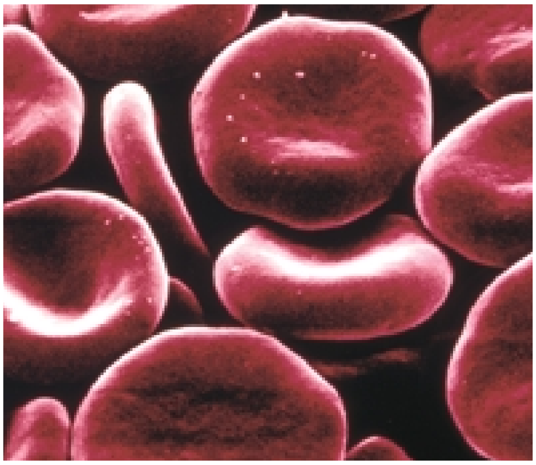
UNIT 1

Mix and Flow of Matter

Rafting … what a rush! As you sweep down a river and manoeuvre against the strength of the rapids, you feel the pull of the swirling pool and invigorating shock of the spray.

Water flowing down a river is an example of **fluidity**, the ability to flow. Wind is another example of a flowing material in nature. Water, air, blood, and any other materials that are able to flow are called **fluids**. Non-fluid materials can behave like fluids if they are melted or dissolved in fluids.



You depend on fluids, such as water and air, in your day-to-day living. Air rushes into your lungs, materials are absorbed into your body after they have been dissolved by water, and blood transports nutrients and wastes in and out of your cells and tissues.

Fluids can also do work. When fluids move, they do so with a force that can be harnessed and used to move mechanical parts in machinery. Enclosed gases, such as in tires and bubble wrap, can be used to absorb the force of impact.

Explore this unit to find out more about how much the technological world depends on fluids and the ability of matter to mix and flow.

Unit Contents

UNIT 1

Preview

Focussing Questions

- What are the properties of fluids?
- How are fluids mixed and separated?
- Which technologies depend on fluids?

How many fluid mixtures can you identify? How do you know that they are mixtures? Do some mixtures look like pure substances? The answers may surprise you. In Topics 1–3 you will learn how fluids can be mixed and separated.

Why is it easier to do a hand-stand in water than in air? How can huge objects like boats float, when a smaller object like a marble sinks? Why does honey flow more slowly than water? What other useful properties do fluids have? Find out in Topics 4–6.

Where will the force come from to stop this heavy load? Simple fluids are behind the enormous strength of a variety of machinery. You will find out why and how in Topics 7 and 8.

Looking Ahead

Look ahead to pages 88–89, A-Mazing Hydraulics. In this project you will work with a group to create and play a game that you design based on the mix and flow of fluids. Start thinking now about ideas for your game. As you work through the unit, watch for information about fluids that will help you in your design. You might wish to

- set up an electronic or paper file for the information you find;
- draw several designs and assess their usefulness as you learn more about fluids; and
- discuss your knowledge with other group members and share design ideas.

TOPIC 1 Matter on the Move

If you have ever watched ketchup pouring from a bottle, you have seen a fluid in motion. You can easily observe fluids such as water flowing out of a tap, milk or juice being poured into a glass, or ketchup oozing from a bottle. Your body contains many fluids, such as blood and the watery cytoplasm inside cells. It is more difficult to imagine gases flowing, but they do. Take a deep breath. What happened? Some of the air that surrounds you flowed into your lungs when your lungs and ribcage expanded. Carbon dioxide flows out of your lungs when you exhale. Like liquids, gases flow and take up space. Therefore, gases and liquids can both be classified as fluids.

Can any solids be classified as fluids? Breakfast cereals seem to flow when you pour them out of the box. Is cereal a fluid? You pour powdered laundry detergent into a washing machine. Is the detergent a fluid? To answer these questions, do the Find Out Activity below.

Find Out ACTIVITY

Can Solids Flow?

Salt is a solid. It can be poured, but can it flow like a fluid such as water? Pour it and find out. Look for evidence that salt is a fluid and evidence that it is not a fluid.

Materials

salt (about 250 mL)
water
2 large plates
2 250 mL beakers

Procedure Performing and Recording

1. Place two large plates on a level surface. While holding your hand steady, slowly pour the salt onto one of the plates. Draw the results.
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.

What Did You Find Out? Analyzing and Interpreting

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?

The Properties of Fluids and the Particle Model

In this unit you will explore the properties of fluids. These properties can help you determine which substances are fluids and how fluids can be used to perform work. The properties of fluids can be explained by looking at tiny particles of matter. In further studies you will be learning about atoms and molecules. These atoms and molecules are believed to be the particles of which materials are made.

In earlier studies you learned about the particle model of matter. In this unit you will revisit the model and use it to help explain the properties of fluids.

The essentials of life — food, water, and air — are examples of substances that occur in the three different states of matter: solid, liquid, and gas. As you learned in earlier science studies:

- **Solid** is the state of matter of a substance that has a definite shape and volume (for example, a sugar cube).
- **Liquid** is the state of matter of a substance that has a definite volume, but no definite shape (for example, water).
- **Gas** is the state of matter of a substance that has neither a definite shape nor a definite volume (for example, oxygen).

By using the particle model, you can explain why liquids and gases flow but solids do not.

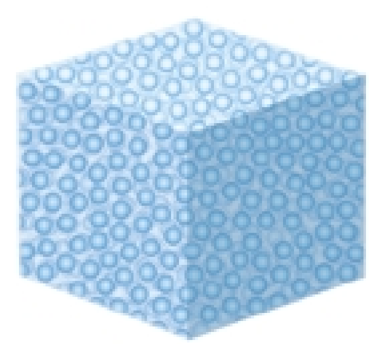
Gas

Particles of a gas completely fill a container. If you removed the stopper in this flask, what would happen to the gas?

Liquid

Liquids take the shape of the container in which they are placed.

Solid



A solid cube of sugar does not need a container to keep its shape.

The particle model of matter involves these key ideas:

1. All substances are made of tiny particles.
2. All particles in a pure substance are the same. Different pure substances are made of different particles.
3. The particles have spaces between them.
4. The particles are always in motion — vibrating, rotating, and (in liquids and gases) moving from place to place. The speed of the particles increases/decreases when the temperature increases/decreases.
5. The particles in a substance are attracted to one another. The strength of the attractive force depends on the type of particle.

Particles in Solids

Viewing matter as particles helps explain the behaviour of solids, liquids, and gases. Solids are made up of particles that are tightly packed together. The particles of a solid are so close together they cannot move around freely — they can only vibrate. This way of thinking about the particles of a solid can explain why solids are greatly affected by gravity. A solid will tumble toward the lowest surface when suspended in the air and then dropped.

Many solids can be ground into small pieces so 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 are examples of solids that can be poured. However, according to the particle model, each tiny fragment of these solids contains billions of even smaller particles that are tightly packed together. Each tiny fragment is like a miniature solid in itself. Solids form a pile when they are poured and they do not keep flowing apart from each other. Even though solids are not true fluids, they can be transported and poured like fluids. You observed this behaviour of solids in the previous Find Out Activity. Are there any other ways that solids can behave like fluids?

Particles in Liquids

The particles that make up liquids have enough energy to pull away from each other. Particles in liquids slide around each other, while at the same time vibrating close together in small clusters. Imagine groups of guests talking and dancing at a party. The party guests can move around by shifting as a group, or by flowing in between the other groups of partygoers. Similarly, liquid particles can slip past each other. Unlike the particles in solids, they do not form rigid clumps. As a result, the particles of a liquid cannot hold their shape; instead, they fill a container and take the shape of that container.

Liquid particles are so tightly packed together that they are easily affected by the downward pull of gravity. Liquids always flow to the lowest possible level, like the water flowing over a waterfall (see Figure 1.1). As well, liquids form a level surface when they are at rest.

Figure 1.1 Liquids always flow to the lowest point possible.

Find Out ACTIVITY

Fluid Circus

What devices do you know that operate on fluid motion? Bring them to school for a fluid circus!

Materials

Bring materials from home that use fluid motion. Some examples are whistles, balloons, and pump-up toys. You might think of many others.

Procedure

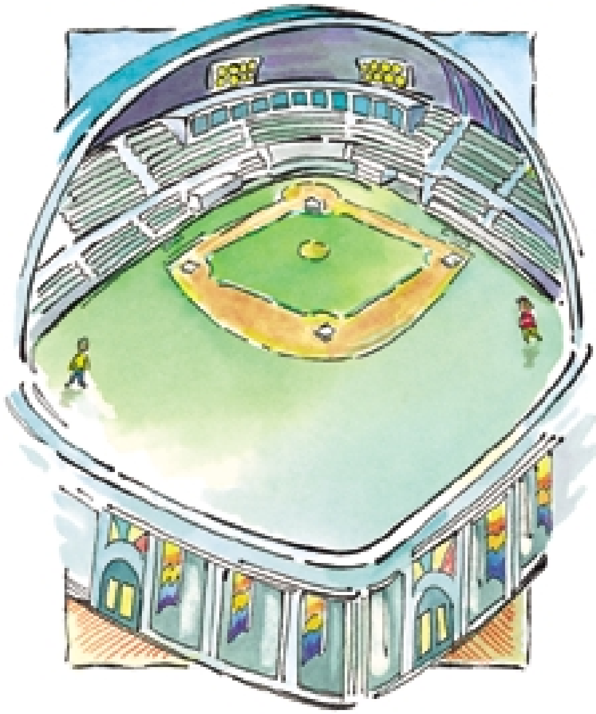
1. Add your objects to the class display.
2. Make a chart in your notebook with the following headings:

Object	Observations	Type of fluid	Reason for movement

3. Complete your chart as you look at the display. Examine the objects and consider how and why they work.
4. Be prepared to explain to the class how these objects work.

What Did You Find Out?

1. Which objects were your favourites? Why?
2. List three other objects in your life that operate on fluid movement.
3. Which state of matter was the most common of the fluids used in the fluid circus?



The distance between yourself and a friend at opposite sides of a stadium can be compared to the distance between gas particles.

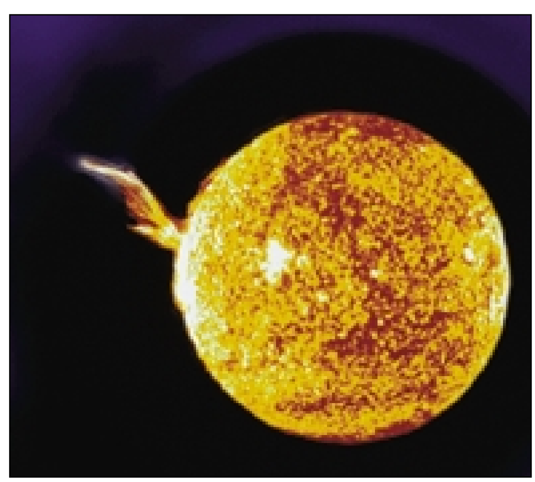
Particles in Gases

All liquids can be transformed into their gaseous state when the liquids are heated. Many substances, such as air, are gases at room temperature. Gas particles are so far apart from each other that there is an enormous amount of empty space between them. Imagine that you and a friend are as far apart from each other as possible in a baseball stadium, and no one else is there. This is similar to what it would be like to be a gas particle. In fact, most gases seem invisible because there is so much empty space. The particle model can be used to explain why gas particles flow past each other easily, move in every direction, and move extremely far apart.

The gas particles spread out so much that in a brief time, they fill up the space of an entire container or room. For this reason, gases, like liquids, take on the shape of the container in which they are sealed. However, most gases do not flow to the lowest possible level as do liquids. Because gas particles are not clustered or packed tightly together, they move in all directions, sometimes against gravity, and remain suspended. Unlike liquids, when the lid is taken off a container of gas, the gas particles will start to spread apart again, until they have filled the entire room or building. The particle model helps us to understand that gases always occupy all the space that they can fill — up, down, or sideways.

Off the Wall

Solids, liquids, and gases are not the most common forms of matter in the universe. The most common form of matter exists in a fluid state called plasma. Plasma is a gaslike mixture of positively and negatively charged particles. When matter is heated to extremely high temperatures, the particles begin to collide violently and to break apart into smaller particles that can conduct electricity. Some scientists consider plasma to be a fourth state of matter. Glowing plasmas occur naturally in stars such as the Sun, and in lightning. A rocket powered by plasma would be capable of much higher speeds than a traditional chemical rocket. The plasma-fuelled rocket could reach Mars in about three months, travelling at a maximum speed of 50 km/s. If the rocket travelled any faster, it would not be able to slow down in time to land on Mars.



Changes of State

As you may recall from earlier studies, all solids can become liquids through the process of melting. Melting is just one example of a change of state, which occurs when the physical state of a substance is transformed into another state (see Figure 1.2). Vaporization, the change from a liquid to a gas, is another type of change of state.

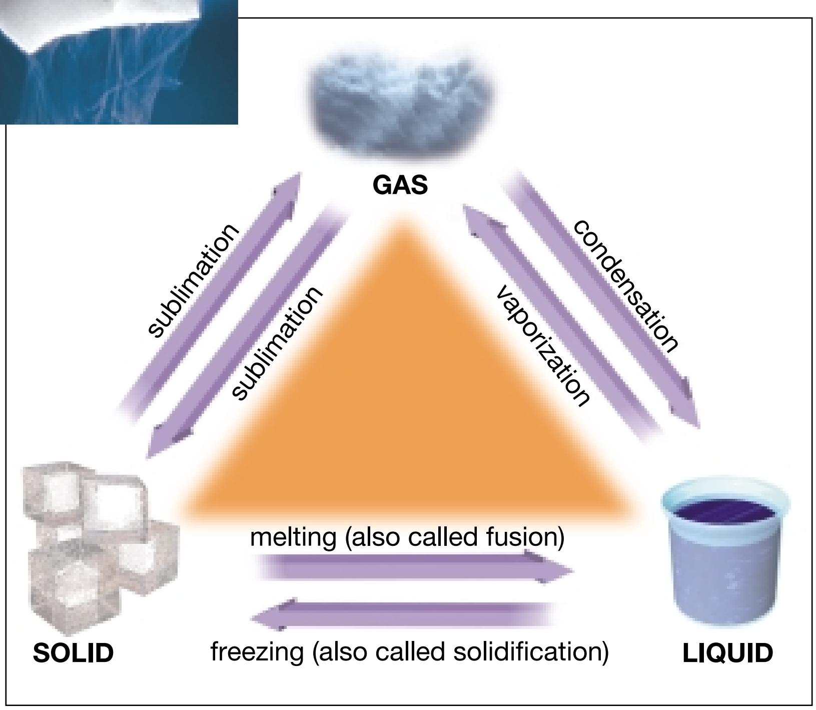
A change of state occurs when a substance is heated and the particles of the substance gain energy. If you were to cool the substance, the reverse changes of state would occur because the particles lose energy. The change from gas to liquid is called condensation. The change from liquid to solid is called freezing.

Sublimation is an unusual change of state that occurs when either a solid turns into its gaseous state or a gas turns into a solid without becoming a liquid first. An example of sublimation occurs when dry ice is used for special effects at a rock concert. A chunk of frozen carbon dioxide (a solid) gains energy and gives off a thick cloud of fog (carbon dioxide gas). Figure 1.2 shows this change of state. An example of a gas changing directly to a solid occurs when frost forms on windows on very cold days.

Off the Wall

Did you know that science fiction script writers often feature changes of state in imaginary ways? "Morphing" has become one of the most popular special effects developed for science fiction movies. By means of computer-generated graphics, characters on screen appear to metamorphose, or morph, into someone or something else. In some movies, for example, solid beings appear to morph into a liquid that can creep under doors, or slip through cracks, and then quickly resolidify. Morphing has also become a popular feature of music videos, television programs, and commercials.

