is related to the temperature of the object. As the average kinetic energy of the particles increases, the temperature increases. If you want to increase the temperature, or average kinetic energy, of the particles of an object, you add heat to the object. Similarly, removing heat from an object reduces its temperature and slows the particles. As a result, the average kinetic energy of the particles decreases. In summary, the speed of the particles in an object, the average kinetic energy of the particles, and the temperature of an object are all related to one another.

Temperature and the Viscosity of Liquids

On a very cold winter morning in Newfoundland and Labrador, it can be hard to start your car. One of the problems is that the oil that lubricates the engine can become very stiff and resistant to flow under cold conditions. When the oil is resistant to flow, it is difficult for the parts of the motor to move. When fluids are used in mechanical devices, it is important that they flow properly.

According to the particle theory of matter, temperature has an effect on the particles that make up a substance. As heat is added to a liquid and the

Figure 7.10 Temperature can affect how easily motor oil pours and how it lubricates engine parts.

temperature increases, the particles have more energy and can therefore pull away from neighbouring particles and slide past them more easily. This increases the liquid's ability to flow, so we can state that its viscosity is lower.

Opposite to this, if heat is taken away from a liquid, the particles lose energy and move slower. Because they have less energy, it is harder for the particles to pull away from other nearby particles. The liquid loses some of its ability to flow and its viscosity becomes higher. In general, a liquid's viscosity *decreases as the fluid is heated and increases as the fluid is cooled.*

Suggested Activity

Think About It Activity 7-3B on page 291

Temperature and the Viscosity of Gases

The effect of temperature on gas particles is opposite to the effect on liquids. Why? The reason is that gas particles do not depend on an increase in energy (a rise in temperature) to move farther apart, as is the case for liquids. The particle theory states that the particles in gases are already very far apart. When energy is added, gas particles speed up and collide with each other more often, causing an increase in internal friction, and therefore an increase in viscosity. Cooler temperatures in gases keep the internal friction of particles (and the viscosity) low.

Suggested Activity

Find Out Activity 7-3D on page 294

7-3A Cool It!

Find Out ACTIVITY

Go back to Conduct an Investigation 7-2B on page 282. Make a hypothesis stating the effect that temperature has on the flow rate of a liquid. Cool the liquids to exactly the same low temperature and repeat the flow rate procedure.

What Did You Find Out?

1. What differences in flow rate did you observe?
2. How can the particle theory be used to predict the effect of temperature on a liquid's flow rate?

Extensions

3. It might be easier to measure flow rate of low-viscosity liquids by dripping them from a spout instead of pouring them down a ramp. Design a "viscosity meter" for these liquids, and explain how you could measure flow rate using your new apparatus.
4. It is common practice for scientists to repeat an experiment two or three times to reduce the effect of any errors during the procedure. Each repetition is called a trial. The average of three or four trials is reported as the final result. Repeat this activity twice so that you have three trials for each liquid. Report the flow rate as the average flow rate for each liquid.

Concentration and Viscosity

You have learned how an increase or decrease in temperature affects the viscosity of a substance, but what other factors can affect viscosity? One such factor is the concentration of a substance. **Concentration** is the amount of a substance dissolved in a specific volume.

Chefs control the viscosity of the foods they make by altering the concentrations of the ingredients. For example, if a chef is making gravy, he or she may thicken the gravy by adding cornstarch. By increasing the concentration of cornstarch, the chef is also increasing the viscosity of the gravy. Generally, by increasing the concentration of a substance, the viscosity is also increased.

Figure 7.11 If you were making pancakes and the batter was too thick, what could you add to help decrease the concentration of the batter and lower the viscosity?

Attractive Force and Viscosity

One of the five points in the particle theory of matter is that all particles of the same substance exert an attractive force on one another. The strength of the attraction can be very strong for some substances but weak for other substances. If the attractive forces between the particles of a liquid are strong, it is difficult for the particles to pull away from each other and slide past each other. As a result, the liquid flows slowly, and therefore has a high viscosity. If the attractive forces among the particles of a liquid are weak, the particles pull apart and slide past each other easily. The liquid flows easily, and therefore the viscosity is low. Attractive forces among particles of a substance have a major effect on the viscosity of the substance.

Did You Know?

Helium is one of the strangest substances in the universe. Although helium is commonly used in its gaseous state, it has unusual properties as a liquid. At a few degrees above –270°C, helium changes from a "normal" fluid to what is known as a superfluid.

Suggested Activity

Investigation 7-3E on page 295.

Did You Know?

You probably know that pancake syrup and ketchup both pour slowly—they are relatively viscous fluids. They both have a lot of sugar dissolved into them. Adding particles such as sugar to a fluid can often (but not always) increase viscosity.

Particle Size and Viscosity

If the attractive forces between the particles of two different substances are similar, then the size of the particles in a liquid plays a role in determining the substance's ability to flow.

Small and Fast

Imagine that the basketball team had a large storage bin full of basketballs. If you put a lot of marbles on top of the basketballs, they would all roll down through the basketballs with ease. They would very quickly reach the bottom of the bin. These small objects can move between and around the basketballs effortlessly. Now if you think of this in terms of particles, small particles can move past each other more easily than large particles can, as they take up less space and have more room to move. Fluids that are made of small particles can therefore flow faster (have a lower viscosity) because their particles are able to move more easily and quickly.

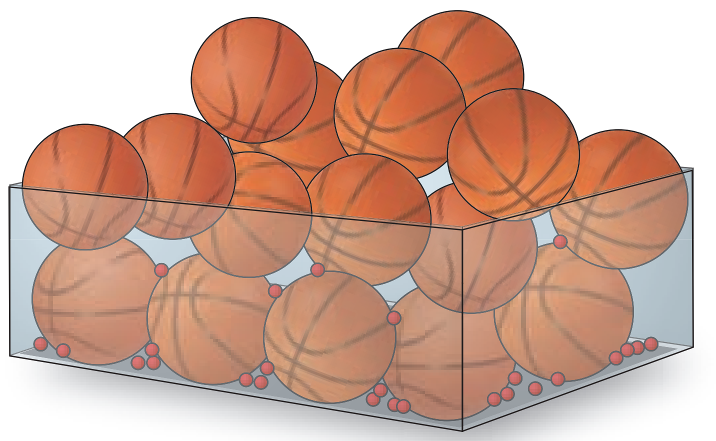


Figure 7.12 Small objects like marbles roll easily between basketballs and reach the bottom of the bin quickly. Similarly, if a fluid is made of small particles, it can flow faster and more easily than a fluid with large particles.

Big and Slow

Now imagine that same bin of basketballs. Suppose you put a large number of tennis balls on top of the basketballs. The tennis balls could possibly fit between the basketballs but only one at a time. As well, some would probably get stuck between some basketballs. It would probably take a long time for all of the tennis balls to reach the bottom of the bin. In fact, some might get stuck and never make it to the bottom. Now if you think of certain fluids this way, some particles in certain fluids are bigger than others. This means that the fluid they make up flows much slower (has a higher viscosity). For example, oil particles are larger than water particles, so oil flows more slowly than water. So, we can say that oil is more viscous than water.

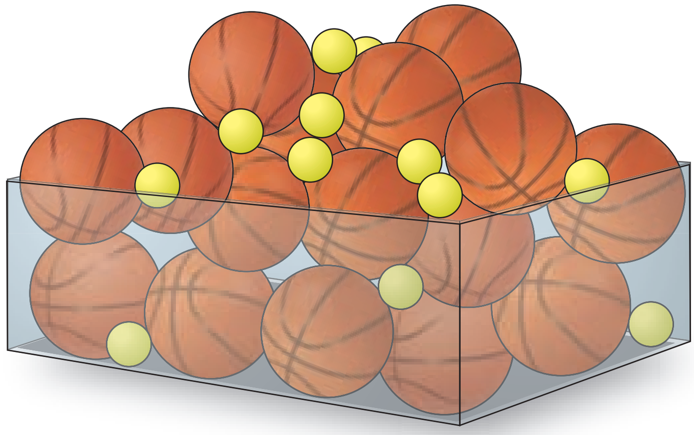


Figure 7.13 Tennis balls can only get between the basketballs one at a time. They sometimes get stuck between the basketballs. In fluids, larger particles flow past each other more slowly than smaller ones.

The shape of particles also affects their ability to slide past one another. Imagine rolling golf balls down a ramp, and then imagine rolling short pieces of rope down the same ramp. The pieces of rope will get tangled up with each other and have difficulty sliding around each other. The golf balls will reach the bottom of the ramp long before the pieces of rope. Both the size and shape of particles affect the viscosity of a liquid.

Reading Check

1. What is kinetic energy?
2. What is a common way of increasing kinetic energy of particles? Of decreasing kinetic energy of particles?
3. List three factors that can affect viscosity.
4. How does an increase in temperature (energy) affect the viscosity of a gas?
5. Provide one example of how the increased concentration of a substance in a liquid can change its viscosity.

Flowing Fluid Floods City

Have you heard the expression "as slow as cold molasses"? In this activity, you will discover that water is not the only fluid that can flood a city.

What to Do

Read the following true story and then answer the questions.

What Did You Find Out?

1. Gather some clues from the story:
   (a) What was the date?
   (b) What was unusual about the weather?
   (c) What was the first clue that something disastrous was about to happen?
   (d) How fast did the molasses pour out of the tank?
   (e) Who was accused of being responsible for the accident?
2. As molasses ferments, it releases gases inside the tank. How might the unusually warm weather that day have helped to contribute stress to the poorly constructed tank?
3. Energy is responsible for making things move. Use the particle theory of matter to explain how something as viscous as molasses could move as quickly as it did on that particular day, at that particular moment.

January 15, 1919, was an unusually warm day. The fine weather lured the citizens of Boston, Massachusetts, outside to enjoy the spring-like temperatures. It hardly seemed like the setting for a disaster.

As Boston was a busy shipping port, the North End had many industries and workers. The workers in Boston's industrial North End were enjoying lunch and the pleasant weather. Suddenly, they heard a low rumbling and then an explosive crack. A 30-m wide cast-iron tank, standing 15 m above street level on the property of the United States Industrial Alcohol Company, burst apart! Like lava spilling from a volcano, crude molasses flowed into the street. The result was a "flash flood" consisting of 10 million litres of sweet, sticky – and deadly – goo.

The "wall of molasses"—some witnesses say was as high as 5 m—poured through the streets at a speed of almost 60 km/h. It demolished buildings, ripping them off their foundations. It flipped vehicles over and buried horses. People tried to outrun the gooey tidal wave, but they were overtaken and either hurled against solid objects, or drowned where they fell. Within minutes, 21 people were killed and more than 150 were injured.

The clean-up took weeks. Molasses could be found in homes, businesses, automobiles, and theatres. Lawsuits were filed against the United States Industrial Alcohol Company, charging it with negligence. After six years, the court made a final ruling against the Company. The court's findings showed that the tank had been overfilled and that it was not properly reinforced. The United States Industrial Alcohol Company had to pay $600 000 in damages (which is equal to over $6 million today).

7-3C Viscosity Plunge

SkillCheck

- Measuring
- Classifying
- Graphing
- Evaluating information

Safety

- Be careful not to touch the hot plate.
- Do not drop the marbles. Release them gently at the top of the liquid.
- Do not touch the heated corn syrup. It will be very hot.

Materials

- 250 mL beaker
- lab stand
- thermometer clamp
- thermometer
- stirring rod
- stopwatch
- ruler
- tongs
- hot plate
- 15–20 small (6–7 mm) metal marbles
- corn syrup

Question

How does temperature affect viscosity?

Hypothesis

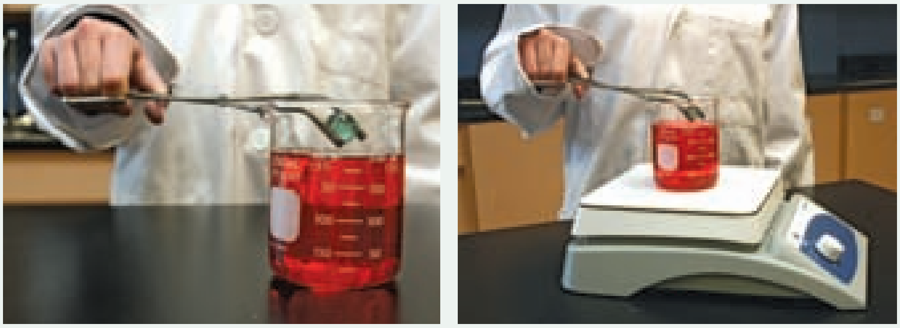
Write a hypothesis about the effect of temperature on viscosity.

Procedure

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

Temperature (°C)	Depth of Corn Syrup (cm)	Time (s)	Rate of Fall (cm/s)

2. Fill a beaker to the 200 mL mark with corn syrup. Place the beaker on the hot plate. Clamp a thermometer to the lab stand and lower the thermometer into the corn syrup.
3. Measure the depth of the corn syrup in the beaker using the ruler. Record the depth in your data table.
4. Note the temperature indicated on the thermometer. Record the temperature in your data table.
5. With the tongs, hold a metal marble at the top of the corn syrup. Before proceeding with the next step, be aware that hot corn syrup will burn if it is splashed on your skin. At exactly the same time, start the stopwatch and release the marble into the syrup. Stop the stopwatch when the marble reaches the bottom of the beaker. Record in your data table the time it took for the marble to reach the bottom.



Step 5

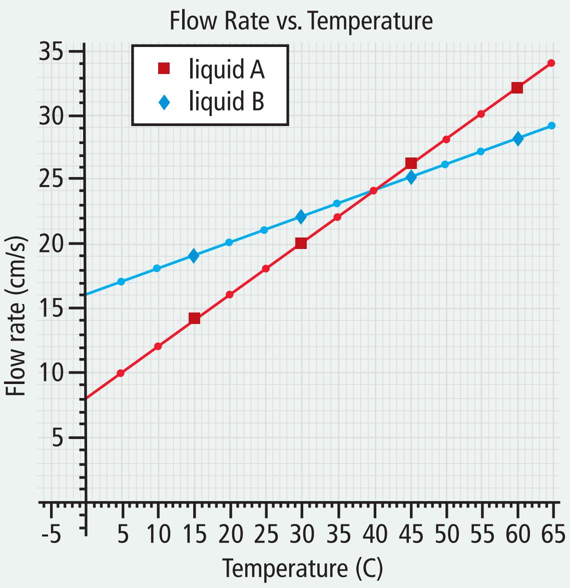
6. Turn on the hot plate to a low-medium setting. During heating, stir the corn syrup very slowly, being careful not to create bubbles.
7. Watch the temperature carefully. Every time the temperature increases by 3°C, repeat steps 4 and 5 (note the temperature, release a marble, and record the time). Remember to continue stirring very gently to ensure that the syrup heats evenly.
8. **Caution! The corn syrup will be very hot.** Stop recording when you have used all the marbles or the corn syrup begins to bubble, whichever happens first. Turn off your hot plate and allow the corn syrup to cool before you remove the beaker to clean it and retrieve the marbles.
9. Clean up and put away the equipment you have used.