Figure 1.2 Solid carbon dioxide is called dry ice because it does not become a liquid before it becomes a gas. Dry ice is much colder than regular ice. A fog of condensed water vapour forms as air surrounding the dry ice cools.



Word CONNECT

In your Science Log, write a short story that involves "morphing." Include an illustration of the morphing process that occurs in your story.

Figure 1.3 Every substance has its own melting point.

Evaporation is a slower form of vaporization that occurs over a wide range of temperatures. A wet towel will dry even if the air temperature is cool. On a cool day it will simply take longer for the water to evaporate from the towel.

Boiling is a more rapid form of vaporization that occurs at a specific temperature, called the boiling point. The boiling point of water is 100°C (at sea level).

Every substance has its own freezing point and melting point. The freezing point of water, for example, is 0°C (at sea level). This is the temperature at which liquid water freezes. It is also the temperature at which ice melts — its melting point. Figure 1.3 illustrates the melting point of two other substances: paraffin (wax) and silver. The pictures show how the properties of a substance, such as the melting point, can have valuable uses. When normally solid substances are melted, the liquid can be poured into moulds of various shapes. When the substance is cooled, it solidifies and takes the shape of the mould. The result can be a wax candle, a silver teapot, or many other products.

Computer CONNECT

How are plastic shopping bags made? Why is Styrofoam™ fluffy? What is a "thermoplastic"? Investigate how changes of state are used throughout the plastics packaging and container industry, or in recycling plastics. Choose one type of plastic, and prepare a scrapbook of downloaded information about its properties, its use, how it is heated, how it is shaped, and if it can be recycled.

TOPIC 1 Review

1. In your own words, what does "to flow" mean?
2. How could you test whether or not a substance is a fluid?
3. A substance has a definite volume but an indefinite shape. Is the substance a solid, a liquid, or a gas?
4. **Apply** Name a product (not mentioned earlier) that depends on changing state for its formation.
5. **Apply** Use the particle model to explain why ice cubes form in your freezer.
6. **Thinking Critically** Describe a place or a situation in which you could find water as a solid, a liquid, and a gas all at the same time.
7. **Thinking Critically** Which substances could you use to demonstrate "morphing"? Are these substances fluids? For each substance, explain your answer.

TOPIC 2 Mixing and Dissolving

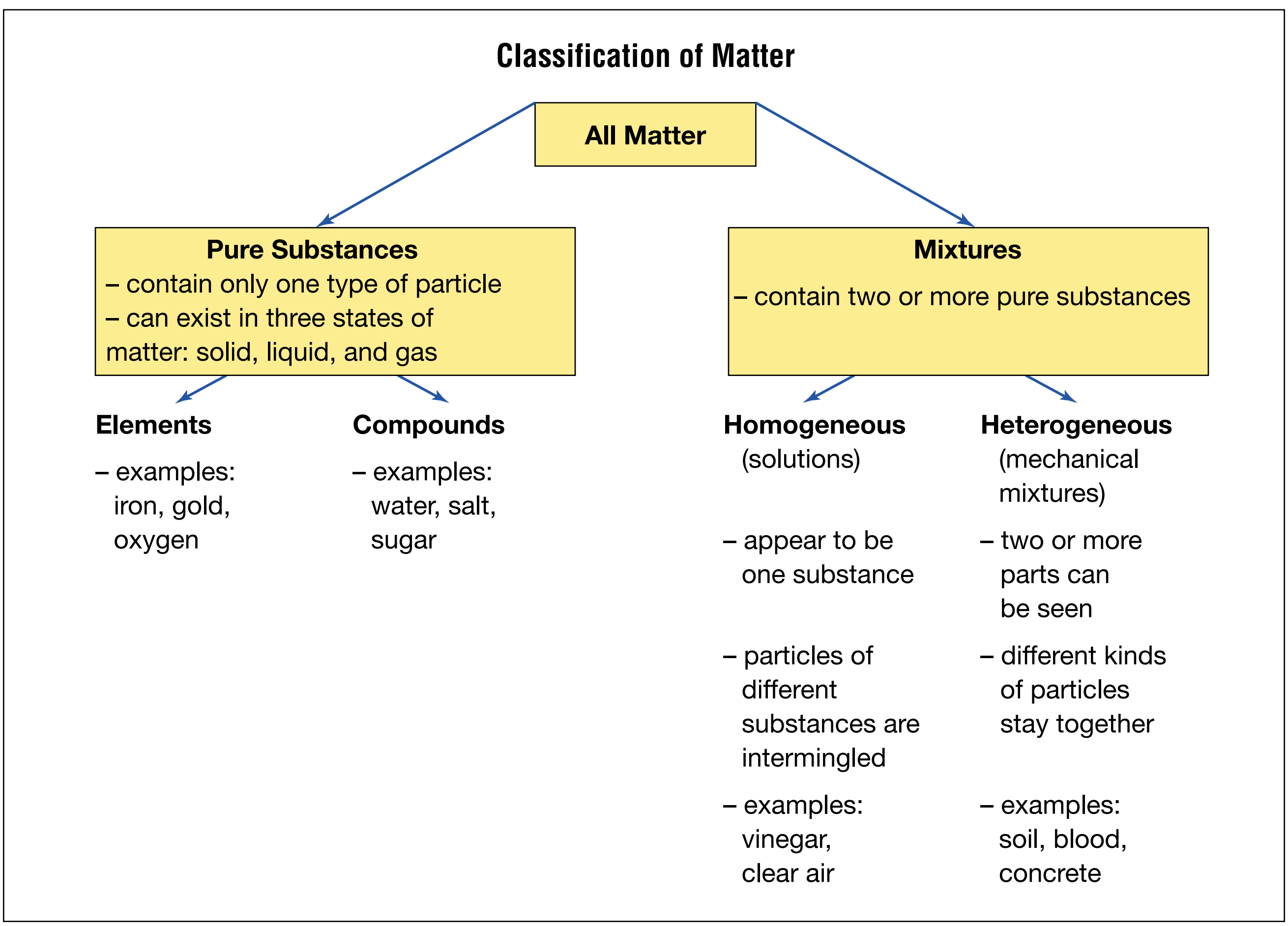
Figure 1.4 Which substances might have been mixed to form the paint for this cave drawing?

One of the earliest signs of human life on Earth is the existence of paintings of bison, human hunters, and other animals on cave walls (see Figure 1.4). Even though the paint was simple, it survived thousands of years. What is paint?

Paint is simply a two-part mixture: the *pigment* (the solid colour) and the *vehicle* (the liquid that carries the pigment to the surface being painted). In order to make a consistent, reliable paint, pure ingredients are used. Each pure ingredient is a pure substance, a material that contains only one kind of particle.

For example, metals such as iron and gold, and non-metals, such as oxygen, sulphur, and carbon, are pure substances. Chemical compounds, such as water, table salt, and sugar, are also pure substances. All pure substances can exist in the three states of matter. Each pure substance has its own set of physical **properties**, or characteristics, such as colour, odour, and hardness.

A **mixture** such as paint contains two or more pure substances such that each one's properties are not lost but may be hidden.



Homogeneous Mixtures

Mixtures that *look* as though they have only one set of properties, such as paints, are called **homogeneous**. These mixtures are blended so thoroughly that every sample of the mixture will contain equal amounts of all matter that make it up. Therefore, "homogeneous" means that every part of the mixture is the same.

A homogeneous mixture of substances in which no settling occurs is a **solution**. According to the particle model, solutions occur when the particles of the components slip in between each other in an even distribution throughout the entire mixture. A solution of water and sugar contains particles of both water and sugar. It is homogeneous because the sugar and water particles are evenly scattered at the particle level, as shown in Figure 1.5. The solution has one set of properties using some of the properties of sugar and some of water. The other properties stay hidden.

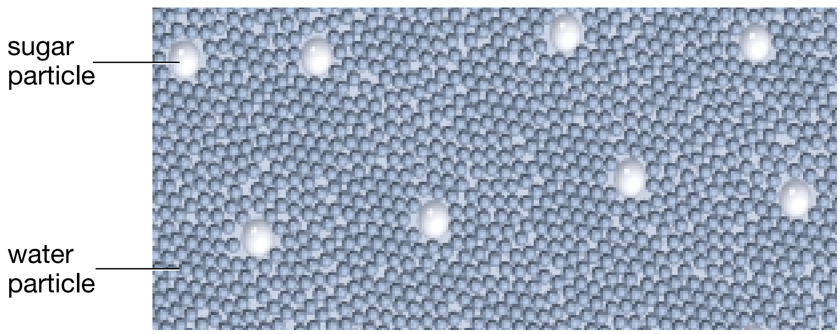


Figure 1.5 The particle model can be used to illustrate a sugar and water solution. Every sugar particle has all the properties of sugar. Every water particle has all the properties of water. The solution blends the properties of both.

Heterogeneous Mixtures

What colour is a rock? Rocks might *look* grey from a distance, but upon careful inspection, they could contain white, grey, pink, or other colours, as seen in Figure 1.6.

Figure 1.6 Which properties of minerals can you detect in these rocks?

The properties of minerals in rocks are not hidden. Some minerals might be white, shiny, and smooth, and others might be black, dull, and rough. On close inspection, you can tell that a rock is a mixture and not a pure substance.

Mixtures that contain two or more materials that are still visible are called **heterogeneous** mixtures. "Heterogeneous" means made up of parts, or mixed.

Figure 1.7 What type of mixture will each beaker contain after the water is poured and mixed?

In-Between Mixtures

It can be difficult to determine correctly whether a mixture is homogeneous or heterogeneous without using a magnifying glass. Orange juice might appear to be a solution, but eventually the natural fruit sediment can settle. A heterogeneous mixture in which the particles settle slowly after mixing is a **suspension**. Suspended particles are large enough to be trapped by most fine filters. Other examples of suspensions are Italian salad dressing and clay mixed with water.

Homogenization helps the fat globules in milk stay dispersed longer than suspended particles. A heterogeneous mixture in which the particles do not settle is a **colloid**. Colloidal particles are small enough to pass through most common filters. The particles in a colloid can be dispersed for an even longer period by adding an emulsifying agent to form an **emulsion**. Mayonnaise is an example of an emulsion. The emulsifying agent is often a protein that prevents the tiny droplets of fat from joining together.

Mixtures that are obviously heterogeneous are usually called **mechanical mixtures**. The separate parts of a mechanical mixture are called **phases**. For example, when oil separates from water, two distinct phases are visible. As well, the bubbles in soda water make up one phase, and the liquid portion makes up the other phase.

DidYouKnow?

Fog is an example of a colloid.

INQUIRY INVESTIGATION 1-A

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Inspector's Corner

How can you determine whether a substance is a homogeneous or heterogeneous mixture? Your task in this investigation is to inspect several beverages, plus five materials commonly found in a kitchen and five materials commonly found in a bathroom or laundry room.

Question

How can common household products be classified as homogeneous and heterogeneous mixtures?

Hypothesis

Make a hypothesis about the features of homogeneous and heterogeneous mixtures that will help you identify them.

Safety Precautions

Apparatus

magnifying glass

Materials

a variety of common household mixtures, such as milk, orange juice, jam, salsa, toothpaste, cereal, and soap.

Procedure

1. **Prepare a data table** for your observations, with the following headings:
   Product
   Observations
   Heterogeneous or Homogeneous
   Reason for Choice
2. **Observe** each product carefully. **Record** your observations in the table.
3. Decide whether the product is heterogeneous or homogeneous. **Record** your choice in the table.
4. Under "Reason for Choice" in the table, **identify** and **describe** which features of the material led you to your decision.
5. Put away all materials and apparatus, and clean any spills.

Analyze

1. **Propose a standard test** or rule (an operational definition) that will work each time to correctly identify a material as homogeneous or heterogeneous.

Conclude and Apply

2. **Re-examine** your hypothesis. How well did your test results support your hypothesis? Modify your hypothesis to reflect your findings.
3. Compare your conclusions with those of other students. Which products were easier to classify? Which ones were more difficult? Why?

What Makes Materials Dissolve?

When you stir salt into a glass of water, it forms a homogeneous mixture — a solution of salt and water. Forming a solution by mixing two or more materials is called **dissolving**. Salt dissolves in water. Mixing materials together does not always make a solution, however. Neither orange juice nor milk is a solution. The pulp of the orange does not dissolve, and neither does the milk fat. Why do these materials not dissolve? What determines whether or not materials dissolve?

Suppose you add sugar crystals to water. What happens to the attraction among sugar particles when you place sugar crystals in water? Why does each sugar crystal break up and dissolve?

Recall these points from the particle model:

- Particles attract each other.
- Particles are always moving.

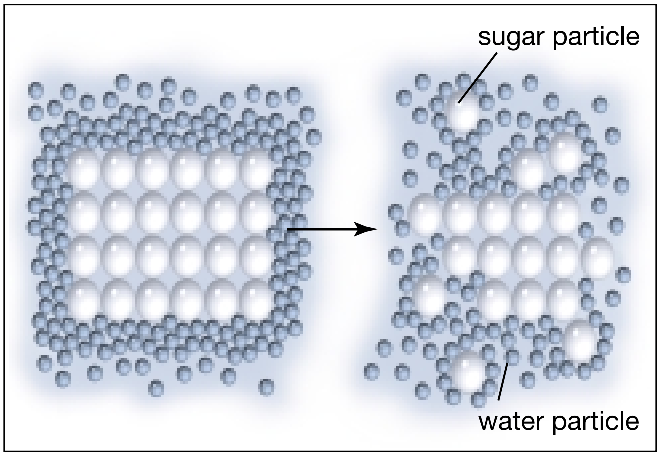


Figure 1.8 The particle model helps us to explain how dissolving occurs.

A group of water particles can attract a sugar particle more strongly than the other sugar particles around it can. Figure 1.8 shows what happens to sugar particles on the edge of a crystal. First the water particles pull a sugar particle away from the other particles in the crystal. Then the motion of the water particles carries it away. This makes room for more water particles to move in and attract another sugar particle. This process continues until all of the sugar is dissolved. Particles of sugar gradually move around and mix evenly throughout the water.

A similar process is at work in a drop of water left on a table. The water particles are attracted to each other, but are always moving. Some particles are on the outside of the drop. The particles on the outside of the drop occasionally escape into the air. Over time, all of the particles escape because the attractions of the water particles to each other are not strong enough to hold them together in the liquid state (see Figure 1.9).

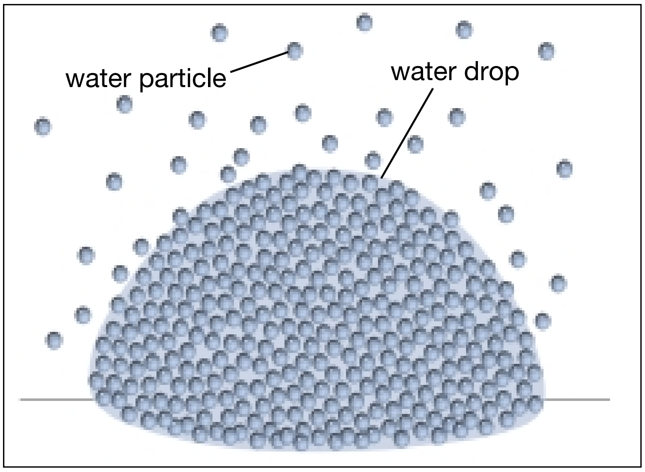


Figure 1.9 Evaporation occurs when a liquid changes to a gas.

Pause & Reflect

Fill a glass with cold water, and let it sit for a few seconds until the water is still. Gently pour one level teaspoonful of a powdered drink mix into the bottom of the glass. Do not stir. Check the glass the next day. Using the particle model, write a brief description in your Science Log of the changes you observe.

Solutes and Solvents

When sugar dissolves in water, we call the water the solvent and the sugar the solute. The **solute** is the substance that dissolves in a solvent to form a solution. There is usually less solute than solvent in a solution. The **solvent** is the substance that dissolves a solute to form a solution. There is usually more solvent than solute in a solution.

Figure 1.10 Nail polish remover can be used as a solvent for some materials that are not soluble in water. Because it is such an effective solvent, however, it may also dissolve plastic, making marks on counters and tabletops.

Another way to say "sugar dissolves in water" is to say "sugar is soluble in water." **Soluble** means able to be dissolved in a particular solvent. For example, sugar is soluble in water. Both solutes and solvents may be solids, liquids, or gases. Table 1.1 shows some examples.

Table 1.1 Examples of Solutions in Solid, Liquid, and Gaseous States

Example	Made up of	States of matter	
		Solute	Solvent
air	oxygen, other gases in nitrogen	gas	gas
humid air	water vapour in air	gas	gas
soda water	carbon dioxide in water	gas	liquid
vinegar	acetic acid in water	liquid	liquid
ocean water	various salts in water	solid	liquid

DidYouKnow?

A group of Swedish dentists and chemists have developed a mixture that may replace the use of the drill for filling certain cavities. The mixture dissolves decayed dentine in teeth. The red gel, called Carisolv, is a mixture of three amino acids and a weak solution of sodium hypochlorite. The sodium hypochlorite solution dissolves the rotten tissue of the tooth. Amino acids attract the dissolved parts. The whole process can be accomplished in less than 30 s with very little discomfort to the patient.

Water — the Universal Solvent

Two-thirds of Earth's surface is covered with water. Water has been called the "universal solvent" because it can dissolve so many materials.

Figure 1.11 Water does not discriminate — it dissolves life-threatening pollutants as easily as life-giving nutrients.

Water is crucial for the survival of all living things, second only in importance to oxygen. Approximately half of your blood is made up of water. The water portion of your blood dissolves and carries food molecules, vitamins, minerals, and other essential substances to all parts of your body. Blood carries dissolved wastes away from your body cells, too. Plants also need water to deliver nutrients and remove wastes. Sap contains water and nutrients that are "picked up" from the roots and other storage locations in the plant. These nutrients are dissolved and then transported in solution to every part of the plant.

The Rate of Dissolving

When we measure how fast a solute dissolves in a solvent, we are measuring the **rate of dissolving**. What factors do you think might affect the rate of dissolving?

Consider what happens when you mix flavour crystals with water. **Agitation** (stirring or shaking) helps the solutes dissolve faster. When the mixture is agitated, water that was near the crystals is pushed far away. Water that was far from the crystals is moved closer to them. The water particles that are near the crystals have a much lower concentration of flavour crystal particles. These water particles can exert a greater force of attraction on the flavour crystal particles.

Agitation is one way of making a solute dissolve faster. Are there other ways? Think about what lasts longer in your mouth — a whole candy, or one that you've crunched up? When the solute is in smaller pieces, there is more surface area where dissolving can occur. Temperature and pressure also affect the rate of dissolving.

Did You Know?

Considering how useful and necessary water is, we are fortunate to have such a plentiful supply on Earth! However, 97 percent of the water on Earth is ocean water, full of dissolved materials. Over 2 percent of the water is frozen in the Arctic and Antarctic. Only about 0.5 percent of Earth's water is usable "fresh" water, but because water is such a good solvent, even fresh water also contains many solutes. Some of these are harmless, but others are not. Water is easily polluted because it mixes readily with so many materials.

Ask an Expert

Turn to page 86 to find out how Gamini Dassayanke uses his knowledge of solutions to treat waste water.

How Much Can Be Dissolved?

The particles of one pure substance are not the same as those of another, so the degree of attraction is different for different substances. The limit to how concentrated a solution can become is called solubility. **Solubility** refers to the mass of a solute that can dissolve in a given amount of solvent to form a saturated solution at a given temperature.

A **saturated solution** is one in which no more solute will dissolve in a specific amount of solvent at a specific temperature. An **unsaturated solution** is one in which more of the solute could dissolve in a specific amount of solvent at the same temperature.

For example, scientists have determined that no more than 35.7 g of salt will dissolve in 100 g of ice-cold water (at 0°C). So the solubility of salt is 35.7 g/100 g of water. Table 1.2 shows the solubility of several common substances. Note that solubility is stated in grams. How many grams of each of these substances will dissolve in 100 g of ice-cold water?

Table 1.2 Solubility of Some Common Substances

Substance	State	Solubility (g/100 g of water)
alum	solid	11.4
baking soda	solid	6.9
canola oil	liquid	insoluble
carbon dioxide	gas	0.34
copper(II) sulfate	solid	31.6
Epsom salts	solid	70.0
ethyl alcohol	liquid	unlimited
limestone	solid	0.0007
nitrogen	gas	0.003
oxygen	gas	0.007
salt (sodium chloride)	solid	35.7
sugar (sucrose)	solid	179.2

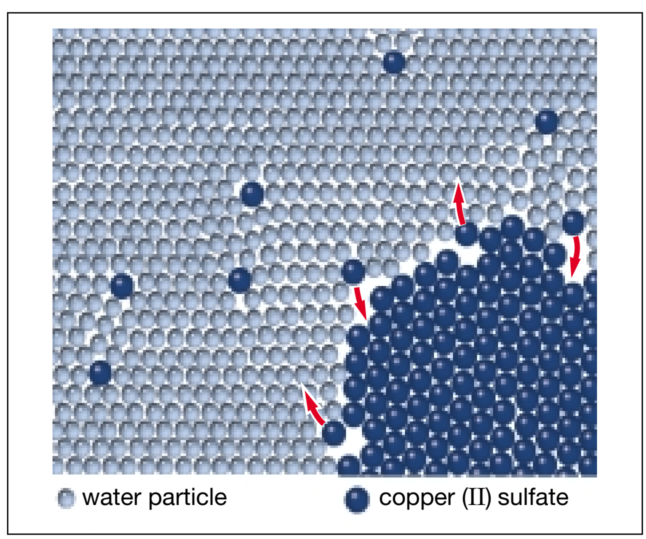


Figure 1.12 The particle model can be used to explain how a substance, such as copper(II) sulfate, reaches a point where no more of the substance will dissolve.

As stated on the previous page, there is a limit to how concentrated most solutions can become. When you prepare a solution, you reach this limit when no amount of stirring can make more solute dissolve in the solvent. At this point, the solution is said to be saturated.

How can the particle model explain saturated solutions? Look at the photograph and the diagram in Figure 1.12. The photograph shows crystals of copper(II) sulfate in a saturated copper(II) sulfate solution. According to the particle model, no more solid dissolves because all of the water particles are already attracted to as many copper(II) sulfate particles as they can be. No additional water particles are available to attract more copper(II) sulfate particles away from the copper sulfate crystals, even though individual particles are moving.

Beyond the Limit: Supersaturated Solutions

It is possible to pass the saturation limit in some solutions. A solution that contains more solute than would normally dissolve at a certain temperature is called a **supersaturated solution**. You can prepare a supersaturated solution from some solutes by making a saturated solution, then cooling it without stirring. The solute stays dissolved for a short time. When a small crystal of solute is added, the extra solute quickly becomes crystals, as shown in Figure 1.13.

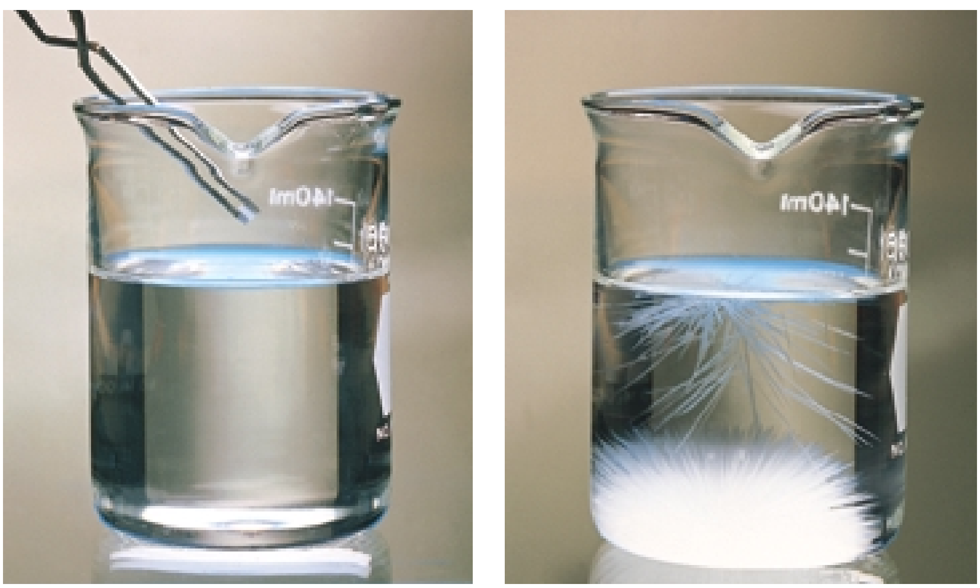


Figure 1.13 The solution of sodium acetate on the left is still homogeneous. No solid crystals have come out of the solution — at least, not yet. When a single crystal enters the supersaturated solution shown on the right, the excess solute crystallizes almost instantly.

Math **CONNECT**

Suppose that you are dissolving a solute into 550 g of water at 0°C. You find that no more than 495 g of solute will dissolve. Calculate the solubility of the solute.

Computer **CONNECT**

Suppose that you work in the school laboratory, making solutions for teachers to use in their classes. Use the information in Table 1.2 to prepare a spreadsheet or database showing the number of grams of solute that are needed to make 10 mL, 50 mL, 100 mL, 500 mL, and 1000 mL of the following saturated solutions at 0°C: alum, copper (II) sulfate, Epsom salts, salt, sugar.

Pause & Reflect

Imagine that you are conducting a test for saturation. Add a small amount of solute to a solution. In your Science Log, explain what the following results would tell you, using the words "saturated," "unsaturated," and "supersaturated."

- The crystal of solute dissolves.
- The crystal of solute does not dissolve.
- Many more crystals form.

INQUIRY

INVESTIGATION 1-B

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Solubility Solutions

Mining companies often use solutions to help transport and separate the valuable ore from the surrounding rock. Your investigation group has been hired to make a saturated solution of a substance for a company that wants to use the solution to transport some new minerals they have discovered. The group that creates the most accurate results in the shortest time will receive the contract. Remember to be accurate in all your measurements.

Question

Which solute has the greatest solubility in water?

Saftey Precaution

Apparatus

test tubes
rubber stoppers for test tubes
metric spoon (1mL)
graduated cylinder
paper funnel
electronic balance

Materials

table salt
sugar
potassium nitrate
baking soda
copper (II) sulfate
water

Procedure

1. Choose which solute your group would like to test. Get approval from your teacher.
2. Obtain the correct equipment and the solute from the assigned area.
3. Read the investigation. **Design a table** to collect the data.
4. **Measure** the mass of 1 mL of the solute you have chosen on the electronic balance.
5. Pour 10 mL of water into a test tube. Add 1 mL of the solute to the water. (It is easier to add a dry powder to a test tube if you make a paper funnel out of half a sheet of paper.) Put a stopper in the test tube and shake the solution until the solute has completely dissolved.
6. If all of the solute dissolves, you have created an unsaturated solution, so you must add more solute. Continue adding solute to the test tube until no more solute will dissolve. **Record** how much solute you add each time. When a small amount of solute remains in the bottom of the test tube, you have created a saturated solution.
7. Repeat 2–3 times.
8. **Calculate** the average amount of solute that can dissolve in 10 mL of water by calculating the average of your trials. **Record** the results on the chalkboard. State your results as grams of solute per 100 mL of solution.
9. **Record** the results of all other groups.
10. Dispose of the solutions as directed by your teacher. Wash your hands when you have completed the investigation.

Analyze

1. Which solute used by the class was the most soluble in water? Which was the least soluble?

2. Which solute used has particles that are the most attracted to water?

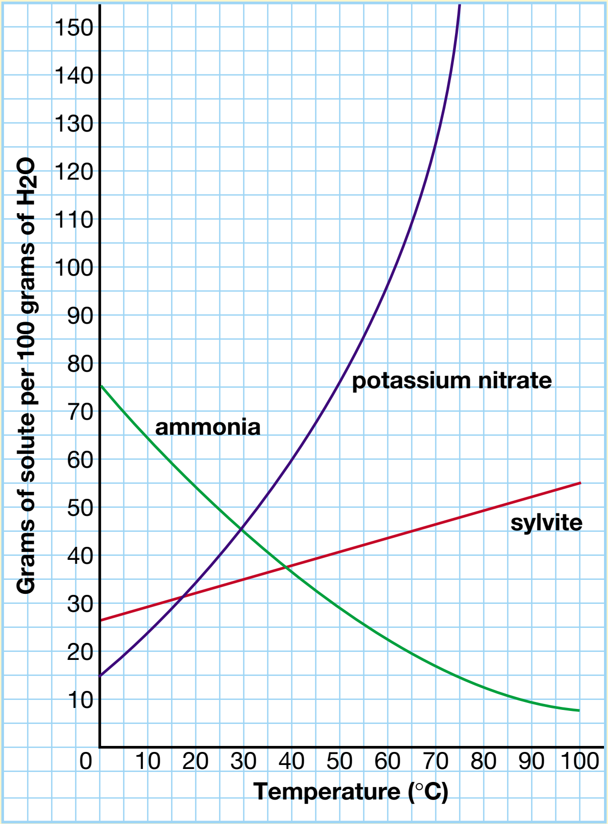
Conclude and Apply

3. Review the solubility graph shown here to answer the next questions. The graph shows the solubility of ammonia, sylvite, and potassium nitrate in water.
   - **(a)** A student adds 50 g of sylvite to 100 mL of water at 60°C. The resulting solution is best described as (i) unsaturated, (ii) saturated, (iii) supersaturated.
   - **(b)** A solution is prepared by adding 50 g of potassium nitrate to 100 mL of water at 50°C. What type of solution has been created?
   - **(c)** Ammonia is a gas. Describe what happens to the solubility of ammonia as temperature increases from 20°C to 80°C.
   - **(d)** Which two substances have the same solubility at 28°C ?

Extend Your Skills

4. Sylvite and halite are the two minerals that make up the rock potash. Sometimes when potash is mined, it is dissolved in water to remove it from the ground. Use the Internet or library to research potash and the technology behind solution mining. Draw a diagram of solution mining.

Solubility Curves



Cleaning Up with Solvents

Simply mixing materials together does not always result in a solution. The pulp in orange juice is not soluble, and neither are the small droplets of fat in milk; these are insoluble. **Insoluble** means not able to be dissolved in a particular solvent.

Why are some materials insoluble? This question can be answered by considering the attractions among particles. For example, grass stains are difficult to get out of clothing. Grass stains are caused by the chlorophyll found in grass. The particles of chlorophyll are more attracted to each other than they are to water particles. To remove grass stains, you need to use a different solvent — one whose particles attract the particles of chlorophyll. Rubbing alcohol can be used to remove grass stains and other spots, as can other solvents. Chlorophyll is insoluble in water, but it is soluble in other solvents.