Analyze

1. Calculate the rate of fall of each of the marbles by dividing the depth of the corn syrup by the time each marble took to fall through the corn syrup. Record the rates of fall in your data table.
2. State the independent, dependent, and controlled variables in this experiment.
3. Create a line graph of your results by plotting the rate of fall of the marbles versus the temperature of the corn syrup. Draw a best-fit line through your data.

Conclude and Apply

1. How is the marbles' rate of fall related to the temperature of the corn syrup?
2. How is the marbles' rate of fall related to the viscosity of the corn syrup?
3. How does viscosity change with temperature?
4. Suppose the corn syrup was at 55°C. Use your graph to predict how fast the marble should fall. Show your work on the graph.
5. The graph below shows the flow rate versus temperature of two substances made from data collected during a flow rate experiment.
   (a) At what temperature is the viscosity of the two liquids equal?
   (b) When the temperature is 10°C, which substance has the greatest flow rate?
   (c) When the temperature is 60°C, which substance has the greatest viscosity?



7-3D Cool Contraction

Find Out ACTIVITY

In this activity, you can observe evidence that a gas contracts when it cools. Your teacher may choose to do this experiment as a demonstration for the class.

Safety

- Be careful when handling hot water.
- Be sure that the flask does not have any chips or cracks.
- Be aware of any latex allergies if the balloons are made of latex.

Materials

- Erlenmeyer
- flask
- small balloon
- large bowl
- ice
- protective mitt
- cold water
- very hot water

What to Do

1. Fill the bowl halfway with ice. Put cold water into the bowl to create an ice water bath.
2. Fill the flask with hot water and let it sit for 3 min.
3. Use the protective mitt to pour the hot water out of the flask. Immediately stretch the balloon over the mouth of the flask. **Caution: the mouth of the flask may be hot.**
4. Place the flask into the ice water bath. Hold the flask upright and make sure the balloon is free to move. You may have to hold the tip of the balloon if it is folded over the edge of the flask.
5. Be patient. It may take up to 10 min for the flask to cool. During this time, watch the balloon carefully.
6. Clean up and put away the equipment you have used.

What Did You Find Out?

1. What do you think happened to the temperature of the gas (air) inside the flask during this experiment?
2. How would you describe the kinetic energy of the particles of the gas inside the flask during the experiment?
3. How is the behaviour of the balloon related to the kinetic energy of the particles of gas inside the flask?
4. (a) How could you inflate the balloon?

   (b) Explain your idea by referring to kinetic energy.

7-3E The Effect of Concentration on Viscosity

Inquiry Focus

SkillCheck

- Measuring
- Predicting
- Observing
- Evaluating information

Safety

- Keep your hands away from your face and mouth. Do not eat or drink any substances in the science laboratory.
- Wipe any spills immediately. Do not leave floors wet.
- Dispose of materials properly, according to your teacher's instructions.

Materials

- ramp made of smooth plastic or glass (minimum 0.5 m × 0.3 m)
- stack of books (0.25 m – 0.3 m high)
- measuring spoon (15 mL), with rounded bottom
- watch with second hand, or stopwatch
- rubber gloves
- waterproof marker or wax pencil
- tape
- paper towels
- soap for cleaning ramp surface
- water
- sugar

The viscosity of a liquid will change as you alter the concentration of a substance within it. You can determine how the viscosity changes by measuring the flow rate of different concentrations of the same substance.

Question

How does concentration affect the flow rate of a liquid?

Procedure

1. Prepare the flow rate ramp as in Conduct An Investigation 7-2B on page 282.

(a) Measure the temperature of the room and record it in your notebook.

(b) Make a data table that looks like the following:

Concentration of Sugar in Water	Time (s)	Flow Rate (cm/s)	Ranked Flow Rate	Ranked Viscosity
0 g/mL				
0.20 g/mL				
0.45 g/mL				

(c) With your group members, hypothesize which of the three concentrations will flow fastest.

2. For the first sugar solution, add 20 g of sugar to 100 mL of water and stir until it has all dissolved. For the second sugar solution, add 45 g of sugar to 100 mL of water and stir until it has all dissolved. Be sure to label each mixture with its concentration in grams of sugar per millilitres of water.

3. Test one mixture at a time, starting with just water. The "spoon student" will pour enough, liquid into the clean, dry measuring spoon so that it is level, then place the spoon at the start mark on the ramp.

(a) another group member, the timer, will work the stopwatch

(b) A third group member, the marshall, will say "go" and will call "stop" when the liquid reaches the finish line.

4. When the marshall says "go," the spoon student rocks the spoon quickly but gently to pour its contents down the ramp. As the same time, the timer starts timing.
5. When the marshall says "stop," the timer stops timing and records the time in the data table. Students clean and dry the ramp and measuring spoon to get ready for the next liquid.
6. Repeat steps 3 to 5 for the two concentrations of sugar water.

   (a) Wash your hands after this investigation.

Analyze

7. Determine the flow rate (in cm/s) for each mixture. Do this by dividing the distance travelled (10 cm) by the time recorded for each substance (in seconds). Record each result in your data table.
8. Rank the liquids from fastest flow rate (1) to slowest flow rate (3). Record these rankings in the fourth column of your data table ("Ranked Flow Rate"). Was your hypothesis correct?
9. Rank the viscosities in the table from lowest (1) to highest (3). Record these values in your data table under "Ranked Viscosity."
10. Describe two sources of error that might affect your results. Are these errors due to the equipment or to human factors? How could you reduce or eliminate these errors?

Conclude and Apply

11. Collect and record the class data. From your results, what is the median flow rate of the liquids you tested? How does it compare with the mean (average) value?
12. How is the flow rate of a liquid related to the concentration?
13. What conclusion can you come to about the relationship between concentration and viscosity?

Check Your Understanding

Checking Concepts

1. A recipe for making gravy calls for 1 tablespoon of cornstarch to be stirred into the mixture. What is the purpose of adding cornstarch? How will it change the consistency of the gravy?
2. Asphalt is the black, sticky material that binds gravel in the pavement that covers streets and highways. Explain why paving is almost always done during the summer months.
3. It is often very hard to get the last few teaspoons of molasses out of a jar. What could you do to help decrease the viscosity of the molasses and allow you to obtain the remaining few teaspoons?
4. Tar is heated in vats before it is applied to roofs to prevent leaks. Why is the tar not spread on the roof while it is cool?
5. Motor oils are manufactured in a variety of viscosities to suit weather conditions. Predict when a mechanic would choose to put a higher-viscosity oil in a vehicle. Explain your reasons.
6. When you take maple syrup out of the refrigerator, it is extremely hard to pour out of the bottle. What could you do to decrease the viscosity of the maple syrup to help it flow more easily?

Understanding Key Ideas

7. Use the particle theory to explain why and how temperature affects the viscosity of a liquid. You may use a sketch in your answer.
8. Explain why the size of particles can affect the viscosity of a liquid.
9. If someone were to ask you to increase the viscosity of oxygen, what steps would you take to carry out this request? Why would it be different from increasing the viscosity of liquids?

Pause and Reflect

Besides temperature and the shape and size of particles, think of another factor or factors that might affect the viscosity of a fluid.

Chapter Review

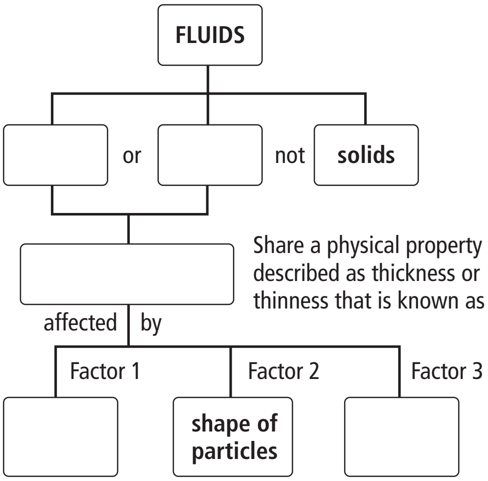
Prepare Your Own Summary

In this chapter, you explored fluids by examining the factors that increase or decrease their viscosity. Create your 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. The Particle Theory of Matter
2. Changes of State of Matter
3. Measuring Flow Rate of Fluids
4. Effects of Temperature on Fluids and Their Viscosities
5. Effects of Temperature on Gases and Their Viscosities

Checking Concepts

1. Define the term "fluid."
2. Use the particle theory to explain why liquids and gases are fluids, but solids are not.
3. Describe how particles change as they change state from
   (a) solid to liquid
   (b) gas to liquid.
4. Explain the difference between
   (a) condensation and evaporation
   (b) sublimation and deposition.
5. Fine sand can appear to flow like a fluid when it is dumped from a bucket. How can you prove to someone that sand is not a fluid?
6. Define the term "viscosity."
7. (a) Summarize the main factors that affect the viscosity of liquids and gases.
   (b) Use the particle theory to explain how each factor affects viscosity.
8. Copy and complete the following concept map using key ideas you have learned in this chapter.

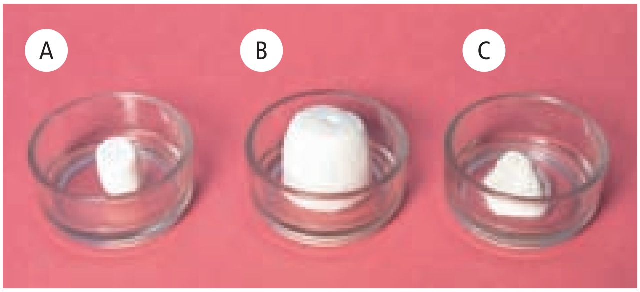


9. Explain why liquids kept in the refrigerator flow more slowly than liquids kept in a cupboard.
10. Define kinetic energy.

Understanding Key Ideas

11. Why are warm gases more viscous than cool gases?
12. Oil flows more slowly than water. Using references to attractive forces or particle size and resistance to flow, explain why there is a difference between the two fluids.
13. How are a liquid's flow rate and its viscosity related?
14. For the following careers, explain why viscosity is important:
    (a) Mechanic
    (b) Candy maker
    (c) Baker

15. Marshmallows are made mostly of a sugar and gelatin mixture that holds thousands of small pockets of air. The photographs below show a marshmallow before it is put in a microwave oven (A), when it has just been removed from the oven (B), and after it has cooled (C).
Consider what happens to marshmallows when they are cooked in a microwave oven and then removed.
(a) Explain why the marshmallow expanded when cooked in the microwave oven.
(b) Explain why the marshmallow shrank when removed.



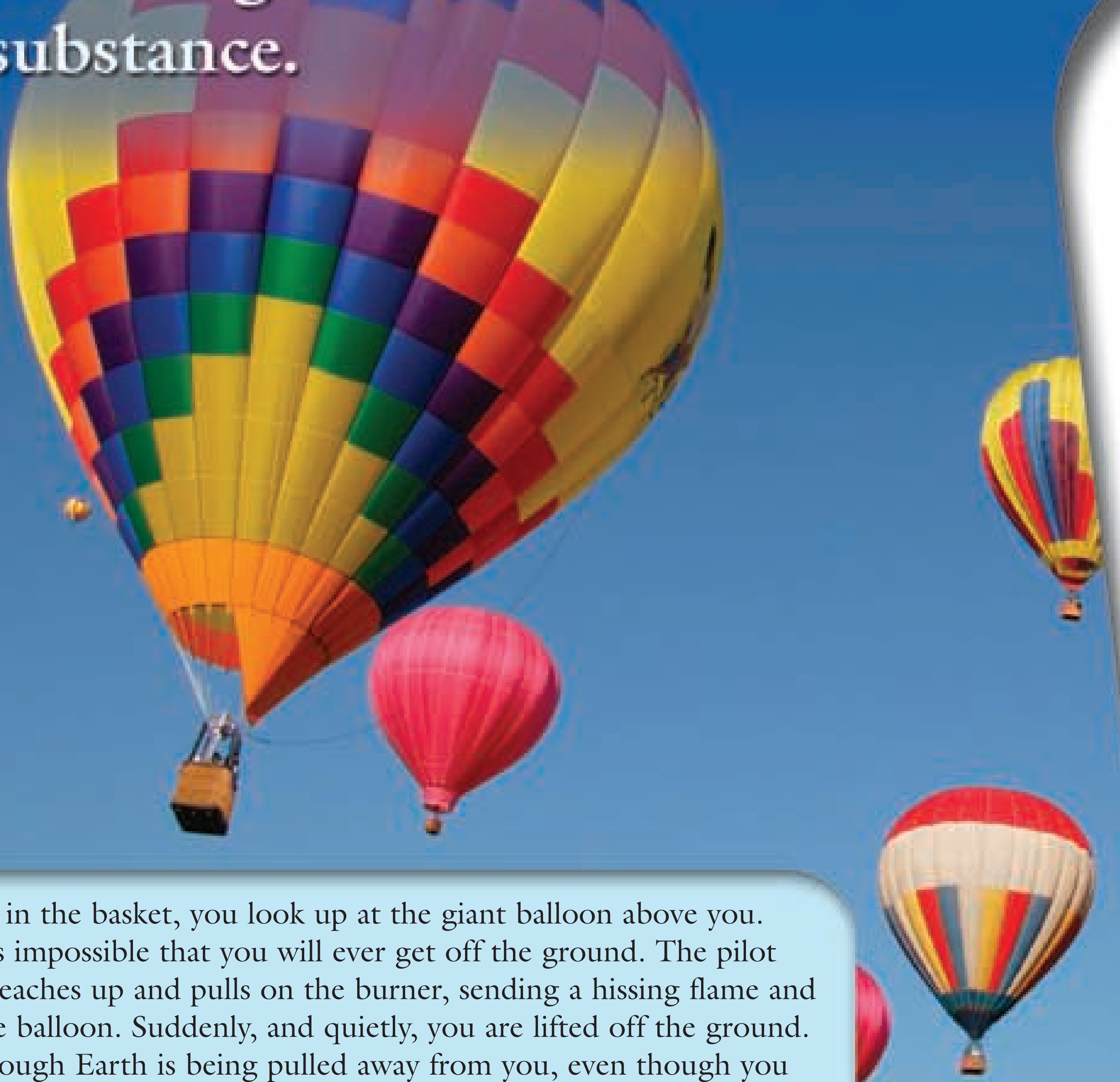
16. Make a bar graph for the following data, with "Flow Rate" along the vertical axis (y-axis) and "Temperature" along the horizontal axis (x-axis).