Normally, water just runs off oily, greasy surfaces, and stubborn stains are often made up of fatty particles. Soap or detergent is needed to help remove these stains. Detergents are mostly synthetic materials, containing long molecules whose ends have different abilities to attract other particles. One end is attracted to fatty particles, such as oil and greasy stains, but not to water. The other end of this long molecule does the opposite: it is more strongly attracted to water and less attracted to fatty particles. Detergent molecules help to dissolve fat particles so that they can be rinsed away with water.

DidYouKnow?

Dry cleaning might better be called "wet" cleaning. Because water can damage some fabrics, such as silk and wool, dry cleaners use different liquids, such as perchloroethylene. The clothing is still put into a washing machine full of liquid, but because the liquid is not water, we call the process "dry" cleaning. Carbon tetrachloride was once used as a dry cleaning fluid but was banned because it is such a dangerous substance.

Figure 1.14 Specialized cleaning products are used to clean off decades, or even centuries, of accumulated dirt from paintings without dissolving the paint. The cleaned painting on the right appears as the artist would have seen it.

WHMIS Safety Symbols

Cleaning solvents are very useful, but they must be used with caution. Soap and shampoo are not often regarded as dangerous chemicals and are, in fact, mild compared to other detergents. Bleach, ammonia, and strong acids are often used to remove dirt and to sanitize.

Skill Focus 1 in the appendix of this book shows the WHMIS (Workplace Hazardous Materials Information System) symbols. These symbols are used throughout Canada to identify dangerous materials found in all workplaces, including schools. For your own safety, make certain you understand what these symbols mean. When you see these symbols on containers in your classroom, at home, or in a workplace, use safety precautions.

Find Out ACTIVITY

Safety First

If you can recognize and understand the WHMIS symbols, you can make better decisions about handling, storage, and disposal of hazardous materials.

Safety Precautions

Do not handle the materials directly.

Materials

hazardous waste containers or labels

Procedure

1. Find any two WHMIS symbols on containers in your school or home, or ask your parent or guardian to look for WHMIS symbols in their workplace.
2. Prepare a table with the following headings: Name of Material, Storage Location, WHMIS Symbol(s), Nature of the Hazard, and Proper Disposal Method. Include enough room for eight materials in total.
3. Performing and Recording Record the name of each substance, its storage location, and its WHMIS symbol(s).
4. Using the information in Skill Focus 1, in the appendix, summarize the dangers associated with the substance in each container.
5. Obtain information about six other materials from three friends. Include the new information in your table.

What Did You Find Out? Analyzing and Interpreting

1. In your opinion, which material was the least harmful, and which one was the most harmful? Explain why you think so in each case.
2. Were all the materials being stored properly? For each one that was not, explain what would need to be done to upgrade the safety.

Extension

3. Find out which of the materials in your list are being disposed of properly and which are not. Of the ones that are NOT being disposed of properly, what are the immediate risks to the environment? What are the long-term effects on the environment?

Looking Ahead

Remember to keep planning for your end-of-unit project. Be thinking about the game as you work through each Topic in this unit.

TOPIC 2 Review

1. Identify the following mixtures as heterogeneous or homogeneous or both. Explain your reasoning for each.

coffee	ink	dirt	
marshmallow	grape soft drink	Italian dressing	milkshake

2. What is a *solution?* What evidence do you need in order to classify a material as a solution?

3. For each *solution* listed in question 1, identify which substance is the solvent, and which one is the solute.

4. **(a)** What does the term "rate of dissolving" mean?

(b) Name three factors that can change the rate at which a solid dissolves in a liquid.

5. Use the particle model to explain how each factor affects the rate of dissolving.

6. Name one property that you think would not have an effect on the rate of dissolving. Explain why not.

7. Use the particle model to explain why rocks do not usually dissolve in water.

8. Why is water considered the universal solvent?

9. **Apply** After completing an activity to measure the solubility of an unknown substance in water, Joanne found that she could dissolve only 15 g of the substance per 450 mL of water. Raylene tried the same activity at home to see if she could confirm Joanne's results. Raylene found that she could dissolve 45 g per bowl.

(a) Is it possible that both girls' results are correct? How?

(b) How could the problem of "varying results" be prevented in the future?

10. **Thinking Critically** A cloud is a mixture of water droplets suspended in air. Is a cloud homogeneous or heterogeneous? Give reasons to support your answer.

11. **Thinking Critically** Why do people recommend removing ink stains with hairspray? Use the terms "solvent," "soluble," and "insoluble" in your answer.

TOPIC 3 Separating Earth's Mixtures

Our planet is rich in natural mixtures. Over thousands of years, humans have developed technologies to process these mixtures to make useful products. Which types of technologies are useful for separating mixtures? Explore some answers to this question in the following Find Out Activity.

Figure 1.15 Most natural resources need some degree of processing. How do you think iron is separated from iron ore?

Find Out ACTIVITY

Separating Strategies

What strategies are useful for separating mixtures? Remember: You must recover all substances from each mixture in their original form. Do not open the containers.

Materials

10 containers of different mixtures, such as:

- salt water
- muddy water
- nuts and bolts
- iron filings and dirt
- oil and sand
- oil and water
- salt and pepper
- Styrofoam™ and plastic building blocks
- pennies and dimes
- wood chips and pieces of brick

Procedure

1. Make a table in your notebook or on a spreadsheet with these headings:
   Mixture separation methods
   Why the method works
2. Examine the mixtures. Consider the physical and chemical properties of each substance. With your group, brainstorm all the possible methods that might be used to separate each mixture.
3. Complete the table. Choose the group's two best methods for separating each mixture. Explain why each method would work.

What Did You Find Out?

1. Which properties of substances did you use most frequently?
2. Which methods of separation did you use most frequently?
3. Which mixtures were easier to separate? Why?
4. Which mixtures were more difficult to separate? Why?

Separating Mixtures

Whenever fluids are used to help solids flow, either by simply mixing or by dissolving, the solids must later be recovered. When separating a mixture, it is useful to know the properties of the components, and how the components differ from each other. Separation methods are designed to take advantage of these differences. For example, gold differs chemically from the other components in the ore. First, certain chemicals dissolve only the gold in water. After this solution is drained away, another chemical reaction restores the gold to its solid state.

The separation methods that will be discussed in this Topic are based on differences in physical properties of components. Later in this Topic you will see how the components of petroleum are separated based on different boiling points. What other separation methods can be used?

Desalinating Water

Imagine being trapped on a desert island in the middle of the ocean. Is there any way you could produce drinking water? You could make the seawater drinkable if you could desalinate it. Desalination means removing the salt from salty water. In many parts of the world, fresh water is scarce, and seawater must be desalinated to provide drinking water. The desert tent method shown in Figure 1.16 is not expensive, but it is very slow. Also, it is practical only in areas that receive a lot of bright sunlight.

Along the Red Sea, where people live between salt water and the desert, huge desalination plants provide drinking water for thousands of people. These plants are very expensive to run, and use enormous amounts of energy.

STRETCH Your Mind

Make a list of general situations where manual separation would be inappropriate, and, in each case, explain why.

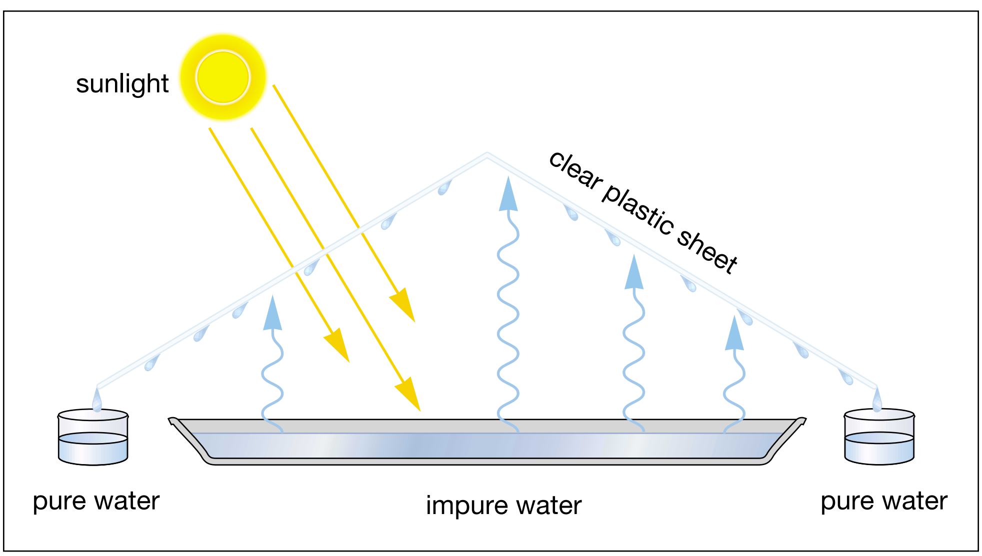


Figure 1.16 This "desert tent" apparatus uses a process very much like distillation. The water in the pans does not boil, but energy from the Sun causes it to evaporate. When the rising water vapour comes in contact with the cooler plastic sheets, it condenses. The drops of water run down the plastic into containers.

The process of removing water from a solution is called dehydration. The solvent (water, in many cases) separates from the solution via evaporation. Many convenience foods come in dehydrated form, such as pasta, sauces, milk, coffee, tea, soups, gravy, cake mixes, etc. To save time and reduce chances of spoilage while dehydration takes place, most food companies add heat to help speed up the evaporation process.

Although solute recovery by evaporation is simple and relatively inexpensive, it may be necessary to recover the solvent as well. Distillation is a separation method that allows all liquid fractions of a mixture to be separated from each other and collected in different containers. Distilled water is manufactured commercially and is used where only pure water is needed. Figure 1.17 illustrates how water can be recovered from seawater using distillation.

Pause & Reflect

In Your Science Log, use the particle model to explain how water particles from seawater leave one flask and end up in another one during a distillation.

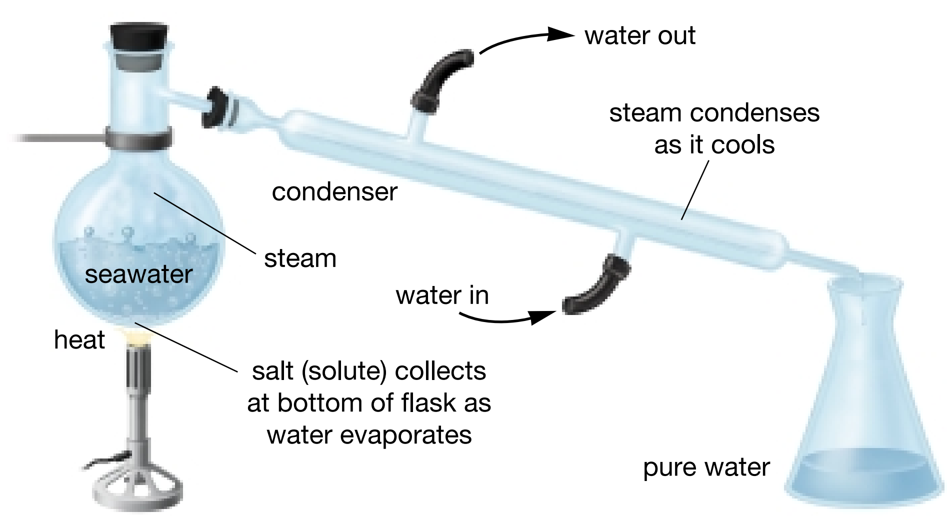


Figure 1.17 Distillation involves evaporating a solvent to separate it from the solute and then condensing it to a liquid. Water circulating in the condenser helps cool the steam as it passes through the tube.

Seawater contains two very important resources: salt and water. All seawater contains salt, but the percentage can vary from one body of water to another (see Table 1.4). It is relatively easy to recover the solute from seawater. Leave the seawater in the sunlight, and let the water evaporate. Eventually you will be left with solid salt.

Table 1.4 Percentage of Salt in Some Bodies of Water

Body of water	Salt (%)*
Arabian Sea	3.7
Atlantic and Pacific Ocean	3.2–3.7
Baltic Sea (some areas)	1 (or less)
Dead Sea	27
Great Salt Lake, Utah	5–27
Red Sea	4.1

*Numbers of grams of solute (salt)/ 100 mL solution

Processing Petroleum

Oil exploration companies spend millions of dollars drilling test holes to locate new underground deposits of petroleum, a naturally occurring mixture of hydrocarbons. Petroleum products, such as kerosene, gasoline, and diesel oil, are burned to produce electricity, move vehicles of all kinds, and do many other kinds of work.

Pumping petroleum to the surface is only the first step. What comes out of the pump is crude petroleum, a raw material. To make usable products, petroleum must be processed.

The process that yields different petroleum products is known as fractional distillation. As you have just learned, distillation is a method for separating the parts of a solution, in this case, a liquid-liquid solution. In any distillation, the mixture is heated so that at least one part begins to change into a gas (vaporize). The gas travels up and away from the mixture and the heat. In a separate chamber, the gas is cooled and it turns back into a liquid (recondenses). The recondensed liquid is collected in a separate container. Eventually all of the parts of the liquid-liquid mixture will vaporize and then recondense in a separate chamber to be collected in separate containers.

Petroleum is a collection of substances that are soluble in each other but not in water. Each substance condenses at a different temperature. Fractional distillation is done in a two-tower structure, as shown in Figure 1.18. In the shorter tower, the petroleum is heated strongly enough to vaporize every part of the mixture. Then the mixture of hot vapours is pumped into the bottom of the taller tower.

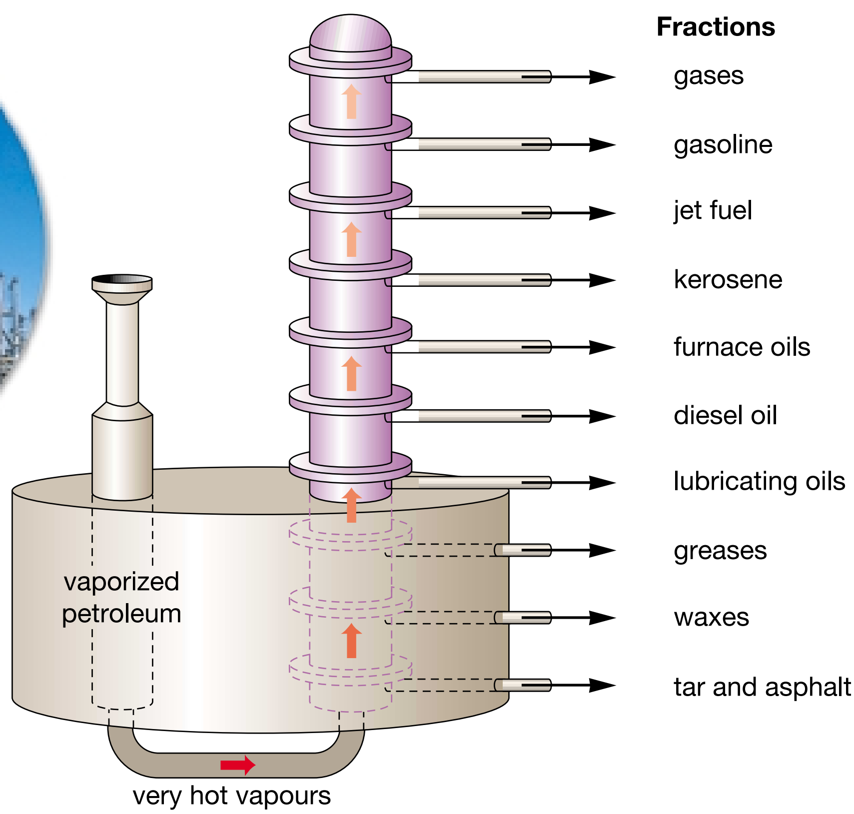


Figure 1.18 Fractionating towers are a common sight in the oil-producing regions of Canada. What raw materials enter the short tower? What change takes place there? What processed materials leave the tall tower?