Substance	Flow Rate at 10°C (cm/s)	Flow Rate at 25°C (cm/s)	Flow Rate at 50°C (cm/s)
1	2.0	4.0	9.0
2	13.0	13.0	14.0
3	0.0	0.0	2.0
4	5.0	8.0	13.0
5	0.0	1.0	4.0

(a) Which substance is the most viscous? Which one is the least viscous?
(b) Which substance is a solid at room temperature (about 20°C)?
(c) Try to explain why the values for substance 2 are so similar at the three different temperatures.

Chapter 8

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



Standing in the basket, you look up at the giant balloon above you. It seems impossible that you will ever get off the ground. The pilot beside you reaches up and pulls on the burner, sending a hissing flame and heat into the balloon. Suddenly, and quietly, you are lifted off the ground. It feels as though Earth is being pulled away from you, even though you are the one who is quietly moving, drifting upward as you are guided by the wind.

Without jet engines and propellers how do these hot-air balloons float upward? The answer has to do with the density of the air inside the balloon. In this chapter, you will learn about the property of density and how it is unique to each individual substance. You will also explore how density helps to explain how certain substances interact with one another.

What You Will Learn

In this chapter, you will
- **Describe** the difference between mass, volume, and density
- **Explain** the relationship between mass, volume, and density using the particle theory
- **Predict** how temperature will affect the density of a substance

Why It Is Important

Density is a property that can help identify a specific substance. Understanding density can also help us understand the way things work around us.

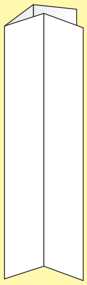
Skills You Will Use

In this chapter, you will
- **Determine** mass-to-volume ratios of different amounts of the same substance
- **Measure** density of fluids and solids
- **Observe** how temperature and density affect our everyday lives

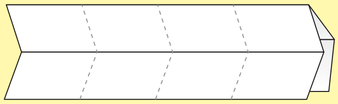
FOLDABLES™
Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 8.

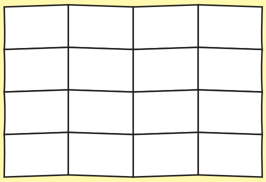
STEP 1 **Fold** a vertical sheet of legal-size paper from left to right two times. Unfold.



STEP 2 **Fold** the paper in half from top to bottom two times.



STEP 3 **Unfold** and draw lines along the folds.



STEP 4 **Label** the top row and first columns as shown below.

	Define States	+ Heat	– Heat
Liquid Water			
Water as a Gas			
Water as a Solid (Ice)			

Read and Write

As you read the chapter, define the states of matter in the *Define States* column of your Foldable. Write what happens when heat is added to or lost from each state.

8.1 Defining Density

Density is a measure of the mass contained in a given volume. Substances with a lower density will float on substances with a higher density.

Key Terms

density

One property that is useful in understanding both fluids and solids is density. **Density** is the amount of mass in a certain unit volume of a substance. In other words, density describes how closely packed together the particles are in a material.

You might think of density in terms of vehicles on a highway. A traffic jam like the one on the left in Figure 8.1A is a model of high density. The photograph of free-flowing loosely packed traffic on the right in Figure 8.1B is a model of low density.

Figure 8.1(A) When traffic gets very dense, it is difficult for vehicles to move. **(B)** When the density of traffic is lower, cars can move more easily.

Word Connect

The word density comes from the Latin word *densus*, meaning "thick or crowded".

Density and the Particle Theory

According to the particle theory, different substances have different-sized particles. The size, shape, and mass of the particles determine how many particles and how much mass can "fit into" a given space. Therefore, each substance has its own unique density, based on particle size, shape, and mass.

The particle theory also suggests that there is empty space between the particles of matter. If you look back at Figure 8.1B, you can see that not as many cars can fit on the highway if there are large spaces surrounding each vehicle. The density of the traffic is reduced. Therefore, the more space that exists between particles of a substance in a certain unit of volume, the less dense the substance will be.

Density of Solids, Liquids, and Gases

How is the density of a substance related to the substance's physical state? Imagine filling a container with liquid water and another container of the same size with water vapour. Both liquid water and water vapour are the same substance, and therefore have particles of the same size and mass. According to the particle theory, however, gas particles have more space between them than do liquid particles. Therefore, the water vapour in the container would have fewer particles than the liquid water. You can then conclude that the density of the water vapour is less than the density of liquid water.

How are density and state of matter related to the physical properties of a substance? Solid objects can move easily through liquids and gases. For example, a diver can jump from a platform and move smoothly through the air and then the water in a pool, as shown in Figure 8.2. According to the particle theory, the fluid properties of water and of air allow water particles and air particles to move out of the way of the solid body of the diver.

Why do solid particles tend to hold together while fluid particles tend to move apart? The answer has to do with the attractive forces between particles. In solids, particles cannot be easily pushed apart. To understand why, imagine that you and a few friends are together. You want to prevent anyone else from pushing your group apart and moving between you. What would you do? First, you would have to stand quite close together. Then, you would probably hold on to each other very tightly. If you do not let go of one another, no one can move between you. Particles in a solid act much the same way. Attractive forces among the particles of a solid are stronger than those between fluid particles. Therefore, particles in a solid cannot slide past each other or move between each other.

If you were to place a rock on the surface of a lake, the water would not support the rock. Instead, the rock would go right through the water, and would continue to fall through the water, pushing water particles out of its way until it reached the bottom. Liquids cannot support

Did You Know?

Could the solid state be less dense than the liquid state of the same substance? The answer is yes for some substances. You have probably seen ice cubes floating in a glass of water. As solid ice forms from liquid water, the ice expands. This means that there is more empty space trapped in a chunk of ice than in the same amount of water. Therefore, solid ice is less dense than liquid water.

Figure 8.2 The particles of a fluid move apart easily when a solid object, such as a diver, travels through the fluid.

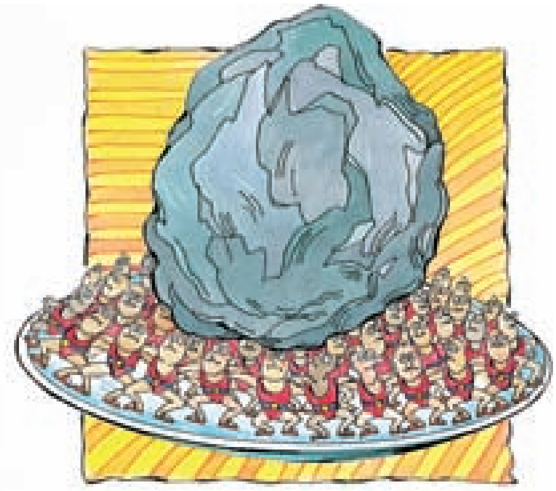


Figure 8.3 The cartoon weightlifters represent the tightly packed particles of the solid plate. The plate can hold its shape and support materials such as the large rock because the weight-lifters (plate particles) are holding on to each other very tightly.

objects in the same way that solids can, because the particles of a liquid move apart easily, allowing a dense, solid object, such as a rock, to pass through the liquid. The attractive forces between liquid particles are not strong enough to prevent a rock from pushing them apart.

Similarly, a rock falls through air because gases are even less dense than solids or liquids. When you move through air, you are moving through mostly empty space. A solid object does not have to move as many particles of air out of the way as it would travelling through water. This explains why running through air is much easier and faster than running through water. In general, *gases are less dense than liquids* and *liquids are less dense than solids.*

Did You Know?

"Empty space" does not mean "air." Empty space means a separation between two objects with nothing between those objects, not even air particles. Simply because empty space and air look the same does not mean they are the same! For example, outer space is mostly empty space, but it has no air. Astronauts would suffocate if they were to venture outside their spacecraft without masks and air tanks, because there is no oxygen in outer space.

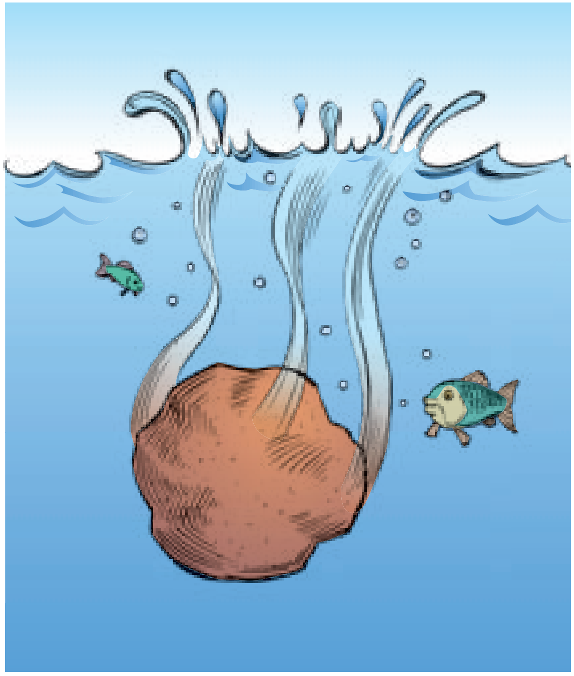


Figure 8.4 Although liquid particles are sometimes quite closely packed together, they cannot support objects in the same way that solids can, because the particles do not have a strong enough attraction for each other. Therefore, liquid particles move apart easily.

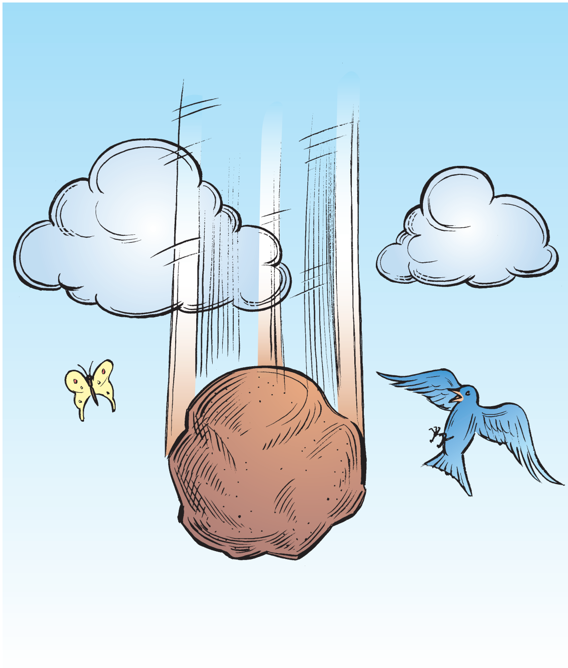


Figure 8.5 When a solid object moves through air, it does not have to move as many particles of air out of the way as it would when passing through a liquid, since gases are usually less dense than liquids. Gas particles are even less attracted to each other than particles in liquid.

8-1A Differing Densities

Find Out ACTIVITY

Using your knowledge of the particle theory, what inferences can you make about the densities of different substances?

Safety

What You Need

3–5 class sets of lettered containers (prepared by your teacher), filled to the brim with various "mystery substances"

What to Do

1. Make a table with the following headings:

Sample (letter)	Rank (ordered heaviest to lightest)	Substance	
		Your prediction	Actual

2. With a partner, pick up each container and observe how heavy or how light each one feels. Decide on the order of the containers from heaviest to lightest. Give the heaviest container rank number 5 and the lightest container rank number 1. In your table, record the ranks of the containers, from heaviest to lightest.
3. Predict what the substance inside each container might be. Record your predictions.
4. Find out what the substances are by checking your teacher's master list. Record the actual substances in the table.

What Did You Find Out?

1. Which substances did you predict correctly (or closely)? Which substances, if any, surprised you?
2. The volumes of the substances were identical because each container was filled to the top. Why is it important to keep the volumes equal in this activity?

In some cases, the densities of two pure substances can be so different that the liquid state of one is denser than the solid state of the other. One example of this is shown in Figure 8.6A. Many solid metals, such as copper, nickel, and silver, can float on liquid mercury, one of the densest substances known. Another example of water being denser than a solid is shown in Figure 8.6B.

Figure 8.6A Liquid mercury is so dense that it can support a solid iron bolt. A layer of oil has been placed on top of the mercury to prevent vapour from escaping into the surrounding air, as mercury is very poisonous.

Figure 8.6B A solid block of wood floats easily on the surface of liquid water.

Reading Check

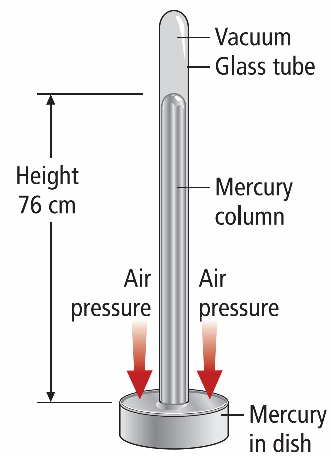
1. Explain what density means in your own words.
2. Explain why solids can support objects more easily than fluids can. You may use diagrams to help in your explanation.
3. How can the density of a pure substance change? Provide an example.
4. Using the particle theory, explain why some liquids can support a solid.

Wild, Weird, Wonderful

www Science

The Mercury Barometer

If you watch a weather forecast, you will often hear the meteorologist talk about high or low pressure systems. Our weather changes as systems of high and low atmospheric pressure are carried by winds and move over the land. Atmospheric pressure is measured by an instrument called a barometer. Although digital and other types of barometers now exist, the original and most common barometers work because of the unique properties of liquid mercury.



Mercury is a dense metal that is liquid at room temperature.

In 1643, Evangelista Torricelli developed the first mercury barometer, and it has changed very little in design since then. The air is removed from a glass tube (about 76 cm in length) that has one closed end and one open end. The open end is then placed into a reservoir of liquid mercury. As atmospheric pressure increses, it presses down on the reservoir and forces the mercury up into the tube. The mercury rises until the weight of the mercury in the tube balances the atmospheric force that is exerted on the reservoir. The higher the pressure, the higher the mercury will rise in the tube.

Why Use Mercury?

You may wonder why water was not used in these original barometers. The answer has to do with the high density of mercury. For a column of water to create as much pressure as the standard atmospheric pressure (101.325 kPa), it would have to be 10 m high. That would not be very practical, as you would have to have a glass tube that was over 10 m in height! Because mercury is much denser than water, but is still a liquid, it only takes 76 cm of mercury to make a column that exerts one atmosphere of pressure.

The End of the Mercury Barometer?

There are some very important problems with mercury that could mean that mercury barometers will stop being made. Scientists discovered that liquid mercury is highly toxic to humans and animals. Many countries have banned the use of mercury in manufacturing industries in order to prevent it from entering the environment.

Icebergs

Each spring, tourists and residents of Newfoundland and Labrador alike gather along the shores to watch white, silent giants slowly drift past in the ocean. The sheer size of these ancient icebergs boggles the mind, especially when we know we are only seeing "the tip of the iceberg." The area from the northern tip of Labrador down to the Grand Banks of Newfoundland is called Iceberg Alley. It is through this alley that many icebergs flow from the Arctic on their journey to warmer waters.

Iceberg Alley is known as one of the best places in the world to see icebergs.

Where do the Icebergs in Iceberg Alley come from?