Inside the tall tower, the hot vapours rise. As they rise, they cool. Remember that these are different pure substances, so they have different properties. This means that some of them condense and form a liquid while they are still very hot, near the bottom of the tower. As the remaining vapours continue to rise, different ones condense at different levels in the tower. Near the top (the coolest part) of the tower, a few remain as a gas.

Each fraction is drawn off by the collecting pipes at its own level and is sent to a different part of the refinery for further processing. There each material may be converted into petrochemicals. Petrochemicals are entirely new products made from the same raw material — petroleum. Scientists have developed and produced over 500 000 different petrochemicals.

Solid Mixtures From Underground

Most underground materials are solid rock. For example, the rock shown in Figure 1.19 is a mixture of two pure substances: white quartzite and yellow gold. This rock is called gold ore because it can be processed to extract gold. An ore is a mineral (or a group of minerals) that contains a valuable substance. Another example of an ore is iron ore.

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/

Examples of products that are made from petrochemicals include Aspirin™, basketballs, chewing gum, duct tape, eyeglasses, and fertilizer. Continue the alphabetical list of petrochemicals by going to the above web site. Go to **Science Resources**, then to **SCIENCEFOCUS 8** to find out where to go next. Try to find a petrochemical product for every letter of the alphabet.

A number of steps are needed to extract gold from its ore. All along the way, the gold must be made to flow from one step to the next. First, the ore is blasted and crushed. The ore powder is mixed with water to create a fine suspension. Chemicals are added to dissolve the gold. Anything other than gold does not dissolve. Only those particles dissolved in water can pass through filters. The rest, called solid wastes, get caught in the filters. In the last step, the gold is released from the solution when zinc is added. The gold residue sinks and is finally carried into a collecting tray.

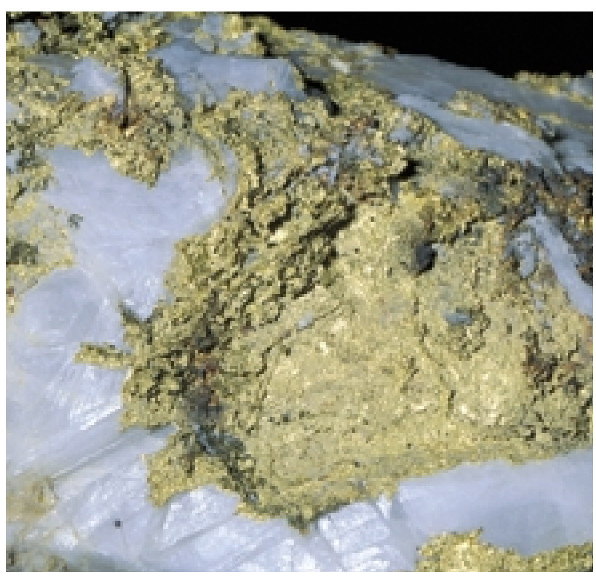


Figure 1.19 The white part of this rock is quartzite. The yellow parts are nearly pure gold.

In the next investigation you will explore the role filters play in separating mixtures. You will then investigate several other methods of separating the parts of mixtures.

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Using Filtration to Separate Mixtures

Filters are at work in your body, in your car, and in your home. How do they work? Which components are they able to separate from mixtures?

Question

How can the process of filtration be used to separate the parts of mixtures?

Safety Precaution

Apparatus

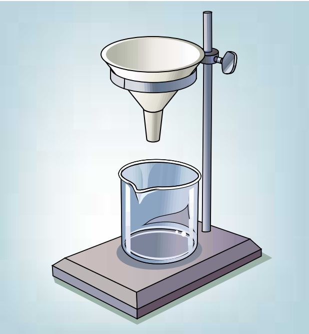
funnel
retort stand
ring clamp
250 mL beaker
600 mL beaker
stirring rods

Materials

filter paper
a variety of liquid mixtures, one for each group

Procedure

1. **Make an observation chart** with these headings:
   Mixture
   Appearance of filtrate
   Appearance of residue
2. Set up a retort stand, ring clamp, and funnel as shown in the diagram.



Place a 250 mL beaker below the funnel to catch the residue.

3. Fold the filter paper as directed by your teacher and place it in the funnel. Dampen the filter paper with water so it will stay in place.
4. Obtain your group's mixture in the 600 mL beaker. Stir it gently.
5. Pour a small amount of the mixture onto the filter paper. Be sure not to pour so quickly that you pour over the edges of the folded filter paper. The level of the mixture in the filter paper should be below the edge of the filter paper.
6. **Record** your **observations** on your chart.
7. **Observe** the results of other groups' filtration. If necessary, carefully add more mixture in the other filter papers.

Analyze

1. Which mixtures were successfully separated by the filtering procedure? Why?
2. Which mixtures were not completely separated by the filtering procedure? Why not?

Conclude and Apply

3. What other methods might be used to separate the mixtures you were unable to separate by filtering? List three of these methods and the mixtures they might separate.
4. Consider the use of filters in your body, in your car, in your home, and in recreational facilities. Draw and explain the workings of at least five of these filters.

Find Out ACTIVITY

Solute Recovery

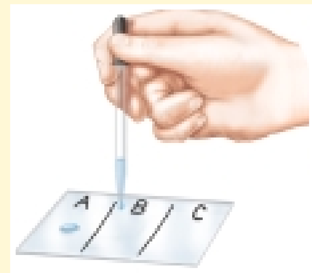
To test for the presence of dissolved salt, you will allow three different samples of liquid to evaporate. Be sure to use the same amount of liquid for all three samples. Handle the glass slides carefully so they do not break.

Materials

- distilled water
- tap water
- salt water
- medicine droppers
- glass slides (very clean!)
- wax pencil or permanent marker
- ruler

Procedure ✷ Performing and Recording

1. With the marker and ruler, divide the glass slide into three parts, marked A, B, and C.
2. Use the dropper to place two drops each of (A) distilled water, (B) tap water, and (C) salt water on the appropriate place on the glass slide.
3. Set the glass slide aside, where it will not be disturbed.
4. After the liquid has evaporated, examine the slide to see what is left on the plate. Record your observations for each sample.



What Did You Find Out? ✷ Analyzing and Interpreting

1. After the drops of liquid evaporated, what remained on the glass slide for (A) the distilled water, (B) the tap water, and (C) the salt water?
2. Which materials are solutions? Which are not? How can you tell?
3. According to the particle model, solute particles and solvent particles attract each other. In this activity, what was the factor that allowed the solute and solvent particles to overcome this attraction and to separate?
4. Predict what would have happened if you had placed your slides on a radiator while you waited. Use the particle model to explain your prediction.

Math CONNECT

The unit for solute concentration is very specific, as seen in the footnote for Table 1.4 on page 29. If 3.7 g of salt is present in every 100 mL of salt solution in the Arabian Sea, how much salt would you expect to recover from 500 L of the Arabian Sea?

DidYouKnow?

Ordinary table salt is sodium chloride. Other salts include potassium chloride, magnesium sulfate, calcium nitrate, and ammonium carbonate. Another salt, potassium chloride, also known as potash, is mined in Saskatchewan. Which kinds of salt have you used? Table salt is made by adding water to salt deposits and evaporating the brine. Kosher salt is similar, but it is raked during evaporation. Sea salt is made from water trapped in ponds.

INQUIRY

INVESTIGATION 1-D

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

Hidden Colours

You have learned how to separate liquids from liquids, solids from liquids, solvents from solutes, and solids from solids. What if you had a solution with more than one solute? Would it be possible to separate different solute molecules?

Ink is made up of coloured compounds called pigments. Which pigments make up each colour of ink? What do you think would happen if you marked a dot on the dry filter paper with a felt-tip marker, and then allowed water to absorb through it?

Prediction

Make two predictions for this investigation and record them in your notebook. Predict the colours that will appear after separation, and predict which colours cannot be separated.

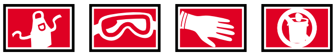
Apparatus

small beakers
scissors
ruler

Materials

filter paper (larger than the beaker opening)
felt-tip markers, various colours, water soluble
felt-tip markers, various colours, permanent
water
methanol or ethanol

Safety Precautions



Do not taste methanol or ethanol, or sniff them directly.

Be sure to wipe up any spills, as wet floors are slippery.

Methanol and ethanol are toxic chemicals; dispose of all wastes as your teacher directs.

Procedure

1. Poke a small hole in the centre of a piece of filter paper, no larger than 0.5 cm in diameter.
2. With one marker, place six small, equally spaced dots in a circle about 0.5 cm away from the centre circle. Be sure to keep the filter paper dry.
3. Fill the beaker to 1 cm from the top with water. Keep the rim of the beaker perfectly dry. Wipe it if it becomes wet.
4. Carefully place the filter paper on top of the beaker.
5. Meanwhile, use another piece of filter paper to cut out a triangle that is 4 cm tall and 2 cm at its base. Roll this into a cylinder that will fit the centre hole of the first filter paper. The triangle will act as a water wick.
6. Place the pointed end of the wick into the centre hole of the dotted filter paper, and carefully push it down until it is 1–1.5 cm into the solvent. Set the beaker off to the side where it will not be disturbed.

7. Allow your chromatogram to develop until the pattern has reached to about 1 cm from the outer edge of the filter paper.

8. Remove your chromatogram and allow it to dry.

9. Make an observation chart to **record** your results.

10. Repeat the procedure with different-coloured markers, both water-soluble and permanent, and different solvents. Do not reuse the water wick.

11. Repeat the investigation with notebook paper, paper towels, and any other paper available. **Record** your results on your observation chart.

12. Continue making trials of ink, pigments, and solvents.

13. Mount your dried chromatograms on a poster. For each one, identify the solvent that you used, and the colour of marker used.

Analyze

1. What was the manipulating variable? What was the responding variable?

2. Which coloured pigments were more soluble in water and which ones were more soluble in methanol or ethanol?

3. Which type of paper produced the best chromatography? Why?

Conclude and Apply

4. Which coloured markers had the most surprising results? Which ones had the least? Propose an explanation for these results.

5. What happened when you altered or changed the solvent? Use the particle model and your understanding of solubility in your answer.

Extend Your Knowledge

6. Research chromatography on the Internet or at the library. Report on several technologies that use chromatography.

THINK & LINK

INVESTIGATION 1-E

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

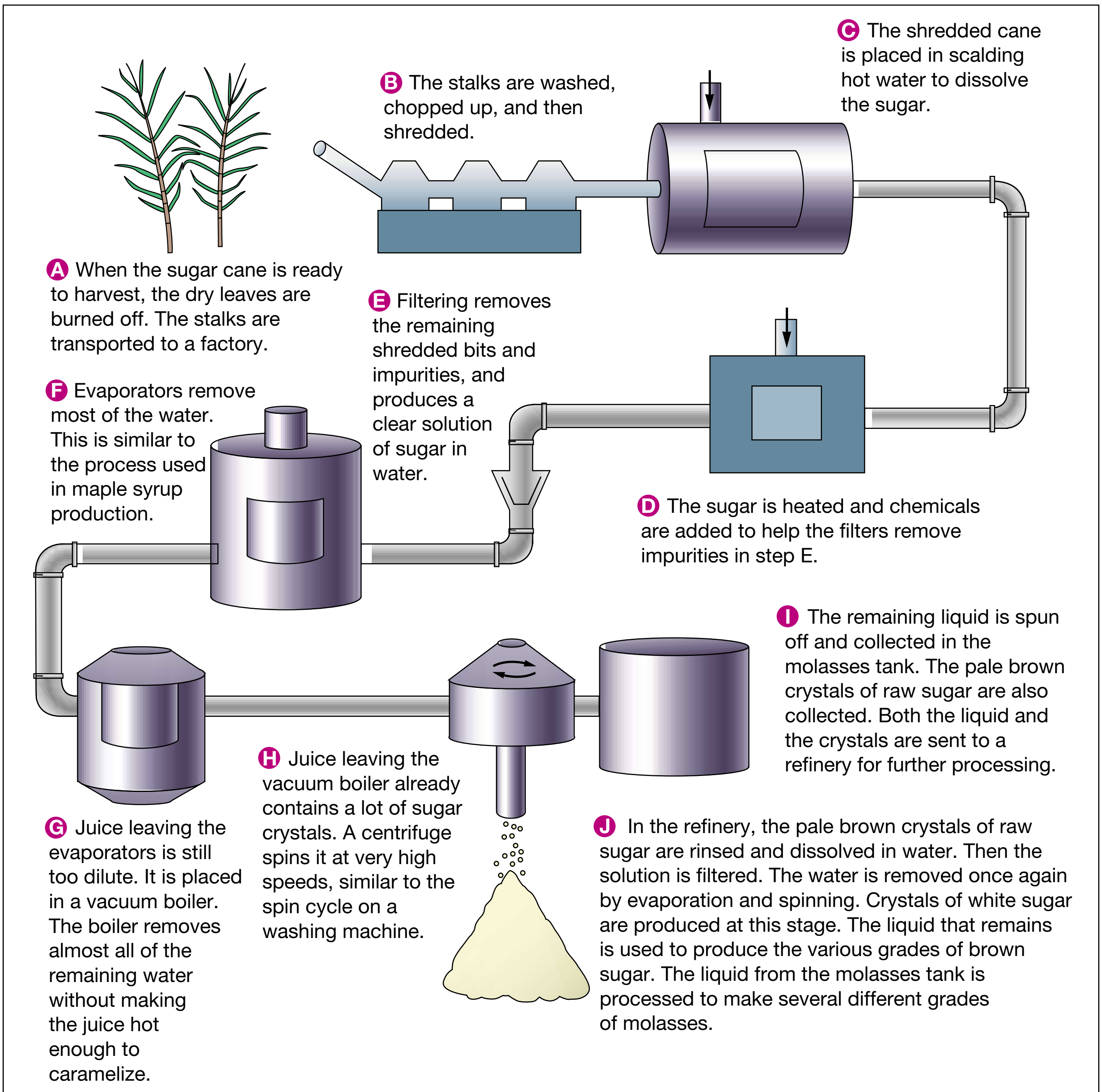
A Sweet Process

Think About It

White sugar, golden brown sugar, dark brown sugar, and molasses are all produced from either sugar beets or sugar cane. How do the steps of separation and processing produce different grades of sugar?

What to Do

With a partner, examine the flowchart below that shows how various sugar products are made.



Analyze

1. What is the purpose of step B?
2. Does step C produce a solution or a mechanical mixture?
3. Draw a sketch to show how the filtration in step E works. Use the particle model to create labels that explain how filtration works.
4. Redraw the evaporation in steps F and G showing where you think the water goes when it is removed, and where the sugar goes.
5. **(a)** What are the first two products that come from a sugar factory? (step 1)
   (b) What happens to each of these products?
   (c) What is the waste product that is discarded in this process?

Sugar beets are grown in Québec, Manitoba, and Alberta.

Across Canada

Almost all of the sugar we buy today is produced from sugar cane and sugar beets. Most sugar refineries in eastern Canada use imported sugar cane as the raw ingredient. Most refineries in western Canada use domestically grown sugar beets. Regardless of which raw material is used, the end products are very similar.

Centuries ago, Canada's Aboriginal people collected "sweetwater" from maple trees and poured it into hollowed-out logs. They turned the clear, colourless sap into a sweet, amber liquid that we now call maple syrup, adding heated rocks to speed up the evaporation of the sap.