The icebergs were originally part of Greenland's glaciers. Breaking off from one of the glacier's edges, an iceberg is caught in the Labrador Current and is carried into the alley along the shores of Labrador and then Newfoundland. But do not be tricked into thinking that this is a quick journey. It takes an iceberg about two to three years to reach the Grand Banks of Newfoundland from Greenland!

The "Tip of the Iceberg"

You have probably heard the saying that 90 per cent of an iceberg remains below the surface of the water. Considering that the average weight of an iceberg off the Grand Banks is one to two hundred thousand tonnes, it is hard to believe that these giants can float at all! Icebergs float because the density of ice is approximately 0.9 g/mL, which is lower than that of seawater (around 1.03 g/mL).

It is hard to imagine that 90 percent of this giant is hidden from view underneath the water.

Iceberg Lingo

Iceberg scientists and enthusiasts use words that a tourist might find strange!

- "growler" – very small chunk of floating ice that rises only about one metre out of the water
- "bergy bits" – small icebergs that rise one to four metres out of the water
- "calving" – when part of an iceberg splits away and falls into the ocean
- "tabular," "wedged," "pinnacled," "domed," "blocky," and "drydocked" – shapes of icebergs

Global Warming—The End of Icebergs?

Since the late 1990s, there has been a decline in the number of icebergs that pass through Iceberg Alley. Many scientists believe that this decline has to do with global warming—the increase in the average temperature of the Earth's near-surface air and oceans. As the air and ocean temperature increases even a few degrees, more icebergs are created from Greenland's glaciers, but they are melting before they reach Iceberg Alley. A lack of icebergs is good news for ships that pass through the alley and for oil rigs such as the Hibernia. However, it is bad news for tourists who come to see the icebergs, and for the province that enjoys the benefits of the tourism industry. The decline could also possibly be a warning for the future of Earth's environment.

Check Your Understanding

Checking Concepts

1. Imagine that you have two equal-sized containers. One is filled with liquid gold, and the other is filled with solid gold. Using the particle theory, explain why each physical state of gold will have a different density, despite the fact that they are both gold.
2. Using the particle theory, explain why dolphins can move easily through the air and the ocean when they jump.

3. Find some small items in the classroom (for example, pencils or paper clips) and determine whether these items are denser than water by dropping them into a container full of water. Organize your observations in a table.
4. The density of molten lava increases as it cools and hardens. List other examples of natural changes in density.
5. Explain why the attractive forces of particles make the densities of solids, liquids, and gases so different?

Understanding Key Ideas

6. Explain why "air" and "empty space" are two different things.
7. Many people take water aerobics classes because it is a good physical activity to stay in shape. Why would doing some exercises, such as running through water, be harder than doing it through the air?

Pause and Reflect

If an oil spill occurs, cleaning up the oil can be a challenge. One technique is the towing of booms that contain the oil within an area. Use what you have learned about density to explain why this technique can help clean up an oil spill.

8.2 Determining Density

How can you measure the density of a substance? You can determine a substance's density if you know how much of a substance occupies a certain space.

Key Terms

displacement
mass
mass-to-volume ratio
volume

Recall that density is the mass of a given volume. To find the density of a substance, you need to know its mass and its volume. **Mass** is the amount of matter in a substance (see Figure 8.7). **Volume** is a measurement of the amount of space occupied by the substance. Figure 8.8 shows how the volume of a solid can be measured. The volume of a liquid can be measured using a measuring cup or a graduated cylinder. The volume of a gas can be determined by measuring the volume of the container that holds it.

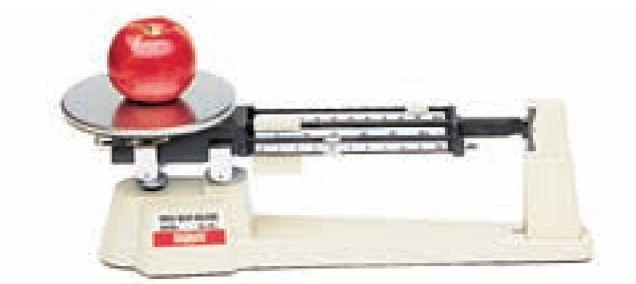


Figure 8.7 A balance is used to measure mass in grams (g) or kilograms (kg). This apple has a mass of 102 g.

Figure 8.8 If an object has a regular shape, such as the block of wood in this picture, you can measure the length, width, and height and then use the mathematical formula, $V = l \times w \times h$, to calculate the object's volume.

Figure 8.9 The volume of an irregularly shaped object can be found by measuring the volume of the water that spills out of an overflow can.

Suggested Activity

Conduct an Investigation 8-2A on page 315.

Displacement

How would you measure the volume of an object with an irregular shape? **Displacement** is the amount of space that an object takes up when placed in a fluid. Have you ever noticed how the water level rises in a bathtub when you get into it? The amount of water you are displacing is the volume of your body that is in the water. So, by measuring the displacement of an object, you can measure the volume of the object.

Calculating Density

The density of a substance can be determined by calculating its **mass-to-volume ratio**. You can do this by dividing the object's mass by its volume. Therefore, the formula for density is:

$$\text{Density } (D) = \frac{\text{Mass } (m)}{\text{Volume } (V)} \text{ or simply, } D = \frac{m}{V}$$

The volume of a solid is often given in units of cm^3. Therefore, the density of solids is often given in g/cm^3. The volume of liquids, however, is often given millilitres (mL). Therefore, the density of liquids is often given in units of g/mL.

Did You Know?

Forensic scientists use density calculations to solve crimes! The density of glass fragments found at a crime scene or on a suspect's clothing can be compared to the density of other samples of glass. This may provide evidence that a particular suspect was present at the crime scene. What information would scientists need to calculate the density of the glass fragments? How might they gather this information?

Figure 8.10A The salt and sugar shown here both have a mass of 0.5 kg and are the same colour. However, their densities are different. Seawater may look like regular water (B) , but its density is closer to that of milk—1.03 g/mL.

As long as the temperature and pressure stay the same, the mass-to-volume ratio, or density, of any pure substance is a *constant*, meaning it does not change. If the mass of a pure substance increases, the volume will also increase. Similarly, if the volume of a pure substance increases, the mass will also increase. According to the particle theory, the size of the particles in a substance do not change when the mass or volume of the substance changes. A certain number of particles of a particular size and mass will always occupy a certain amount of space. Density is a property of matter that is unique to a specific pure substance. Table 8.1 on the following page lists the approximate densities of some common substances.

Suggested Activity

Investigation 8-2B on page 316.

Table 8.1 Approximate Densities of Common Fluid Substances and Solid Substances

Fluid	Density (g/mL)	Solid	Density (g/cm³)
hydrogen	0.00009	styrofoam	0.005
helium	0.0002	cork	0.24
air	0.0013	oak	0.70
oxygen	0.0014	sugar	1.59
carbon dioxide	0.002	salt	2.16
ethyl alcohol	0.79	aluminum	2.70
machine oil	0.90	iron	7.87
water	1.00	nickel	8.90
seawater	1.03	copper	8.92
glycerol	1.26	lead	11.34
mercury	13.55	gold	19.32

Scientists determined the values in Table 8.1 by making very careful measurements of the mass and volume of samples of the substances and using the formula for density. Learn how scientists make these calculations by studying the sample problem below. Then, develop your problem solving skills by completing the practice problems that follow.

Sample Problem

Find the density of a 10 g mass of a substance that has a volume of 2.0 cm³.

- Write the formula for density. $D = \frac{m}{V}$
- In place of *m* for mass, write 10 g. $D = \frac{10\text{ g}}{V}$
- In place of *V* for volume, write 2.0 cm³. $D = \frac{10\text{ g}}{2.0\text{ cm}^3}$
- Carry out the division. That is, divide 10 by 2.0. $D = 5.0\ \frac{\text{g}}{\text{cm}^3}$

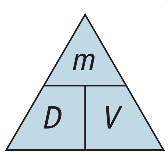
The density of the substance is 5.0 g/cm³.

Practice Problems

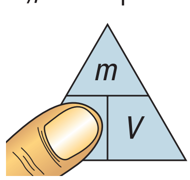
1. A piece of metal has a mass of 8.1 g and a volume of 3.0 cm³. What is the density of the metal? Look at the densities of the solids in Table 8.1. What type of metal do you think was described in this problem?

Did You Know?

You can place the density 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 density (solve for *D*), cover up the *D*:



The formula can be read as "*m* over *V*", or mass divided by volume.

2. Imagine that you poured a liquid into a measuring spoon that holds 2.5 mL. When you measured the mass of the liquid, you discovered that its mass was 3.15 g. What is the density of the liquid? Was this liquid water? Explain how you could check if the liquid was water.
3. You collect 1000 mL of a gas in a balloon. If the gas in the balloon has a mass of 2.0 g, what is the density of the gas? Use Table 8.1 to identify the gas.

If you know the density of a substance and are given the mass of a sample of the substance, you can predict the volume of the sample. To do this, you use a different form of the formula. If you rearranged the formula, you would find that $V = \frac{m}{D}$. Learn how to use this form of the formula by studying the sample problem below. Then, complete the Practice Problems.

Sample Problem

You want to put 10.0 g of salt into a container. What is the volume of the container if the salt completely fills it?

- Write for formula for volume when you know the mass and density. $V = \frac{m}{D}$
- Look up the density of salt in Table 8.1. $D = 2.16\ \text{g/cm}^3$
- In place of *m* for mass, put 10.0 g. $V = \frac{10.0\ \text{g}}{D}$
- In place of *D* for density, put 2.16 g/cm³. $V = \frac{10.0\ \text{g}}{2.16\ \text{g/cm}^3}$
- Carry out the division. That is, divide 10.0 by 2.16. $V = 4.63\ \text{cm}^3$

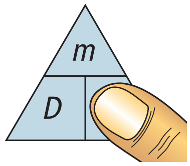
The volume of 10.0 g of salt is 4.63 cm^3. The container holds 4.63 cm^3.

Practice Problems

1. A piece of gold has a mass of 9.66 g. What is its volume?
2. What volume is taken up by 15 g of helium?
3. What is the volume of 250 g of sea water? Would the same mass of pure water have a larger volume or a smaller volume than the sea water? Explain.

Did You Know?

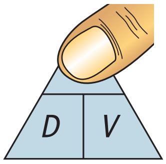
Use the triangle graphic technique to find the volume by covering up the *V* in the triangle:



The formula can be read as "*m* over *D*", or mass divided by density.

Did You Know?

Use the triangle graphic technique to find the mass (solve for *m*) by covering up the *m* in the triangle.



The formula can be read as *D* times *V*, or density multiplied by volume.

By rearranging the formula for density in another way, you can calculate the mass of a given volume of a substance if you know its density. The formula for calculating mass is $m = VD$ or mass equals the volume times the density. Study the following sample problem, and then complete the practice problems.

Sample Problem

What is the mass of 1500 mL of helium?

- Write the formula for mass when you know the volume and density. $m = VD$
- Look up the density of helium in Table 8.1 . $D = 0.0002$ g/mL
- In place of *V* for volume, write 1500 mL. $m = (1500 \text{ mL})D$
- In place of *D* for density, write 0.0002 g/mL. $m = (1500 \text{ mL})(0.0002 \text{ g/mL})$
- Carry out the multiplication. That is, multiply 1500 by 0.0002. $m = 0.3$ g

The mass of 1500 mL of helium is 0.3 g.

Practice Problems

1. What is the mass of 20 000 mL of oxygen?
2. When you lower an irregularly shaped piece of copper into water in a graduated cylinder, the volume of the water increases by 6.5 mL. What is the mass of the copper?
3. What is the mass of 7.0 mL of machine oil?

Reading Check

1. What two measurements do you need to determine the density of a substance or object?
2. What is the formula for density?
3. Describe how to measure the volume of an object with an irregular shape.
4. If the mass of a pure substance increases, what happens to the volume of the substance?

8-2A What is the Density of a Pencil?

Find Out ACTIVITY

You need two measurements to calculate the density of a pencil. What are they?

What You Need

- balance
- 100 mL graduated cylinder
- water
- pencil

What to Do

1. Use the balance to measure the mass of a pencil in grams.
2. Pour 90 mL of water into a 100 mL graduated cylinder.
3. Lower the pencil, eraser end down, into the cylinder. Continue to push the pencil down until it is completely underwater, but be sure your finger is not also submerged.
4. Read and record the new volume of water.
5. Determine the volume of the pencil by calculating the amount of water displaced. You can calculate this value by subtracting the original volume of water from the final volume of the water after you submerged the pencil.
6. Calculate the pencil's density by dividing its mass by its volume.

What Did You Find Out?

1. Is the density of the pencil greater or less than the density of water? How do you know?
2. How does the method you used to determine the density of the pencil differ from the method you would use for an object with a regular shape, such as a cube or a sphere?

Extension

Use the same method to find out the density of another object, such as a rubber stopper or a cork. Make a prediction, and then carry out the activity to see if you were correct.

8-2B Determining Density

Core Lab

SkillCheck

- Predicting
- Measuring
- Calculating
- Graphing

Safety

- Handle balances with care and use them as instructed by your teacher.
- Avoid spilling liquids and sand on the balances.
- Do not pour substances down the drain. Dispose of them as instructed by your teacher.

Materials

- 500 mL beaker (or 500 mL cup)
- balances (or one shared by the class)
- 5 different coloured pencil crayons or markers
- 500 mL (per trial) of each of the following substances: water, oil, glycerol, molasses, sand
- graph paper for each student

The following investigation will show, by means of accurate measurements, how mass and volume can be used to determine density.

Question

How can measurements of mass and volume be used to determine the density of a substance?

Part 1

Mass-to-Volume Ratios

Procedure

1. Before beginning the investigation, predict how the substances will rank according to density. Rank the substances from the least dense (1) to most dense (5). Record your hypothesis and a brief note explaining your ranking order.
2. (a) Your teacher will divide the class into groups and will assign one substance to each group. Subdivide each group into smaller groups or partners to provide multiple trials for each substance.
   (b) Copy the data table below into your notebook.

Individual Results

Substance Tested:				
A	B	C	D	E
Volume (mL)	Mass of Beaker Only (g)	Mass of Beaker and Substance (g)	Mass of Substance Only (g)	Ratio of Mass to Volume (g/mL)
100				
200				
300				
400				
500				

3. Measure the mass of the empty beaker. Record this value in column B of your table.

Step 3.

4. Pour 100 mL of your substance into the beaker. Be as accurate as possible.

Step 4.

5. Measure the mass of the beaker plus the substance. Record this value in column C in your table.
6. Subtract the mass of the beaker (column B) from the mass of the beaker and the substance together (column C). Record the difference in column D.
7. Repeat steps 3 to 5 four more times, each time adding 100 mL of your substance to what is already in the beaker. (The last time, you will be measuring 500 mL.)

Step 5.