Some of Canada's 13 000 maple syrup producers in Ontario, Québec, and the Maritimes still use the traditional method to collect and process the sap. They carry it to the sugar shack on sleds or in wagons. There it is boiled to remove the extra water and reduce the syrup so that it is the right flavour and thickness.

Other producers use more modern methods: kilometres of plastic tubing connect thousands of trees, carrying the sap to the sugar shack. Filtering systems and pasteurization processes are then used to prepare the syrup for sale all over the world. The basic process is still the same, however — many hours of boiling large quantities of sap down to a small quantity of delicious concentrate.

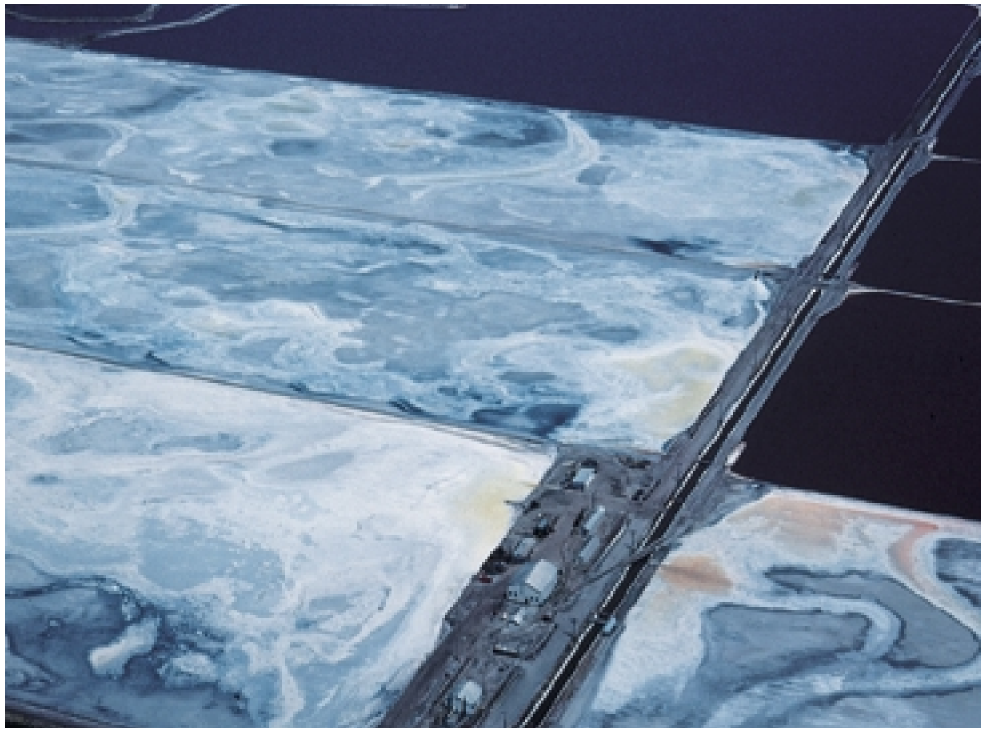


Figure 1.20 These shallow basins are being used to recover salt from sea water. The water evaporates from the basins, leaving behind crystals of salt.

TOPIC 3 Review

1. Give four examples of naturally occurring mixtures, two from this Topic, and two from your own experience. State whether each is homogeneous or heterogeneous.
2. (a) What is a petroleum refinery?
   (b) Name the process that is used to refine petroleum. Explain how it works by drawing a simple labelled sketch.
3. How is dehydration different from distillation as a method of removing a solute from a solvent?
4. Compare the distillation method shown in Figure 1.18 with the desert tent evaporator in Figure 1.16. What is similar? What is different? Refer to the particle model of matter in your answer.
5. Sugar can be produced from three different raw materials: cane, beets, and maple sap. Regardless of the raw material, a lot of fuel is needed. Explain why.
6. Write your own definition of filtration.
7. List six ways for separating the components of a mixture.
8. **Apply** Could settling be used to separate the components of petroleum? Explain why or why not.

Wrap-up TOPICS 1-3

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

solid	homogeneous	mechanical mixture	rate of dissolving
liquid	solution	phases	agitation
gas	heterogeneous	dissolving	saturated solution
pure substance	suspension	solute	unsaturated solution
properties	colliod	solvent	supersaturated solution
mixture	emulsion	soluble	insoluble

Reviewing Key Terms

1. Which of the key terms best matches each of these phrases? Write your answer in your notebook.

(a) a state of matter with no definite volume (1)

(b) how fast a solute dissolves in a solvent (2)

(c) a homogeneous mixture in which no settling occurs (2)

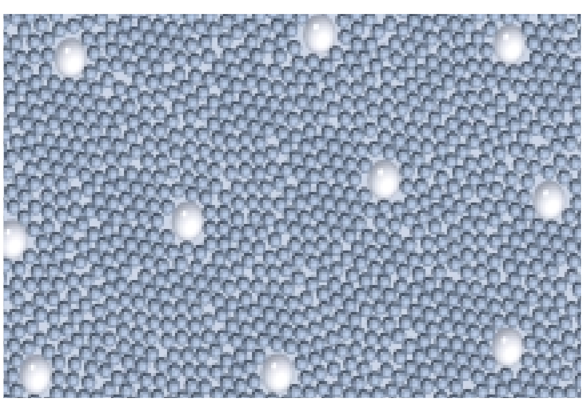
(d) a hetergeneous mixture in which no settling occurs (2)

(e) separate parts of a mechanical mixture (2)

(f) able to be dissolved in a particular solvent (2)

(g) characteristics, such as colour, odour, and hardness (2)

(h) the substance that dissolves in a solvent to form a solution (2)



Understanding Key Concepts

2. From Table 1.1 on p. 18, find

(a) two solutions that are gases

(b) a solution in which both solute and solvent are liquids

(c) a solution of gas in a liquid (2)

3. (a) What is the purpose of distillation? Use the terms "solute" and "solvent" in your answer.

(b) Use the particle model of matter to explain how distillation works. (3)

4. Apply In the past, people collected rainwater to use for washing hair and clothes. Why do you think people did this, rather than using water from a river or a well? (2)

5. Thinking Critically The cleaning and stain-removal industry understands how to separate the components of a mixture. What can you add to a grass stain to separate it from the mixture of stain and clothing fibre? (2)

6. List the solutes and solvents for these solutions:

(a) sweetened tea **(b)** coffee with cream

(c) ocean water **(d)** orange soft drink

(e) perfume **(f)** mouthwash

(g) cherry Kool-Aid™ (2)

TOPIC 4 Flow Rate and Viscosity

Does your mouth water at the thought of gooey caramel topping, pancakes drizzled with syrup, or melted chocolate chips in cookies hot from the oven?

Some of the most delicious treats are liquids that flow thickly and smoothly. The property that describes a liquid's thickness or thinness is called **viscosity**. A thicker liquid is more **viscous** and has a higher viscosity. Viscosity is a property of all fluids, including liquids and gases, whether they are pure substances or mixtures. It is more difficult to imagine the viscosity of a gas, because gases are invisible and difficult to feel for "thickness."

Viscosity in gases increases and decreases in a different way than it does for liquids. You will learn more about the viscosity of gases at the end of this Topic.

Most fluids in our lives are liquid mixtures. Some liquids can flow faster than others. How would you describe the flow of chocolate syrup from a bottle or the flow of honey from a jar? Look at the fluids shown on the right. 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.

If you wanted to know how fast you could run, you might ask a friend to time how long it would take you to run, say, 100 m. The measurement would be your speed. In a similar way, you could measure how fast a fluid "runs." You could measure the time it takes for the fluid to flow from one point to another point. This measurement is called the fluid's **flow rate**.

Just as certain variables can slow you down in a race, certain variables can also slow down the flow of fluids. What properties of fluids might cause a liquid to speed up or slow down? Explore this question further in the next investigation.

INQUIRY INVESTIGATION 1-F

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Determining Flow Rate

Part 1

Viscosity is a difficult property to measure directly. However, the flow rate of a liquid 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 fast can different liquids flow?

Prediction

Predict the relative flow rates of the liquids to be tested from fastest flowing to slowest.

Safety Precautions

- 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.

Apparatus

ramp made of smooth plastic or glass (minimum 0.5 m x 0.3 m)

stack of books (0.25 m–0.3 m high)

thermometer

measuring spoon (15 mL) with rounded bottom

watch with second hand or stopwatch

rubber gloves

Materials

waterproof marker

tape

paper towels

soap for cleaning ramp surface

water

15 mL of any three of the following liquids (at room temperature):

cooking oil	honey
motor oil	liquid detergent
molasses	ethyl alcohol
corn syrup	

Procedure

1. Draw a line across the width of the ramp, approximately 10 cm from the top. Draw one dot in the centre of the line and another dot 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.
3. **Measure** the temperature of the room and **record** it in your notebook.
4. **Make a data table** with the following column headings:
   Liquid [water plus 2 others]
   Time (s)
   Flow rate (cm/s)
   Ranked flow rate
   Ranked viscosity
5. **Predict** which of the three liquids will flow fastest.

CONTINUED

6. 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 then call "stop" when the liquid reaches the finish line.

7. When the marshall says "go," the spoon student rocks the spoon quickly but carefully to pour its contents down the ramp. At the same time, the timer starts timing.

8. When the marshall says "stop," the timer stops timing and **records** the time in the data table. Clean and dry the ramp and the measuring spoon to get ready for the next liquid.

9. Repeat steps 3 to 5 for the other two liquids. (Do this at least twice for each liquid; note that alcohol should be tested last because it might erase the start and finish lines.)

10. Wash your hands after this investigation. Keep the flow rate ramp assembled so you can do the following Find Out Activity.

Analyze

1. Make a list of the manipulated, responding, and controlled variables in this investigation.
2. 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.
3. 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?
4. Rank the viscosities in the table from lowest (1) to highest (3). **Record** these values in your data table under "Ranked viscosity."
5. 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

6. How is the flow rate of a liquid related to its viscosity?
7. Which liquids were more difficult than others 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.

Part 2

Another way to determine differences in viscosity is to examine how fast an object can move through different liquids.

Question

How fast can an object flow through different liquids?

Hypothesis

With your group, propose a hypothesis about the relationship between the speed of an object's movement through a liquid and the flow rate of the liquid.

Apparatus

graduated cylinders (100 mL or larger) or hydrometer jar

marbles, beads, pins, and any other small objects

stopwatch

rubber gloves

Materials

1–2 L of the same liquids used in Part 1

soap

Procedure

1. **Design a procedure** that will allow you to determine how fast an object can move through the liquids that you examined in Part 1. **Determine the units** you will use to calculate how fast the object moves through the liquid. In a series of sketches, **draw** and **label** the design of your apparatus, and how you would use it. Have your teacher approve your procedure and apparatus design.

2. Use your apparatus to determine how fast an object moves through each of the liquids in your test. **Record** your results in a data table.

3. Dispose of your materials properly, and clean your apparatus with soap and water. Wipe up any spills as wet floors are slippery.

Analyze

1. How did your variables change in Part 2 compared to Part 1?
2. Organize your new rates in order from the fastest to the slowest. Does this order match the order you determined in Part 1?

Conclude and Apply

3. Did the rates in Part 2 differ from liquid to liquid by the same amount as they did in Part 1? If so, what can you conclude about your hypothesis?
4. If your results were different than the rates in Part 1, how could you determine whether or not the differences were due to experiment error? How might you fine tune the design of your experiment to reduce the chances for error?
5. If you were certain of a good match between the results in parts 1 and 2, which method would your prefer to do? Why?

Skill FOCUS

For tips on designing your own experiment, turn to Skill Focus 6.

Pause& Reflect

Lubricants are used in machines to reduce the friction between moving parts. Motor oil is used in vehicles to lubricate the engine, preventing wear and tear on the engine parts. Therefore, motor oil must be viscous enough to coat and lubricate machine parts. However, motor oil must also be thin enough to reach the engine parts as soon as the vehicle is started. Motor oils are manufactured with a variety of viscosity values to suit weather conditions. Predict which viscosity values are needed in which temperatures. Write down your prediction in your Science Log. Invite a mechanic from a service garage to visit the class. Ask for an explanation about the conditions under which specific grades of motor oil are used.

Figure 1.24 Thermoplastic polymers can be melted, "blown" full of air, and cooled to form a solid foam.

Find Out ACTIVITY

Cool It!

Can the viscosity of liquids be changed? Go back to Inquiry Investigation 1-F, Determining Flow Rate on page 41. 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 model be used to predict the effect of temperature on a liquid's flow rate?

Extensions

3. It might be easier to measure the 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. Explain how you could measure flow rate using your apparatus.
4. Scientists commonly repeat an experiment two or three times to reduce the effect of 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.

DidYouKnow?

All foams are made when air bubbles moving through a liquid get trapped. Foam rubber and polystyrene foam are solid foams made when air is blown into highly viscous molten (melted) rubber and polystyrene. When the rubber and polystyrene cool and resolidify, the air trapped inside forces the new solid to have tiny holes. The air can move in and out, but the holes stay. A similar process happens when you bake a cake. Cake batter is light and frothy; baking just solidifies the batter (baking involves chemical changes). The tiny air bubbles get trapped, making the cake light and fluffy.

Product Performance and Viscosity

Why might it be important to know how to determine the flow rate and, therefore, the viscosity of a liquid? The viscosity of liquids is an important property that must be measured precisely in some industries. For example, the viscosity of paints and varnishes is closely regulated so that they can be applied smoothly and evenly with a brush or a roller.

The cosmetics industry depends on the flow properties of matter. Lipstick is a mixture of many different ingredients, and, unlike nail polish and mascara, is a solid when sold. Therefore, it is necessary to change the viscosity of the ingredients so that they can be combined. Then the final mixture can be poured into a mould to obtain a distinctive shape. The manufacture of lipstick involves heating, dissolving, melting, mixing, grinding, straining, pouring, and cooling. Figure 1.22 shows the steps in the process.

Figure 1.21 Paint, varnishes, and other such liquids must have just the right viscosity.

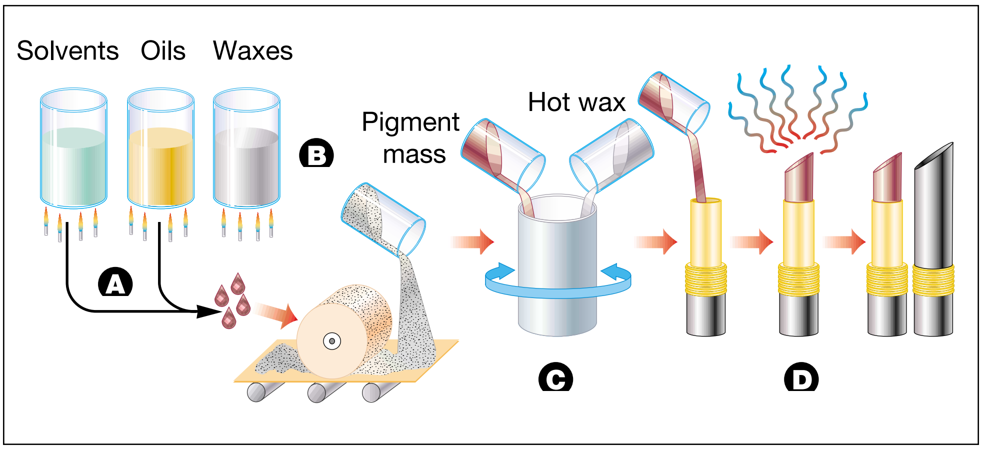


Figure 1.22 Flow diagram of the manufacture of lipstick

A Two mixtures are prepared. One contains the oils, antioxidants, and any other oily ingredients, such as sunblock compounds and fragrance oil. The second mixture contains dissolving ingredients (solvents), mainly alcohol. Both of these mixtures are heated separately to allow complete mixing. They are blended together with the colour pigments or dyes and passed through a large roller mill to grind the grainy pigment to ensure a smooth product.