Continued on next page

SkillCheck
- Predicting
- Measuring
- Calculating
- Graphing

8. The mass-to-volume ratio is the relationship between mass and volume expressed as a quantity of the mass divided by its volume. To find the mass-to-volume ratio for each amount of each substance, divide the mass (column D) by the volume (column A). Show your calculations and results in column E. Wash your hands.
9. When each group has finished, your teacher will display a set of class results for all the substances in a summary chart with the following headings:

Class Results

Substance	Mass (g)	Volume (mL)	Mass-to-Volume ratio (g/mL)

Copy these results into your notebook. (If there were two or more trials for each substance, calculate the averages for the mass, volume, and mass-to-volume ratio values for each substance.)

Part 2
Graphing

Procedure

1. Make a line graph of the class results recorded in Part 1. Place the volume scale along the horizontal axis (*x*-axis), and the mass scale along the vertical axis (*y*-axis).
2. Plot the (average) results for the first substance on the graph. Draw a line through these points in one colour. Record this colour in a legend on the graph, and write the name of the substance beside it.
3. *On the same graph*, plot the results for the next substance. Draw a line through these points using another colour. Record this colour in the legend, and write the name of the substance beside it.
4. Repeat step 3 for the three remaining substances.
5. Give your graph a title.

Analyze

1. Describe the lines on your graph. Are they straight or curved? Are some lines steeper than others? Are some lines closer together than others?
2. Look back to the data table you made for your substance. What happens to the mass-to-volume ratio for each volume measurement of your substance? Why do you think this happens?
3. Compare your hypothesis to the final results.
4. There is a chance of error in every experiment. Suggest ways to improve (a) how you performed the investigation (more accurate measurement, avoidance of spilling, etc.), (b) how you calculated results (possible math errors), and (c) how you graphed your results.

Conclude and Apply

5. Why are some lines in the graph similar to each other while some are different?
6. How can you tell from your mass-to-volume ratios and your graph which substance is the least dense? Which substance is the most dense?
7. Look at the mass-to-volume ratios in the Class Results table in Part 1. Compare these values with the steepness of the lines in the graph that correspond to them. How does the steepness of a line change as the mass-to-volume ratio changes?
8. Add a sixth line to your graph for a substance that is denser than water but less dense than sand. Between which values would its mass-to-volume ratio be?
9. Use the particle theory to explain the relationship between the mass, volume, and density of the substances you examined in this investigation.

Extend Your Skills

10. From your observations, do you think that density and viscosity are related? Explain your answer.
11. Use the particle theory to predict the effect of temperature on mass-to-volume ratios.

8-2C Comparing Densities

Think About It

When you compare the masses of equal volumes of different kinds of matter, you are comparing their densities. Scientists have recorded the densities of many substances. Does knowing how the density of a substance compares with the densities of other substances tell you something about the characteristics or behaviour of the substance? Find out in this investigation.

What to Do

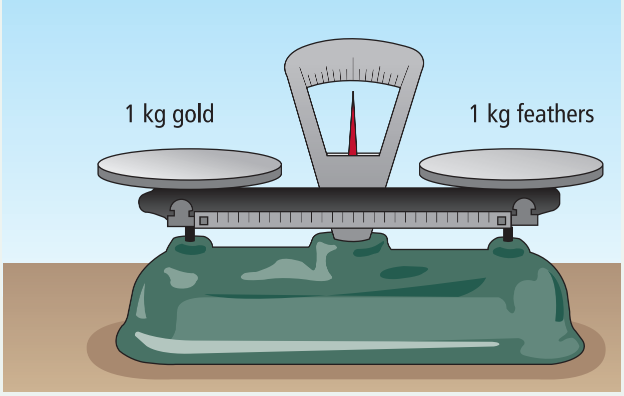
Use the information in Table 8.1 on page 312 to answer the following questions:

1. Which substance in the table is the most dense? Is it a solid, a liquid, or a gas at room temperature?
2. Which substance is the least dense? What is its physical state at room temperature?
3. Write a conclusion about which physical state tends to be the most dense.
4. Name the substance that is denser than mercury.

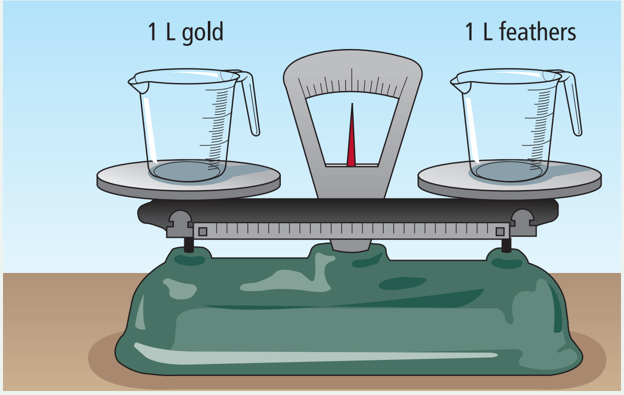
Analyze

1. Which substances would float in water?
2. Which substances would sink in water?

Extension



1. Copy and complete the diagram above by adding a sack of gold and a sack of feathers. If both sacks have the same mass, which one will have the larger volume?



2. Copy and complete the diagram above. Add the gold and the feathers to the measuring cups, and show how the balance would tip as a result. If both substances have the same volume, which one will have the larger mass? Record your answer. Comment on how a knowledge of density helped you with your answers.

Wild, Weird, Wonderful

www Science

The Galileo Thermometer

Walking into your friend's home, you see a large glass tube with several colourful glass balls that are suspended in liquid. While it may look like a strange piece of art, chances are you are looking at a Galileo thermometer!

In the early 1600s, Galileo Galilei knew that the density of water changes as its temperature increases or decreases. He also realized that different objects that had slightly different densities would rise or sink depending on the density of the water around them. Putting these ideas together, Galileo created the thermoscope, which eventually changed into the Galileo thermometer.

Modern Galileo thermometers consist of a glass tube filled with a liquid that undergoes a greater density change with temperature than water does. Also in the tube are several hollow glass balls that have been filled with coloured water. Because the glass balls are different sizes, they each have varying amounts of liquid to make them equal in weight. Attached to each glass ball is a small metal tag that has a temperature engraved on it. (For example, the red ball may be 20°C, and the blue ball may be 25°C.) If you could take these tags off and weigh them, you would find that each tag is a little different in weight. The result is that each glass ball has a slightly different density.

As the temperature of the air rises, the temperature of the liquid inside the thermometer also rises. As the density of the liquid changes with the increase in temperature, it causes the weighted glass balls to either rise or sink, depending on their density. The temperature of the air can be read on the tag of the lowest ball that is still suspended in the liquid.

The glass balls filled with coloured liquid all have slightly different densities. Depending on the temperature of the liquid around them, they will rise or sink.

Science

Math connect

Working With Density Measurements

Density is an example of a property that can be used to identify pure substances. Therefore, you could measure the density of a pure substance to help determine its identity.

In the science lab, you collect all sorts of measurements. Taking these measurements and turning them into numbers that allow for analysis and comparison is very important. In the case of density, we need to convert a variety of mass and volume measurements to decimal values that make comparison of densities easy and make it possible to identify substances.

Density is really a ratio of mass to volume. For example, a 155 mL sample of glycerol is placed on a scale and records a mass of 195 g.

(a) This would be a mass-to-volume ratio of 195 g : 155 mL.

(b) This ratio can be expressed as a fraction $\frac{195\text{ g}}{155\text{ mL}}$

(c) You can convert this fraction to a decimal by dividing the numerator by the denominator:

$$\frac{195\text{ g}}{155\text{ mL}} = 1.26\text{ g/mL}$$

Practice Problems

Try it yourself. First convert the following measurements into:

(a) a mass-to-volume ratio
(b) a fraction
(c) a decimal

To be consistent, round each of your answers to two decimal places. Then, compare your decimal values to Table 8.1 on page 312 to identify each mystery substance.

1. Mystery substance A has a mass of 1780 g and a volume of 200 cm^3. What substance is it?
2. Mystery substance B has a mass of 972 g and a volume of 360 cm^3. What substance is it?
3. Mystery substance C has a mass of 132.79 g and a volume of 9.8 mL. What substance is it?
4. Mystery substance D has a mass of 1404 g and a volume of 650 cm^3. What substance is it?
5. Mystery substance E has a mass of 1422 g and a volume of 1800 mL. What substance is it?

Check Your Understanding

Checking Concepts

1. What is the density of a 2 cm^3 sugar cube that has a mass of 3.18 g?
2. The mass of 1 cm^3 of lead is 11.34 g. The mass of 1 cm^3 of iron is 7.87 g. Which solid has the greater density?
3. Using information from Table 8.1 on page 312, copy the table below and fill in the missing information.

Substance	Mass (g)	Volume (cm^3)	Density (g/cm^3) (Mass-to-Volume Ratio)
aluminum	5.40		
	6.48	3.0	
		5.0	8.92
oak	0.33		
salt		4.0	

4. The picture shows that a can of diet soft drink floats in water, but a can of regular soft drink sinks. What does this tell you about the relative densities of water, the can of regular soft drink, and the can of diet soft drink?

5. Explain why the lines representing pure substances on a mass vs. volume graph are straight.

Understanding Key Ideas

6. How do you measure the volume of a liquid? Of a solid? Of a gas?
7. What does the mass-to-volume ratio tell you about a substance?
8. Why is the process of displacement a good tool for measuring volume?
9. Liquid mercury (13.55 g/mL) is denser than solid copper (8.92 g/mL). When a drop of mercury is placed on solid copper, it stays on top. If mercury is denser than copper, why does the mercury not move down through the copper?

Pause and Reflect

Dissolving substances such as salt into water increases the density of water. Salt water has a greater density than distilled (pure) water. Considering the formula you have learned for calculating density, offer an explanation for why salt water is denser than distilled water.

8.3 Changes in Density

Just as changes in temperature affect the viscosity of fluids, changes in temperature also affect the density of a substance. By learning about the effects of temperature on density, you will begin to understand how these two factors are linked together in the world around us.

Changes in Temperature and Density

Suggested Activity

Find Out Activity 8-3B on page 328.

As you know, as temperature increases, a substance will change from a solid, to liquid, to gas. The particle theory states that the particles of a substance spread out as they gain energy when heated. Since they spread out, the particles take up more space, which means that the density of a substance decreases. It is almost always true that, for each pure substance (for example, silver), the density of its solid state is greater than the density of its liquid state. The substance's solid state and liquid state are, in turn, denser than its gaseous state.

Although most substances are denser in their solid form, water is an exception to this rule. When water freezes, the particles move slightly farther apart as they become fixed in position. This means that ice is actually less dense than liquid water, so it floats.

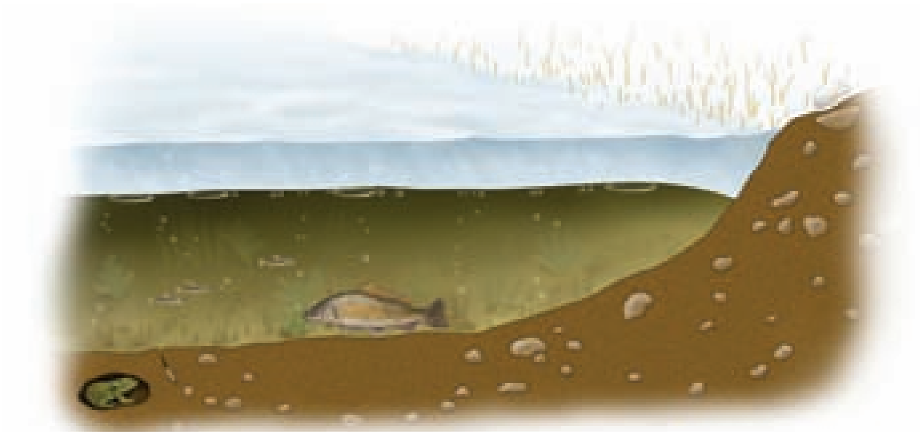


Figure 8.11 The property of ice floating on water makes life in freshwater lakes possible. If ice sank as it froze, lakes would freeze solid. Instead, the floating ice builds slowly from the top down, creating an insulating barrier against cold temperatures.

Temperature and Density in Everyday Life

You don't have to conduct an experiment in your science classroom to see the effects of temperature on density. All you have to do is look around you. For example, have you ever noticed that the tires on an automobile need more air during the winter than they do during the summer? As the temperatures decrease in the winter months, the particles inside the air in the tires lose energy, and therefore, take up less space. Therefore, the density of the air decreases, and the tire deflates a little. During the summer, however, increasing temperatures give the air particles more energy, meaning they require more space to move around. The air in the tire then expands, and the tire inflates.

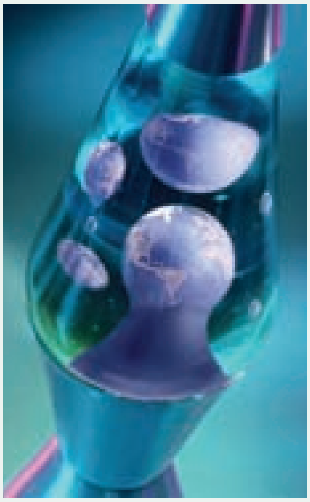
A hot-air balloon is another example of the effect of temperature on density. When a balloon pilot is preparing to fly, you will notice that he or she turns on a gas burner that heats the air inside the balloon. As they gain energy from the heat, the air particles inside the balloon begin to move around more and spread further apart from one another. Eventually, the air particles move so far away from each other that some of them are forced out of the bottom of the balloon. As the density of the air inside the balloon decreases, it becomes less dense than the air surrounding the balloon, so it rises. The pilot can now control the altitude of the balloon by controlling the amount of heat that enters the balloon.

Figure 8.12 A hot-air balloon rises by adding heat to the air, and therefore decreasing the density of the air inside the balloon.

8-3A Lava Lamps

Think About It

In this activity, you will discover how the "lava" flows inside a lava lamp.



At the bottom of a lava lamp sits an incandescent bulb, which heats up the mixture of water and wax that sits at the bottom of the glass when it is cold. At room temperature, the wax is slightly denser than water. By answering the following questions and using your knowledge of density, see if you can figure out how the "lava" moves up and down.

1. What happens to the density of the wax in relation to the water when it is heated?
2. As the density of the wax changes, what happens to it?
3. Once the wax reaches the top of the lamp, it begins to flow back down. Why?
4. Using the particle theory, explain in your own words how a lava lamp works.

Did You Know?

Have you ever gone swimming in the ocean? If you have, then you know that it is much easier to float in salt water than in fresh water. The reason is that the density of salt water is greater than that of fresh water. Therefore, it can support more of your body weight, making it easier for you to float.

Changes in the density of a substance can also occur naturally. If you have ever stacked wood, you will know that freshly cut wood from a living tree is much heavier than wood that has been cut and dried in the air for a period of time. Why is this? A living tree, or one that has been freshly cut, contains a high quantity of water. In fact, the water in a living tree often has a greater mass than the wood itself. The density of a living or freshly cut tree is, therefore, high due to its high water content.

Once a tree has been cut and is left to dry, the water particles in the wood evaporate, and are replaced with air. Because air is much less dense than water, the dry wood is less dense than the moist wood. Therefore, the wood is lighter and easier to lift. As well, the absence of water makes the wood easier to burn.

Figure 8.13 Firewood is often stacked and left to dry before being used. As the water evaporates, the density of the wood decreases, making it lighter and easier to burn.

Wild, Weird, Wonderful

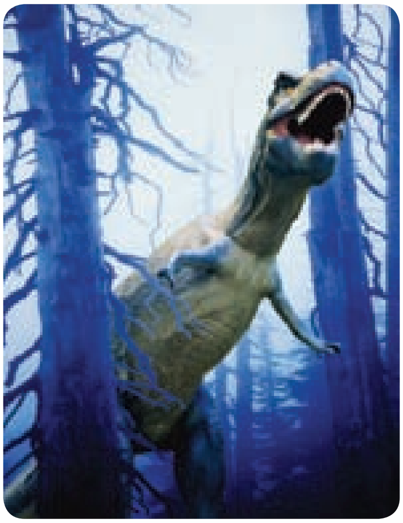
www Science

Iridium—The Densest Substance on Earth

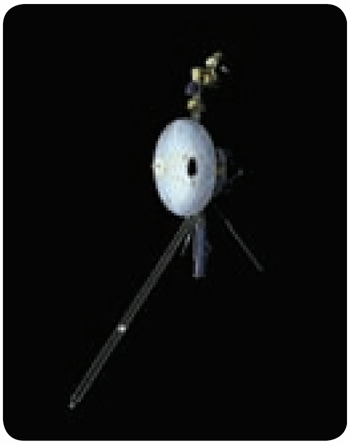
Imagine a substance that is so resistant to heat, its melting point is at 2446°C and its boiling point is at 4428°C. What kind of uses can you think of for a substance like that? The substance is iridium, and it is the densest known substance on Earth. Discovered in 1803, iridium is a very hard and brittle metal that was named after the Greek word *iris*, meaning "rainbow." Although it looks silvery-white, the salts that are in iridium ore are many different colours. Canada is the primary source for iridium, which is a by-product of nickel mining.

With such unique properties, iridium has many uses. It is an ingredient in crucibles, electrical contacts such as spark plugs, and platinum jewellery. It is also used in cancer radiation therapy.

Iridium and the Dinosaurs?



There is one theory that iridium may have caused the extinction of the dinosaurs. All over the world's surface, there is a layer of iridium in the sediment. As iridium is found in meteors, scientists believe that Earth was struck by a large meteor during the time of the dinosaurs. The impact of the meteor would have created clouds of dust all over the world that contained iridium. This dust would have also blocked out the Sun for a long period of time, bringing an end to many plant and animal species, including the dinosaurs.



Iridium is used in unmanned space probes, such as the Voyageur probes, to enclose electrical generators to protect them from high temperatures.

Because of its high tolerance for heat, iridium is often used in making crucibles that can be heated to high temperatures to melt metals.

Iridium is used as a hardening agent in platinum. This allows jewellery, such as these platinum rings, to be more durable.

8-3B Layers of Water

Find Out ACTIVITY

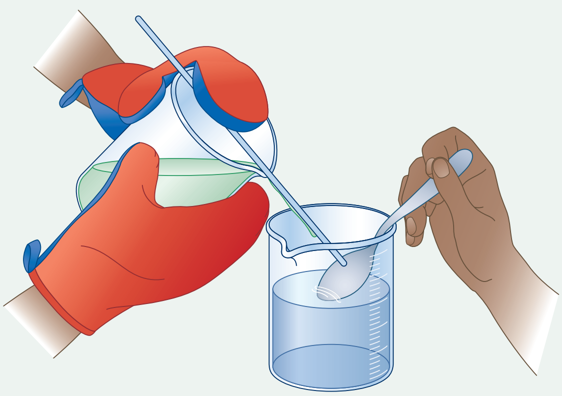
In this activity, you can find out how the temperature of a liquid affects its density.

Safety

- Be careful when handling hot water.

Materials

- two 250 mL beakers
- very cold water
- very hot water
- stirring rod
- large spoon
- food colouring



What to Do

1. Add 100 mL of water to a beaker. Use water as cold as possible from the tap.
2. Add 100 mL of water to the other beaker. Use water as hot as possible from the tap. Do not burn yourself. Use protective mitts to handle your hot water beaker.
3. Add a few drops of food colouring to the hot water and stir.
4. Put the stirring rod across the top of the hot water beaker, and very gently tip it so that the water runs along the stirring rod into the cold water beaker.
5. To make sure the hot water enters gently, have your partner hold the head of the spoon at the top of the cold water level. Pour the hot water into the head of the spoon. Continue pouring very slowly until the beaker is full.
6. Observe your beaker. If you have created two layers, look at them very carefully, especially where the two layers meet. If you do not have two layers, look at the beakers of other students in class.
7. Clean up and put away the equipment you have used.

What Did You Find Out?

1. How does the density of hot water compare to the density of cold water?
2. Occasionally this experiment is unsuccessful with the hot and cold water not forming layers. Provide an explanation, based on the particle theory, as to why the layers sometimes do not form.
3. How does the kinetic energy (energy of motion) and distance between particles compare between hot water and cold water?
4. If you repeated this activity by trying to pour the cold water on top of the hot water, what do you think would be the result? Explain.

Check Your Understanding

Checking Concepts

1. The photograph shows six substances—oil, corn syrup, water, plastic, Styrofoam®, and a grape—layered in a cylinder. Based on how they are layered, place these six substances in a list from lowest to greatest density.

2. A balloon is filled with helium in a cold room. The balloon is taken to a warm room where, after some time, the balloon expands. Has the density of the helium changed? Explain.

Pause and Reflect

A weather balloon is a type of unmanned balloon that takes readings of atmospheric pressure, temperature, and humidity. Unlike hot-air balloons that are usually made of a type of nylon fabric, weather balloons are made with a flexible latex material. Why do you think weather balloons are made of this type of material rather than a nylon fabric?

3. In picture below is an outdoor thermometer. It is made of a small tube with a quantity of coloured alcohol. We can tell how warm or cold it is outside by reading the temperature that is next to the top of the coloured alcohol line. Using your knowledge about temperature and density, explain how the alcohol moves up or down, depending on the temperature.

Understanding Key Ideas

4. Use the particle theory to explain how temperature affects density.
5. Explain why the properties of water are critical for the survival of living organisms in the water during winter.

Chapter Review

Prepare Your Own Summary

In this chapter, you explored fluids by learning how to calculate their densities, and by examining factors that increase or decrease their density. Create your 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:

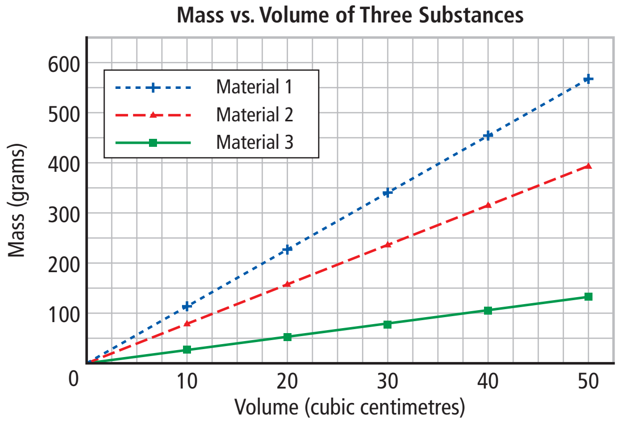
1. Densities of Solids, Liquids, and Gases
2. Calculating Density
3. Effect of Temperature on Density
4. Temperature and Density in Everyday Life

Checking Concepts

1. Define density.
2. Explain density using the particle theory of matter.
3. Why would the contents of two equal sized containers, one filled with water, and the other with water vapour, have two different densities?
4. Using the particle theory of matter, explain why solids can move easily through liquids and gases.
5. Give an example where the liquid state of one substance is denser than the solid state of another substance.
6. Why must the measurement of displacement of water be used in order to determine the density of some objects?
7. Compare and contrast *mass* and *density*.
8. What two factors must remain the same for the density of a pure substance to stay constant?
9. Changes in temperature can often change the density of a substance. Provide one example of this effect. Explain why the temperature change of the substance affects its density.

Understanding Key Concepts

10. The graph below shows the density of three different substances.



(a) Which substance has the largest mass when the volume is 50 cm^3?

(b) Which substance takes up the most space at 100 g?

(c) Calculate the mass-to-volume ratio for each material from the lines on the graph.

11. (a) Plot the following data on a line graph representing mass vs. volume:

Mass (g)	Volume (cm^3)	Mass-to-Volume Ratio (g/cm^3)
15.7	15.7	
39.3	39.3	
55.0	55.0	
82.9	82.9	
94.4	94.4	

(b) Calculate the mass-to-volume ratio for each mass.

(c) Be a sleuth and identify this mystery substance from the densities listed in Table 8.1 on page 312.

(d) Where would the line for a lower-density substance fit on your graph? For a higher-density substance? Indicate these lines on your graph.

12. Explain how you would measure the volume of water in its various states as ice cubes, in a water bottle, and as water vapour.

13. Why is a bag containing 1 kg of feathers much larger than a bag containing 1 kg of gold coins?

14. Do you think density and viscosity are related? Provide one example that demonstrates that they are related and one that demonstrates that they are not related. Use the particle theory of matter to suggest an explanation.

Pause and Reflect

In the human body, some materials are solids, and some are liquids. Gases are found in the lungs and respiratory system. How might you determine the density of at least three of the substances making up the human body?

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.

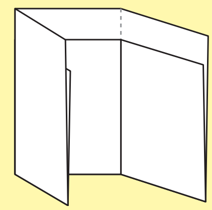
Back on land, fluids are at work around us all the time. When force is applied, fluids can be used for mechanisms such as the brakes in a car, or for the tools that your dentist uses. In this chapter, you will learn about the properties of fluids that make it possible to use them in a wide variety of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

FOLDABLES™
Reading & Study Skills

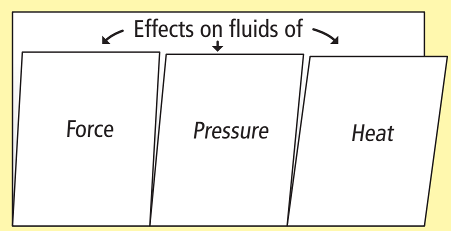
Make the following Foldable to take notes on what you will learn in Chapter 9.

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.

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

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.

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

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.

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.

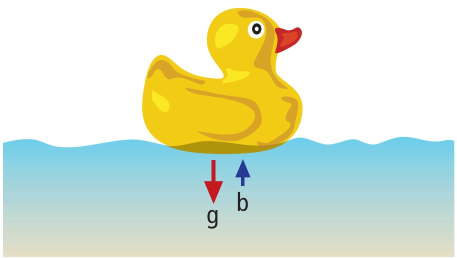


Figure 9.5A The duck weighs more than the volume of water it has displaced, so the force of gravity (g) is stronger than the buoyant force (b) acting on the duck. This means the duck will sink further into the water.

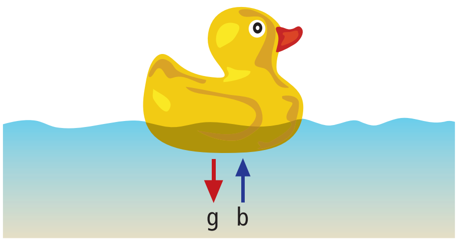


Figure 9.5B The duck has now displaced a volume of water that has the same weight as the entire duck. The force of gravity now equals the buoyant force, and the duck floats.

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.

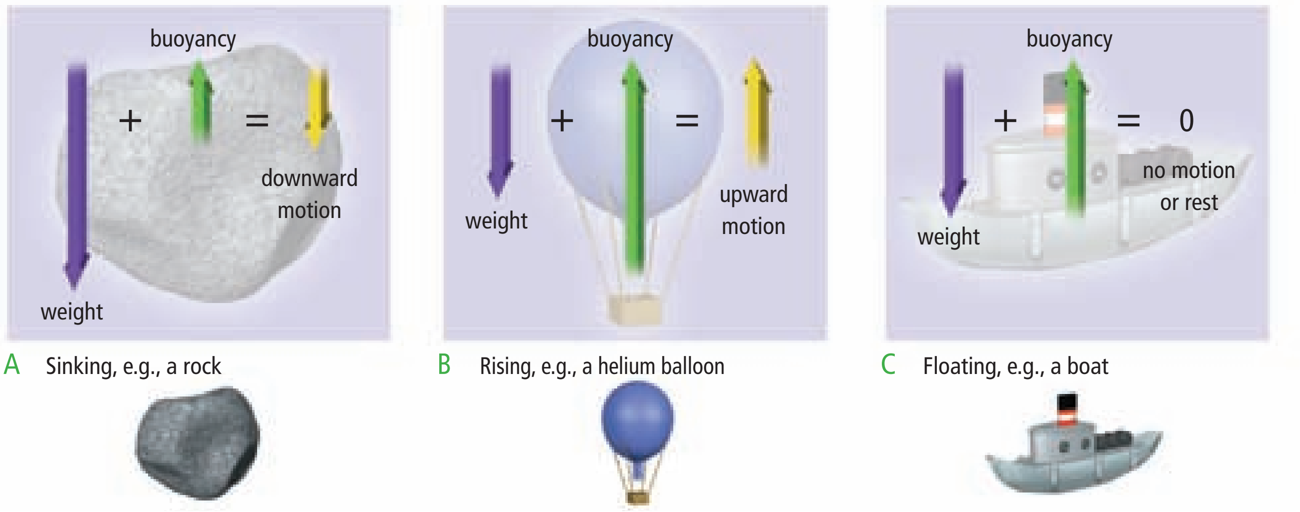


Figure 9.6 The difference between an object's weight and the buoyant force acting on the object will determine whether the object sinks, rises, or floats.

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!