B A wax mixture is heated and melted in a separate container. Waxes, such as beeswax, candelilla wax, and carnauba wax, enable the final product to hold its distinctive "stick" shape.

C The warm pigment mixture is then added to the hot wax and stirred until a smooth, homogeneous solution is formed. The molten lipstick solution is strained and poured into the tube.

D After cooling, the lipsticks are inspected for undesirable marks, such as mould separation lines and air holes. If the lipsticks have an acceptably smooth, clean, untouched appearance, they are inserted into their containers, capped, and packaged. If not, they are removed, remelted, and remoulded.

Cool Tools

Furniture stripping liquid was once difficult to use because it tended to drip off the furniture before it had a chance to remove old paint. The viscosity was increased to a gel-like texture. Now the product is easier to apply and sticks well to the surface of the furniture.

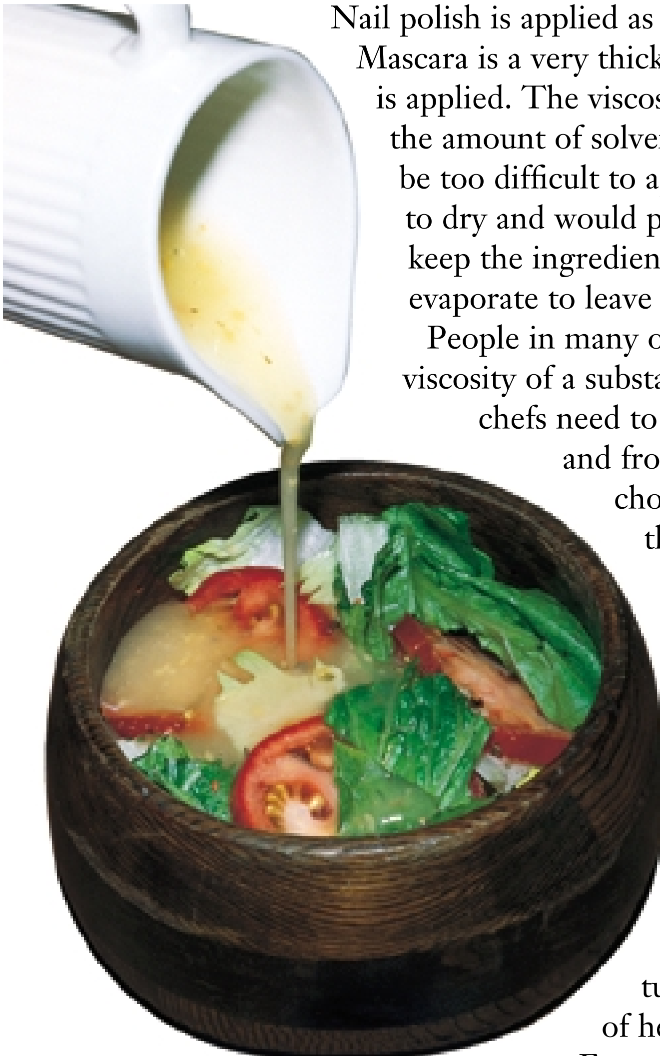


Figure 1.23 What are the appealing qualities of the thickness of this salad dressing?

Nail polish is applied as a slick fluid, but dries into a solid finish. Mascara is a very thick fluid, which dries extremely quickly after it is applied. The viscosity of both of these products is controlled by the amount of solvent that is added. Any less, and they would both be too difficult to apply; any more, and they would take too long to dry and would possibly run off the intended areas. Solvents keep the ingredients dissolved and fluid while applying, then evaporate to leave a dry, solid finish.

People in many occupations need to know how to adjust the viscosity of a substance to suit specific applications. For example, chefs need to know how to make gravies thinner than sauces and frostings thicker than icings. Mechanics must choose an engine oil that is the right viscosity for the season. Artists need to know how to thin or thicken oil paints or acrylics. Technicians must control the viscosity of various chemicals in chemical processing plants.

Product Appeal and Viscosity

Your mouth is highly sensitive to viscosity, so food manufacturers ensure that ice cream toppings, pasta sauces, soups, gravies, salad dressings, and other products are just the right consistency (thickness). Food manufacturers must also know how to regulate the effect of heat on the viscosity of a substance.

For example, chocolate coating for candy bars must be at precisely the right consistency and temperature in order to cover the bar completely with the same amount of chocolate each time. Some candy coatings are especially sensitive to temperature. If the candy were to stay too hot for too long, it might become too hard to bite.

Career CONNECT

Viscosity at Work

As a class, brainstorm how fluid viscosity might be used in each of these occupations: candy maker; glass blower; beekeeper; baker; motor mechanic; maple syrup processor. 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.

INVESTIGATION 1-G

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Flowing Fluid Floods City

Think About It

You may have heard the expression "as slow as molasses in January." Read the following true story and then answer the questions.

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

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, deadly goo.

The "wall of molasses" — some witnesses say 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 injured.

The clean-up took weeks. 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 more than $1 million in damages.

Analyze

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. Use the particle model to explain why the tank burst.
3. Energy is reponsible for making things move. Use the particle model to explain how something as viscous as molasses could move as quickly as it did on that particular day, at that particular moment.
4. For what purpose do you think the company used the molasses?

How Does the Viscosity of Liquids Vary?

Why do some liquids flow more slowly than other liquids? Even though all fluids flow smoothly, they flow at different rates because liquids have different viscosities. Particles can move around, but it may be difficult for them to pass by each other. Another way to define viscosity is the resistance to flow. Resistance to flow creates internal friction. Friction is caused when two surfaces are rubbed together. For example, it is easier to skate on ice than on pavement because the friction between the skates and the ice is less than the friction between skates and pavement.

Similarly, it is easier for some fluid particles to move past each other, compared to other fluid particles. Water particles slip past each other easily, but particles of oil have more internal friction and do not flow past each other as easily. The particle model explains that attractive forces exist between particles in any substance. The attractive forces between particles in some fluids are stronger than the attractive forces in other fluids. As particles of oil, for example, flow past other particles, they are attracted to each other so readily that they slow down as they pass by.

According to the particle model, as the temperature of a material increases, the attractive forces between the particles of the material decrease. As the temperature decreases, the attractive forces increase. Warmer liquids flow more quickly and cooler liquids flow more slowly. Therefore, *the viscosity of a liquid DECREASES as it is HEATED, and INCREASES as it is COOLED*.

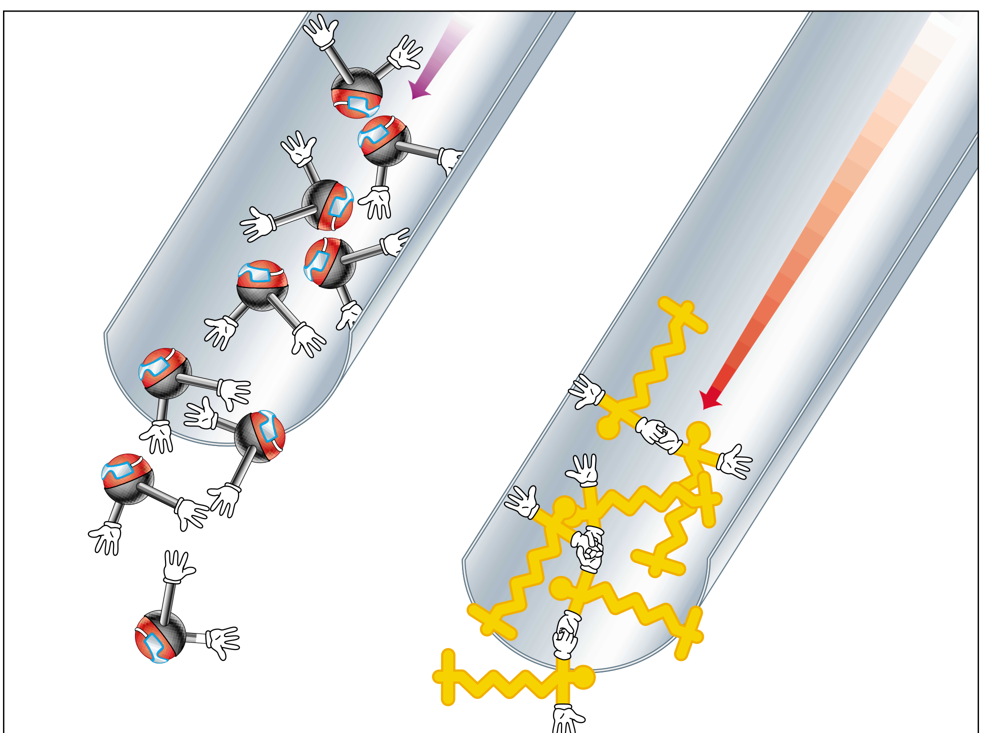


Figure 1.25 Some liquids have more internal friction because of their strong attractive forces.

How Does the Viscosity of Gases Vary?

The viscosity of gases can vary although they generally flow more easily than liquids. Gases flow differently than liquid particles. Gas particles are so far apart, and the attractive forces are so low, that the type of gas particle is less important than in a liquid. Particles of gas are more likely to collide with each other than rub against each other.

How can the internal friction of a gas be affected? When a constricted gas flows, it moves in one direction. For example, air flows out of a hole in a tire, or out of the neck of an untied balloon. But how do particles move inside that mass of gas? If the gas particles have low enough energy so that most are moving in the same direction, then the viscosity will be low. The gas will flow quickly and easily out of the opening. As gas particles gain energy, however, their motion increases in all directions, increasing the number of collisions. Under this circumstance, internal friction is high, and the gas will not flow as easily or quickly out of the opening.

The temperature of a gas has a direct effect on viscosity. As gases are heated, the particles gain energy and move faster. The number of collisions between gas particles increases. Cooler gases contain particles that are not colliding as much or as often. Therefore, *the viscosity of a gas INCREASES as it is HEATED, and DECREASES as it is COOLED.* Temperature has the opposite effect on the viscosity of gases as on liquids.

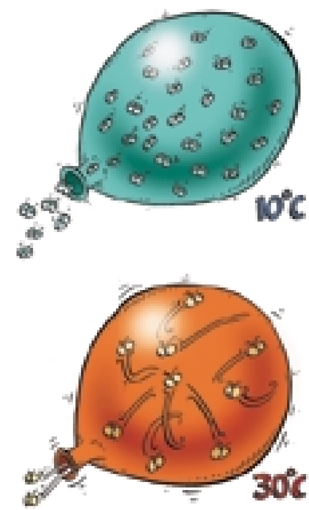


Figure 1.26 Heated gases flow less quickly and smoothly because of an increased number of collisions among particles at higher temperatures.

TOPIC 4 Review

1. List two materials that have a low viscosity and two that have a high viscosity.
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. **(a)** What is the effect of temperature on the flow rate — and thus the viscosity — of a liquid?
   (b) What is the effect of temperature on the viscosity of gases?
   (c) Explain these effects using the particle model.
5. **Thinking Critically** How are viscosity, the size and shape of particles, and internal friction related?
6. **Apply** 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.

Off the Wall

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 absolute zero (about –270°C), helium changes from a "normal" fluid to a superfluid, a substance that can flow without friction. Superfluids have zero viscosity and no internal resistance to flow. These properties allow them to pass through a hole of any size and to flow up and over the sides of containers. Scientists are researching future uses of superfluids.

TOPIC 5 Density

DidYouKnow?

Could the solid state be less dense than the liquid state of the same substance? The answer is yes. 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. Solid ice is less dense than liquid water.

Have you ever been on a crowded elevator? It is definitely uncomfortable when too many people are jammed together tightly, or densely, on an elevator. Using everyday words, density can be described as the "crowdedness" of the particles that make up matter. In scientific terms, **density** is mass per unit volume of a substance.

We can use the particle model to help explain that different substances have different-sized particles. The size of the particles determines how many particles can "fit into" a given space. Therefore, each substance has its own unique density, based on how close together the particles are.

The particle model can also help us to visualize empty space between the particles of matter. Could as many people fit onto an elevator if each person were surrounded by a large "spacing box"? Would larger spaces among the people increase or reduce the density (crowdedness) of the people travelling on the elevator?

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, dolphins can leap through the air and then dive back underwater so smoothly that the activity appears almost effortless. The fluid properties of water and of air allow water particles and air particles to move out of the way of the firmer, non-fluid bodies of marine animals. Why do solid particles tend to hold together while fluid particles tend to move apart?

Density of Solids, Liquids, and Gases

How is the density of a substance related to the substance's physical state? Imagine filling one container with liquid water and another container with water vapour. Both liquid water and water vapour have particles of the same size. According to the particle model, 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. The density of the water vapour is less than the density of liquid water.

If you were to step onto the surface of a lake, the water would not support your foot. Instead, your foot would push the water particles out of the way, as shown in Figure 1.27. Liquids cannot support objects in the same way that solids can. The particles of a liquid move apart easily, allowing a dense, solid object, such as your foot, to pass through the liquid. The attractive forces between liquid particles are not strong enough to prevent your foot from pushing them apart.

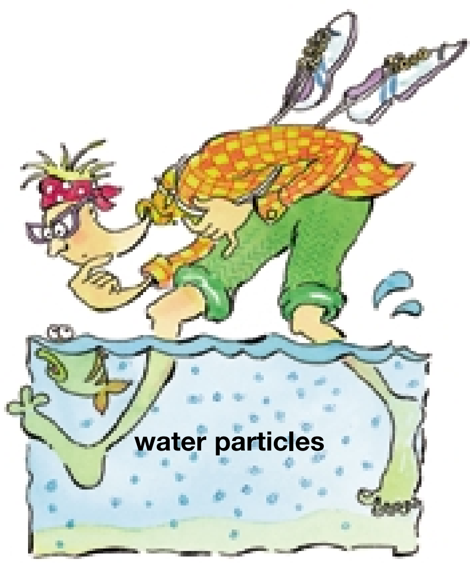


Figure 1.27 Although liquid particles are sometimes quite closely packed together, they cannot support objects in the same way that solids can. Liquid particles move apart easily because the particles do not have a strong enough attraction for each other.

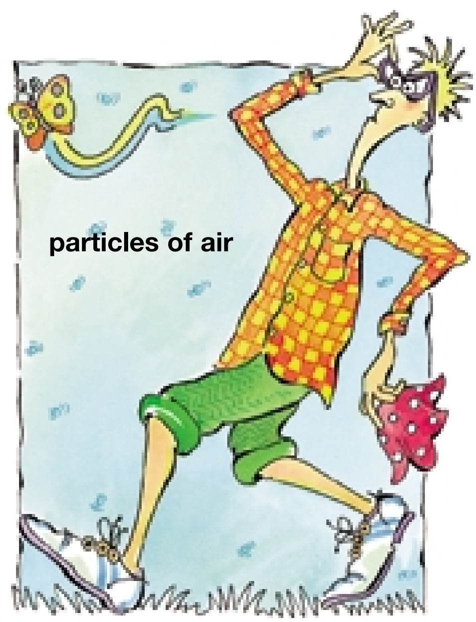


Figure 1.28 When you move through air, you do not have to move as many particles of air out of the way as you do water particles in water.

Similarly, you cannot walk on air, because gases are even less dense than solids or liquids. When you move through air, you are moving through mostly empty space. You do not have to move as many particles of air out of the way as you do in water (see Figure 1.28). Running through air is much easier and faster than running through water. In general, *gases are less dense than liquids*. Compare the densities of gases and liquids in Table 1.5 on page 52.