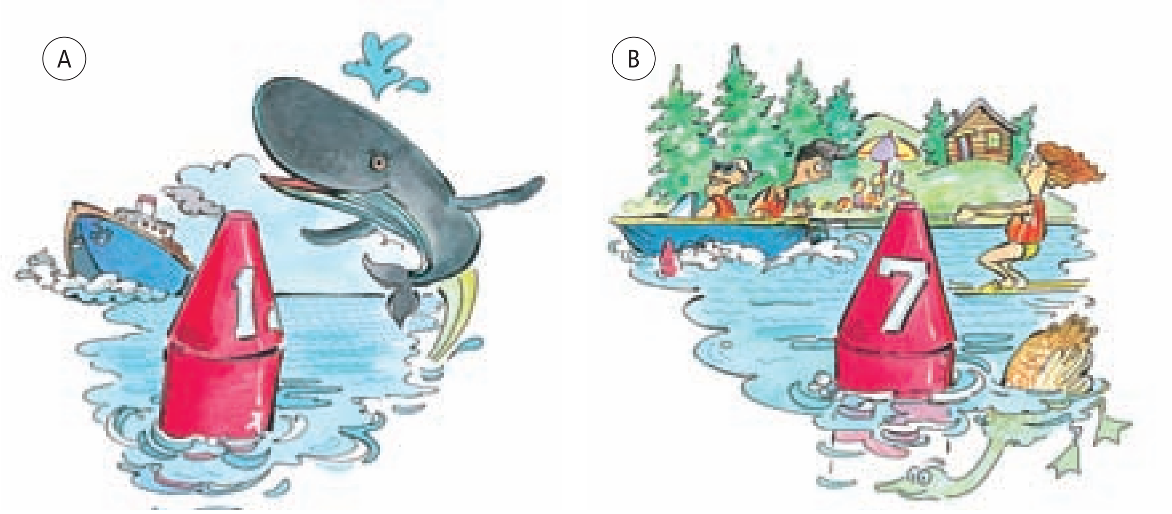


Figure 9.7 Objects experience a greater buoyant force in salt water (A) than in fresh water (B).

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.

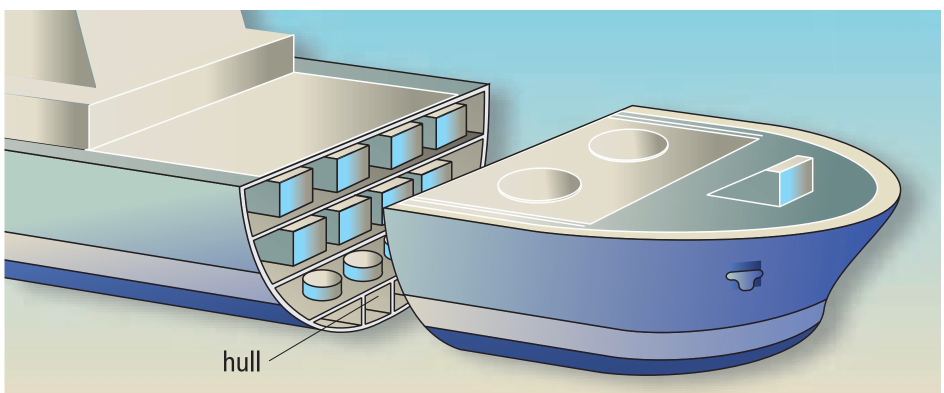


Figure 9.8 By having a large, hollow hull, a ship can float because its average density is less than that of water.

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).

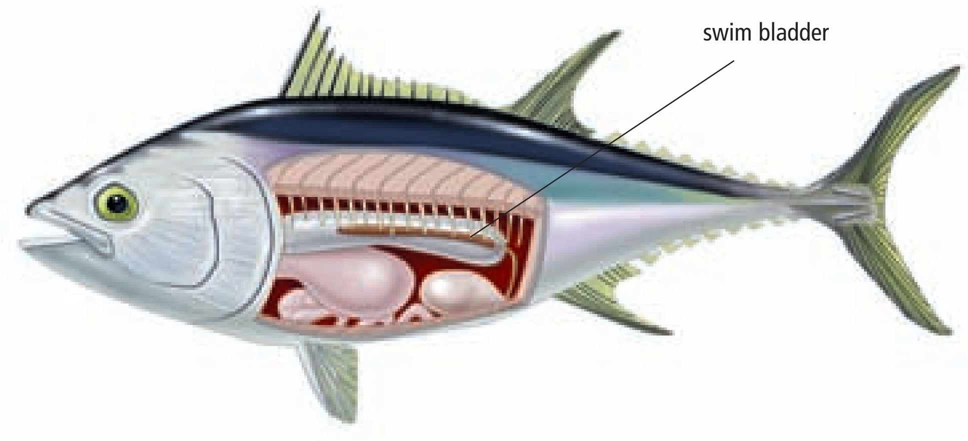


Figure 9.9 Cutaway drawing showing the swim bladder inside a fish. The fish can control its depth in the water by changing the amount of air in the bladder.

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.

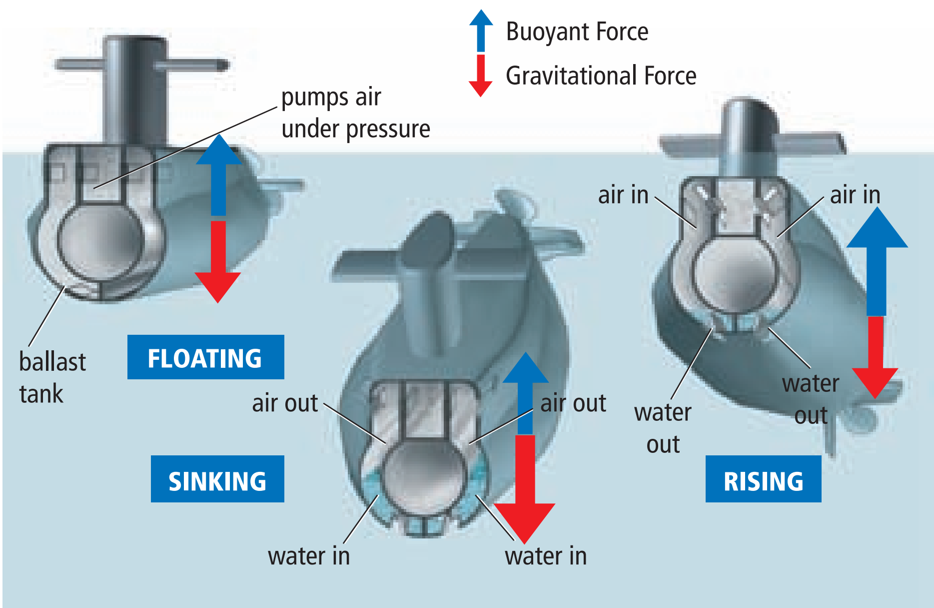


Figure 9.10 Engineers have used the example of a fish's swim bladder to allow crews to control the depth of a submarine. By allowing water to flow in or out, the submarine can rise or sink in the water. The submarine floats when its weight is equal to the buoyant force. The submarine sinks when its weight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

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:

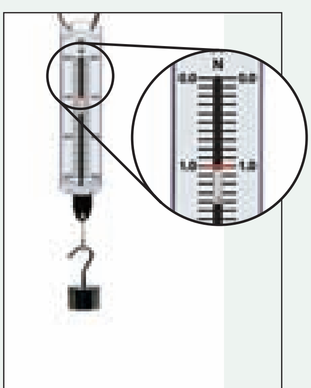
   $F_{\text{buoyant force}} = W_{\text{weight in air}} - W_{\text{weight in liquid}}$

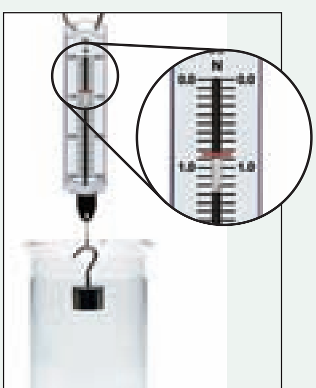
   Using the data in set 1, calculate the buoyant force on the mass in each liquid.
2. Using your calculations from step 1, list the liquids in order of the buoyant force they exert on the mass, from the greatest to the least.
3. Using set 2, list the liquids in order of greatest density to smallest density.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

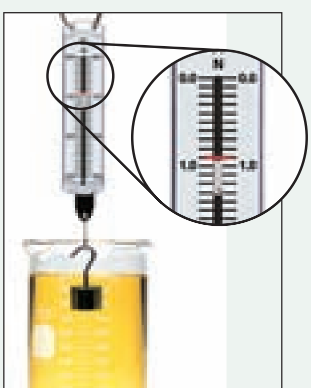
Analyze

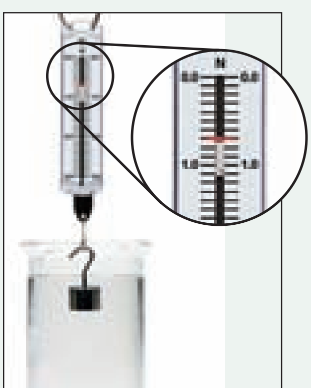
1. Give a reasonable explanation for the relationship you found between the density of a liquid and the buoyant force it exerts on the mass.
2. Using set 2, describe any differences that you see in the hydrometers.
3. How do these differences relate to the buoyant forces that these liquids exert on the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

Set 1

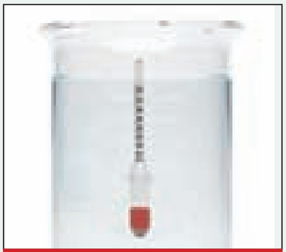

Weight = 1.0 N
100 g mass in air

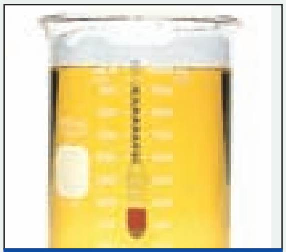

Weight = 0.85 N
liquid 1


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

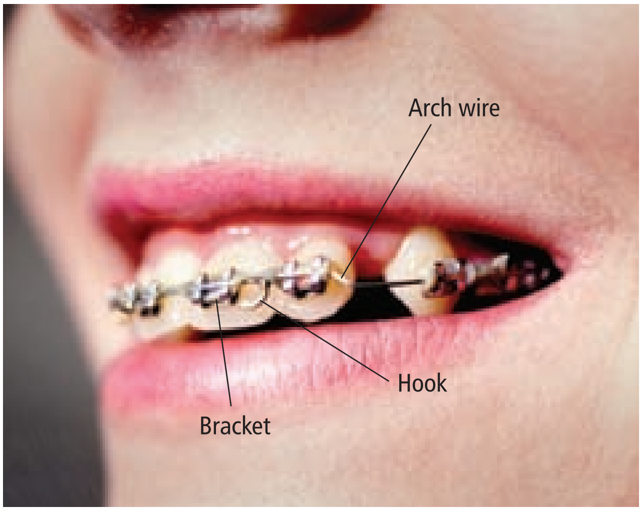

Density = 2.0 g/mL
liquid 3

Science Watch

Brace Yourself for the Force

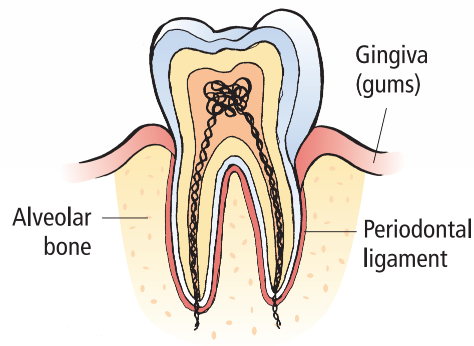
Forces are at work everywhere, but did you know that they at work in a dental office? If you have paid a visit to an orthodontist, you may have a special system of forces at work in your mouth!

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.

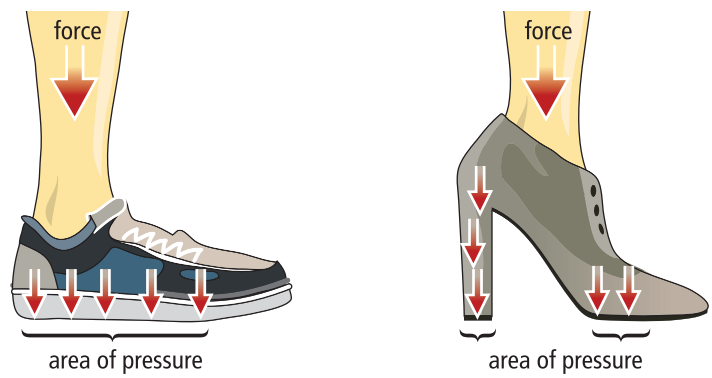


Figure 9.14A and 9.14B High heels exert more pressure on the ground because the pressure is concentrated into a smaller area than a flat shoe.

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?

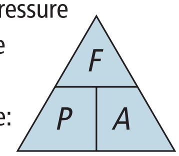
2. Assume that the text book that is sitting on your desk weighs 14 N. If it has an area of 0.60 m^2, how much pressure is the book exerting on the desk?

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.

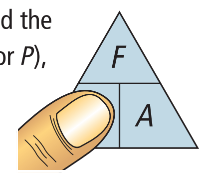
Did You Know?

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.

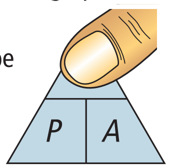
If you wish to find the pressure (solve for *P*), cover up the *P*.



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/m^2. (Remember that Pa is the same as N/m^2.) $A = \frac{4.9\ \text{N}}{1700\ \text{N/m}^2}$
- 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

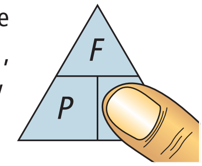
1. A large stack of bricks is sitting at a building site. The total weight of the bricks is 102 000 N. If the bricks exert an average pressure of 153 000 Pa on the ground, what is the area of the ground where the bricks are stacked?

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

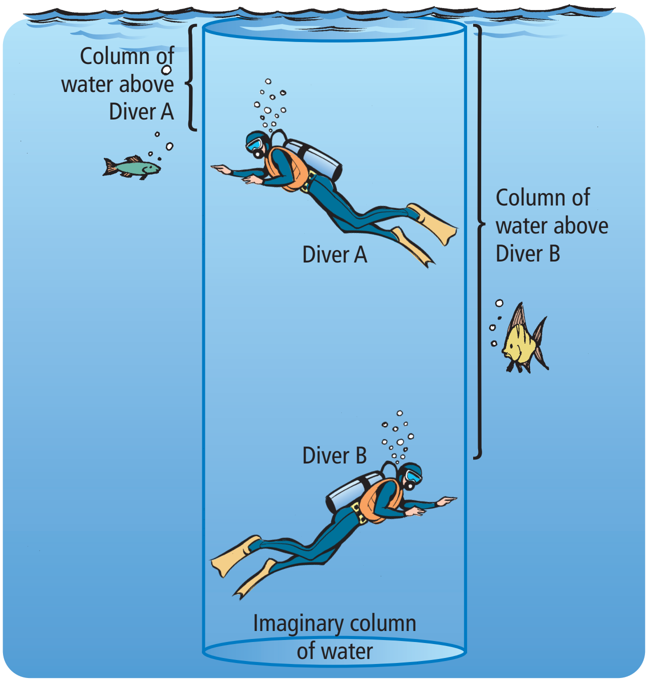


Figure 9.15 As you swim deeper in water, more pressure is exerted on you from the water above.

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**

Suggested Activity

Investigation 9-2D on page 360.

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**.

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.

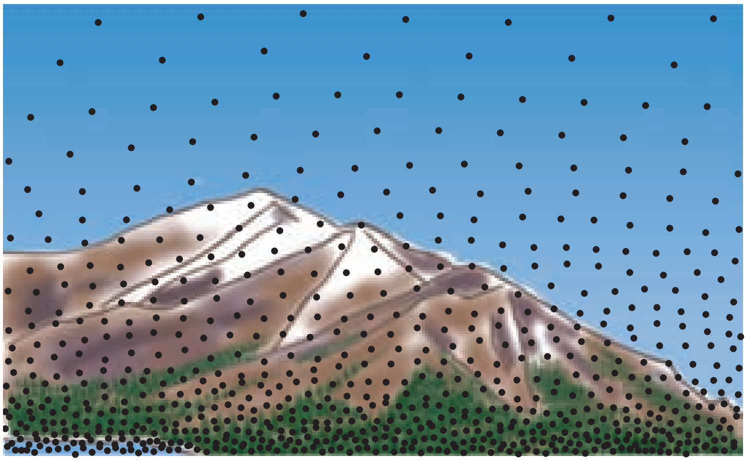


Figure 9.17 Because of Earth's gravitational pull, air particles (represented here by black dots) are most dense near the surface of Earth. The higher you go in altitude, the less dense the air particles, and therefore, the less atmospheric pressure (the amount of force that is exerted by the weight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

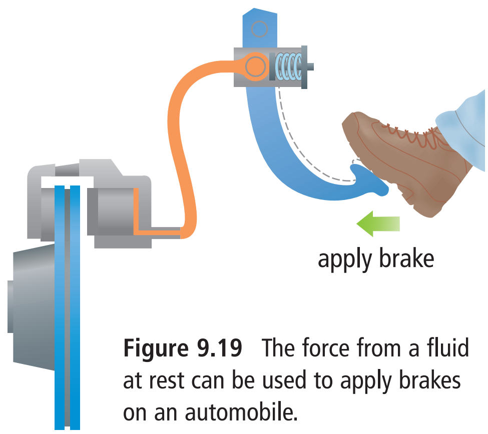


Figure 9.19 The force from a fluid at rest can be used to apply brakes on an automobile.

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

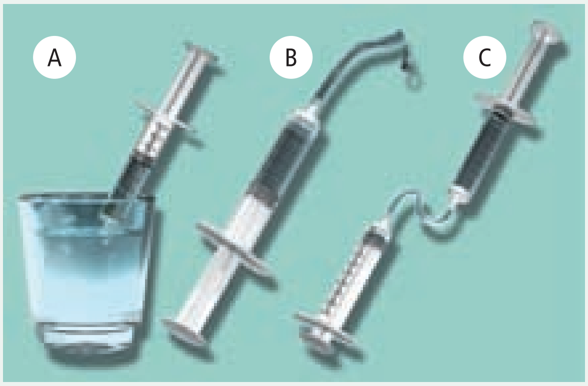
Modified syringes filled with water and joined with plastic tubing provide a simple model of a hydraulic system.

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.

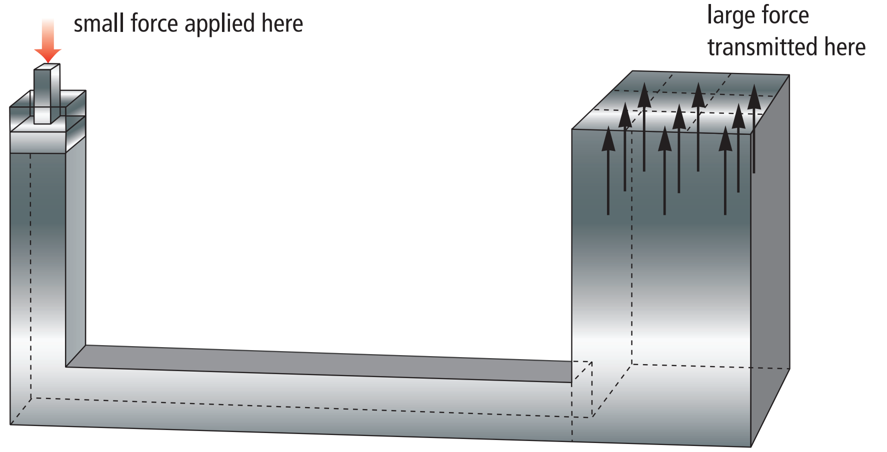


Figure 9.21 This simplified diagram of a hydraulic lift shows how a small force can be transmitted into a large force.

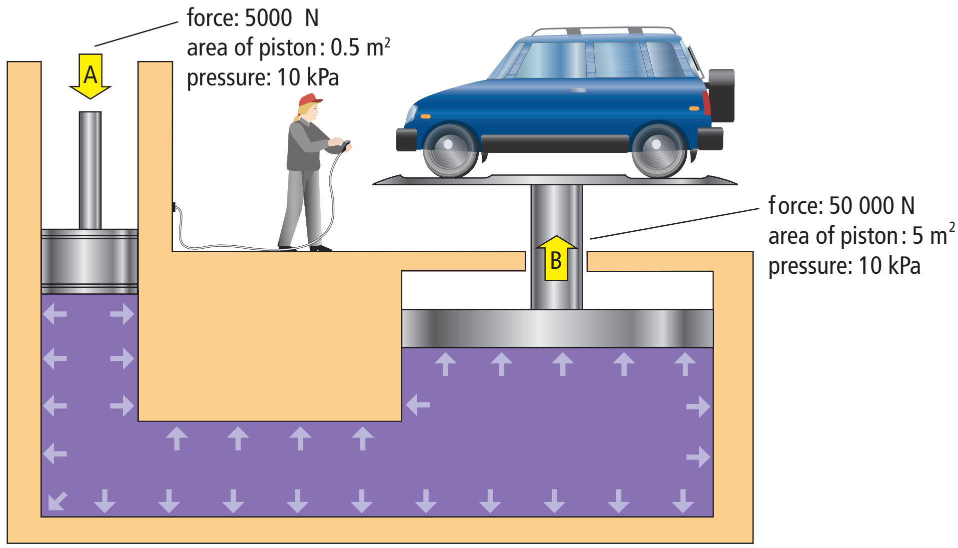


Figure 9.22 Hydraulic multiplication greatly increases force over a relatively small distance.

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?

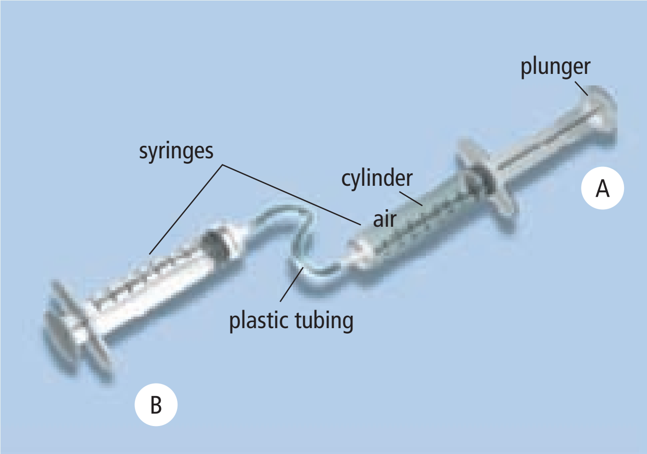
9-2C Exploring Pneumatics

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

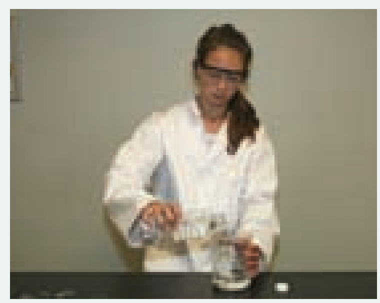
How do the compressibilities of solids, liquids, and gases compare?

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.

Step 2

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.



Step 3

4. Half-fill the other two bottles, one with water and one with sand. Repeat step 2 for each of these bottles.

Step 4

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 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.

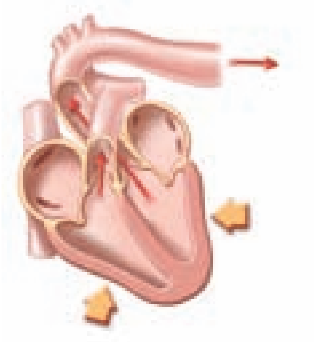


Figure A Heart during contraction. Which valves are open and which valves are closed?

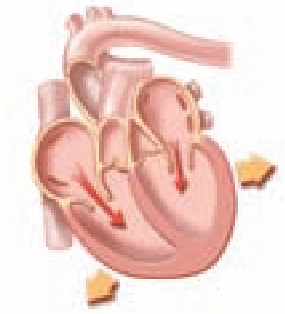


Figure B Relaxed heart, between contractions. Which valves are open and which valves are closed?

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.

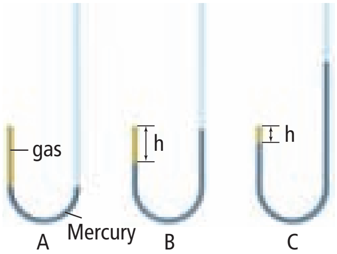


Figure 9.25A Propane gas is compressed into a liquid form that can be stored in special cylinders. The high pressure in the cylinder reduces the volume of the gas so much that the propane enters the liquid state. Why is it important to avoid heating a propane cylinder?

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?

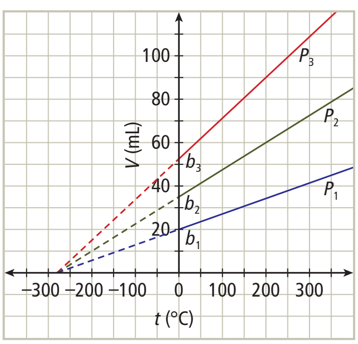
1. What happened to the balloon as you blew into the straw? Which part of the balloon inflated first?
2. Was it harder to blow up the balloon with two books on top of it rather than one? If so, why?
3. How many books were you able to lift by blowing up the balloon?

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.

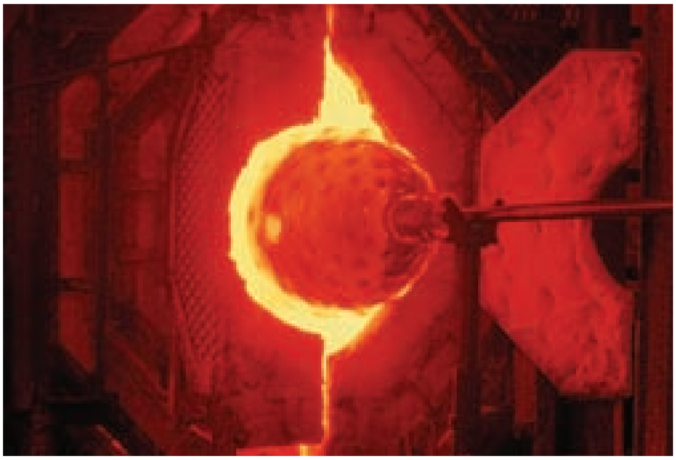
- The particle theory of matter states that solid particles, liquid particles, and gas particles behave differently. (7.1)
- Viscosity is a fluid's resistance to flow. (7.2)
- The viscosity of a fluid is affected by temperature. (7.3)

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

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

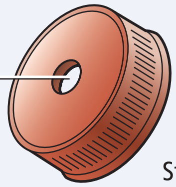
Criteria

- 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

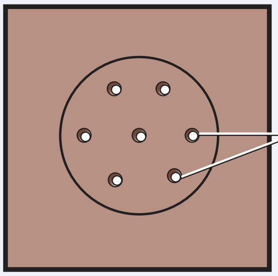
1. Meet with your partner or group and plan your design for your hovercraft with a propulsion system. Keep all of your sketches to attach to your final diagram. Have your teacher approve your plan.
2. Build your model hovercraft. Be sure to record your steps of construction in your design log. Whenever 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.**



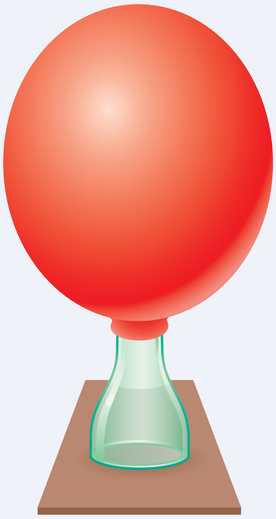
Step 3

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.



Step 6

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

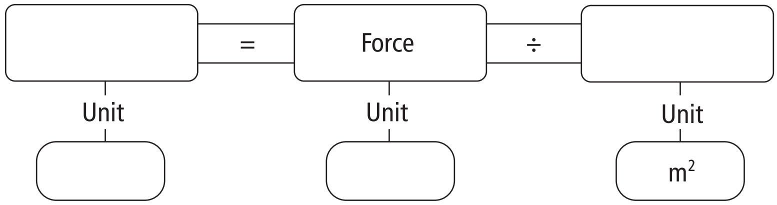
Report Out

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 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?

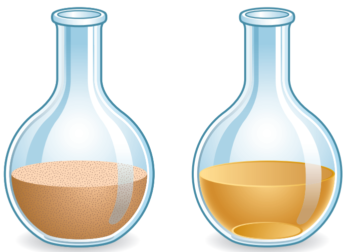
17. How does a hydraulic system differ from a pneumatic system?
18. What change can cause the volume of a gas to increase if the temperature of a gas remains constant?
19. If you increase the temperature of a gas while keeping the pressure on it constant, what change will take place?
20. What can cause 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.

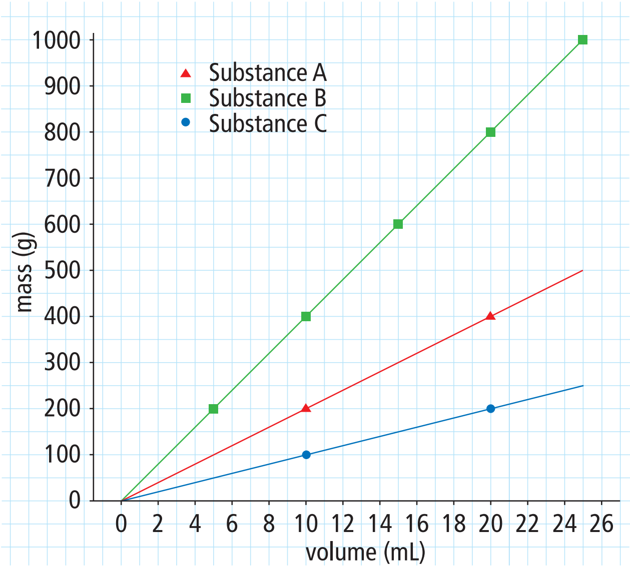


35. Deep-sea exploration vehicles must be built with very thick steel.
    (a) Why?
    (b) What would happen if the structure of the deep-sea vehicle were not strong enough?
36. Aerosol spray cans often have a warning on their label to avoid heating them. Explain, in terms of pressure, what would happen 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.