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 cannot venture outside their spacecraft without masks and air tanks, because there is no oxygen in outer space.

Pause & Reflect

Find any small items in the classroom (for example, pencils or paper clips). Determine whether these items are denser than water by dropping them into a container full of water. In your Science Log, organize your observations in a table.

Table 1.5 Approximate Densities of Common Substances at 20°C

Fluid	Density (g/mL)	Solid	Density (g/cm^3)
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

When an object moves through a fluid, it pushes particles apart and moves between them. Particles in a solid cannot be 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. That is what particles in a solid do. Attractive forces among the particles of a solid are stronger than those between fluid particles. Thus the particles in a solid cannot be pushed apart. Compare the densities of various solids in Table 1.5.

As temperature increases, a substance will change from solid, to liquid, to gas. The particle model states that the particles of a substance spread out as they gain energy when heated. The particles will take up more space, which means that the density of the substance decreases. For most pure substances, the density of the solid state is greater than the density of the liquid state. The substance's solid state and liquid state are, in turn, denser than its gaseous state. Ice, of course, is the exception.

In some cases, the densities of two 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 1.29. Many solid metals, such as copper, nickel, and silver, can float on mercury, one of the densest substances known. A more familiar example of differing densities is shown in Figure 1.30.

Figure 1.29 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.

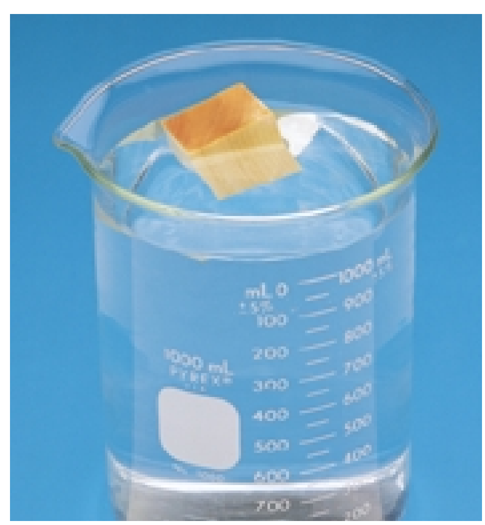


Figure 1.30 A solid block of wood floats easily on the surface of liquid water.

Density: How Are Mass and Volume Related?

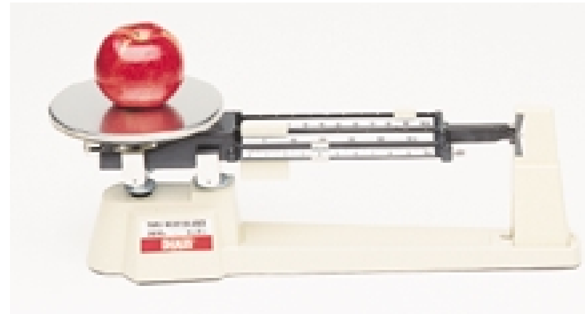


Figure 1.31 A balance is used to measure mass in grams (g) or in kilograms (kg). This apple has a mass of 102 g. It weighs about 1 N.

How can you measure the density of a substance? You first need to know how much of the substance occupies a certain space. To find out how much of a substance occupies a space, measure the mass of the substance. **Mass** is the amount of matter in a substance (see Figure 1.31). **Volume** is a measurement of the amount of space occupied by the substance. Figures 1.32 and 1.33 show how the volume of a solid can be measured either directly or indirectly, depending on the shape of the solid. 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. The greatest amount of fluid that a container can hold is called its capacity. Capacity is usually measured in litres or millilitres.

Mass and weight are not the same. **Weight** is the force of gravity exerted on an object. As you may recall from earlier studies, a **force** is a push or a pull, or anything that causes a change in the motion of an object. **Gravity** is the natural force that causes an object to move toward the centre of Earth. All forces, including weight, are measured in newtons (N). The pull of gravity everywhere on Earth's surface is almost the same. On Earth, gravity pulls on an object with a downward force of 9.8 N for every kilogram of its mass. A bag of sugar with a mass of 2.26 kg weighs 22.1 N on Earth.

The mass-to-volume ratio is the relationship between mass and volume expressed as a quantity of the mass divided by its volume. Density, as shown in Table 1.5, is a way of expressing a mass-to-volume ratio. In the next investigation, find out how measuring mass and volume can determine the density of a substance.

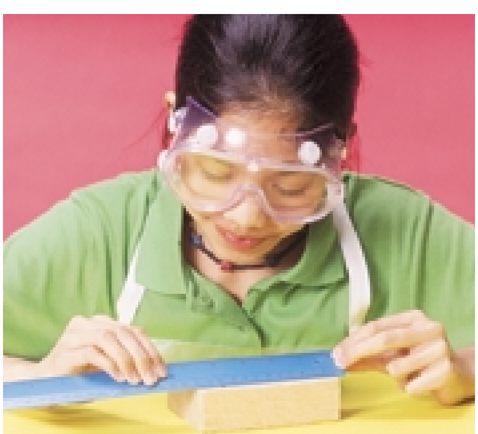


Figure 1.32 If an object has a regular shape — for example, if it is a block of wood — you can use a mathematical formula to calculate the object's volume: $V = l \times w \times h$.

Figure 1.33 The volume of an irregularly shaped object can be found by measuring the volume of the water that spills out of an overflow can.

INQUIRY

INVESTIGATION 1-H

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Determining Density

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 determine the density of a substance?

Prediction

Predict how the substances will rank according to density. Rank the substances from least dense (1) to most dense (5). Record your prediction and a brief note explaining your ranking order.

Part 1

Mass-to-Volume Ratios

Safety Precautions

- 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.

Apparatus

500 mL graduated cylinder (or 500 mL measuring cup)

balances (or one shared by the class)

5 different-coloured pencil crayons or markers

Materials

500 mL (per trial) of each of the following substances: water, oil, glycerol, molasses, sand

graph paper for each student

Procedure

1. **(a)** Your teacher will divide the class into five groups and will assign one substance to each group. Subdivide each group into smaller groups of partners to provide multiple trials for each substance.

   (b) Copy the data table below into your notebook.

2. **Measure** the mass of the empty cylinder. **Record** this value in column B of your table.

3. Pour 100 mL of your substance into the graduated cylinder. Be as accurate as possible.

Individual Results

Substance tested:				
A	**B**	**C**	**D**	**E**
Volume (mL)	**Mass of cylinder only (g)**	**Mass of cylinder and substance (g)**	**Mass of substance only (g)**	**Ratio of mass to volume (g/mL)**
100				
200				
300				
400				
500				

4 **Measure** the mass of the graduated cylinder plus the substance. **Record** this value in column C in your table.

5 Subtract the mass of the graduated cylinder (column B) from the mass of the graduated cylinder and the substance together (column C). **Record** the difference in column D.

6 Repeat steps 3 to 5 four more times, each time adding 100 mL of your substance to what is already in the graduated cylinder. (The last time, you will be measuring 500 mL.)

7 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.

8 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 average mass, volume, and mass-to-volume ratio values for each substance.)

Skill FOCUS

To review how to measure mass using a balance, turn to Skill Focus 5.

Skill FOCUS

For tips on how to measure volume, turn to Skill Focus 5.

Math CONNECT

The ratio "mass to volume" (or "mass : volume") means the "mass divided by the volume." To find the decimal value, convert the fraction of mass over volume into a decimal. For example, suppose a mass of 3 g has a volume of 5 mL. How would you convert its mass-to-volume ratio (3 g : 5 mL) into a decimal value? Begin by expressing the ratio as a fraction: $\frac{3\text{ g}}{5\text{ mL}}$. A decimal is any fraction with a denominator of any power of 10, for example, 10, 100, 1000, etc. Here is how to convert $\frac{3\text{ g}}{5\text{ mL}}$ into a fraction with a denominator of 10:

$$\frac{3\text{ g}}{5\text{ mL}} \times \frac{2}{2} = \frac{6\text{ g}}{10\text{ mL}} = 0.6\text{ g/mL}$$

Now, try converting the mass-to-volume ratio 6 g : 25 mL into a decimal value.

CONTINUED

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. 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. Write the name of the substance beside it.
4. Repeat step 3 for the three remaining substances.
5. Give your graph a title.

Skill FOCUS

To review how to make a line graph, turn to Skill Focus 10.

Analyze

1. Describe the lines on your graph. Are they straight or curved? Do they have the same slope? If not, 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 predictions to the final results.
4. There is a chance of error in every experiment. Suggest ways to improve (a) how you performed the investigation, (b) how you calculated results, 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 slope of the lines in the graph that correspond to them. How does the slope 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 model to explain the relationship between the mass, volume, and density of the substances you examined in this investigation.
10. From your observations, do you think that density and viscosity are related? Explain your answer.

Extend Your Skills

11. Use the particle model to predict the effect of temperature on mass-to-volume ratios.

***Computer* CONNECT**

Create a computer file for a data base of all the "raw data" in the class. Use the program features to sort the data, find averages, and generate computer graphs. Make a poster to display your results.

A Formula for 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. The formula for density is:

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

For example, the density of an object having a mass of 10 g and a volume of 2 cm^3 is 5 g/cm^3. The density of solids is usually given in g/cm^3 (grams per cubic centimetre). The density of liquids and gases is often given in g/L (grams per litre) or g/mL (grams per millilitre). Using pure water as an example, you could express its density as either 1 g/cm^3 or as 1 g/mL (1 cm^3 = 1 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*, which means it does not change.

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

Word CONNECT

Density is an example of an *intrinsic property* of a pure substance, because density depends only on the particles that make up the substance. Intrinsic properties can be used to identify pure substances, because each pure substance has its own specific set of intrinsic properties. Therefore, you could measure the density of a pure substance to help determine its identity. Name two other intrinsic properties of a pure substance.

STRETCH Your Mind

What shiny solid has a mass of 356 g and a volume of 40 cm^3? (Hint: The substance is listed in Table 1.5.)

Find Out ACTIVITY

What Is the Density of a Pencil?

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

Materials

100 mL graduated cylinder
balance
pencil
water

Procedure — Performing and Recording

1. Use a 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. Calculate the pencil's density by dividing its mass by the change in volume of the water level when the pencil was completely underwater.

What Did You Find Out? — Analyzing and Interpreting

Is the density of the pencil greater or less than the density of water? How do you know?

Extension

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

STRETCH Your Mind

The mass of an object depends on the amount of matter that makes up the object. The weight of an object changes as gravitational forces change. The pull of gravity on the Moon is about one sixth of Earth's gravity, or approximately 1.6 N/kg. On the Moon, what would your mass be? What would your weight be?

TOPIC 5 Review

1. Explain why solids can support objects more easily than fluids can.
2. (a) What is the only way in which the density of a pure substance can change?
   (b) How can the density of a solution change?
3. If you were to measure the mass and the volume of a material, what would the mass-to-volume ratio tell you about it?
4. **Apply** Using information from Table 1.5 on page 52, 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	

TOPIC 6 Buoyancy

A scuba diver exploring the dark and mysterious waters off the west coast of Canada might well come face-to-face with a Giant Pacific Octopus, the largest of its kind. The octopus is only one example of the large and unusual creatures that inhabit the ocean. How can animals with such huge bodies move so gracefully and so swiftly through the water? What enables completely submerged animals, such as octopuses, fish, and whales, to float at different depths? Why do objects such as icebergs, sailboats, ocean liners, and oil rigs float partially submerged on the surface?

Buoyancy is the tendency for materials to rise or float in a fluid. Without it, matter could not be transported from one place to another. Also referred to as the **buoyant force**, it is the upward force exerted on objects submerged in fluids. The transportation of nutrients through our bloodstream, pollen floating in the air, and boats and planes moving around the world would not be possible without the buoyant force.

Looking Ahead

As you work through the rest of the unit, think about your end-of-unit game. Jot down some ideas to share with your group.

The "Anti-Gravity" Force

Buoyancy refers to the ability of a fluid to support an object floating in or on the fluid. **Floating** occurs when an object does not fall in air or sink in water, but remains suspended in the fluid. The particles of a fluid exert a force in a direction opposite to the force of gravity. The force of gravity *pulls down*, toward the centre of Earth. Buoyant force — the upward force on objects submerged in or floating on fluids — *pushes up*, away from Earth. Like all other forces, buoyant force is measured in newtons (N). Why do you think fluids can support certain objects? Explore this question in the next investigation.

INQUIRY

INVESTIGATION 1-I

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

Build a Density Tower

Find out if density plays a role when a fluid supports an object.

Question

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

Prediction

Make a prediction about the order of the layers of the density tower.

Safety Precautions

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

Apparatus

tall plastic jar or cup (or transparent container) with lid

cork

toothpick or wood chip

paper clips

rubber gloves

Materials

water, with food colouring added

vegetable oil

Procedure

1. Combine the water, oil, cork, wood chip, 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.

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 model 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, for example, a rubber stopper, a small rubber duck, a candle stub, a small plastic toy, and a safety pin. **Predict** where you think these objects will settle in the tower. Then **test** your prediction.

Sinkers and Floaters

How can people travel in the air and on water if the density of their bodies is greater than the density of both these fluids? Why don't they sink? Is density the only factor that explains why fluids can support certain substances? Look at Figures 1.34 and 1.35. It seems that water can support objects that have densities greater than water — as long as the weight of the object is spread over a large enough area. Design can be as important as the density of the materials used.

Figure 1.34 The *Hibernia* oil rig in Atlantic Canada has a mass of more than 14 000 t, yet it floats on water.

Figure 1.35 The mass of this straight pin is slightly less than 1 g. However, the pin sinks when placed in water.

Find Out ACTIVITY

Cartesian Diver

Make your own model of a diving device that can adjust its own depth.

What You Need

1 L plastic pop bottle and cap

water

medicine dropper

What to Do

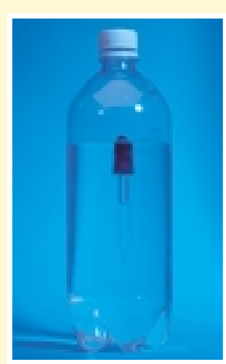
1. Fill the pop bottle three quarters full with water.
2. Fill the medicine dropper half full with water.
3. Drop the medicine dropper, or "diver," into the pop bottle. Put the cap on the bottle.
4. Squeeze the bottle hard, then release it. Record your observations and include a sketch.

What Did You Find Out?

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

Extension

Reconstruct your bottle. This time lay an empty eye dropper on the surface of the water inside the bottle. Squeeze the tightly sealed bottle hard with both hands. Can you explain what happens?



Average Density

Ships can be built of steel (density = 9.0 g/cm^3) as long as they have large, hollow hulls. A large, hollow hull ensures that the **average density** of the ship (the total mass of all substances on board divided by the total volume) is less than that of water. Similarly, life jackets are filled with a substance of very low density. Life jackets lower a person's average density, allowing the person to float. Many fluids, such as air, salt water, and petroleum, are solutions. Because solutions contain more than one pure substance, the density of a solution is actually an average density.

Figure 1.36 The Dead Sea contains many salts. Its density is great enough for people to float effortlessly on its surface.

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). The swim bladder, a large sac near the spine of the fish, contains a mixture of air and water (see Figure 1.37). The fish's depth 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 in the submarine, allowing the submarine's crew to adjust its depth underwater (see Figure 1.38).

STRETCH Your Mind

It took 3 h for submersibles (underwater vessels) to free-fall 4 km through the icy waters 650 km off the coast of Newfoundland 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?

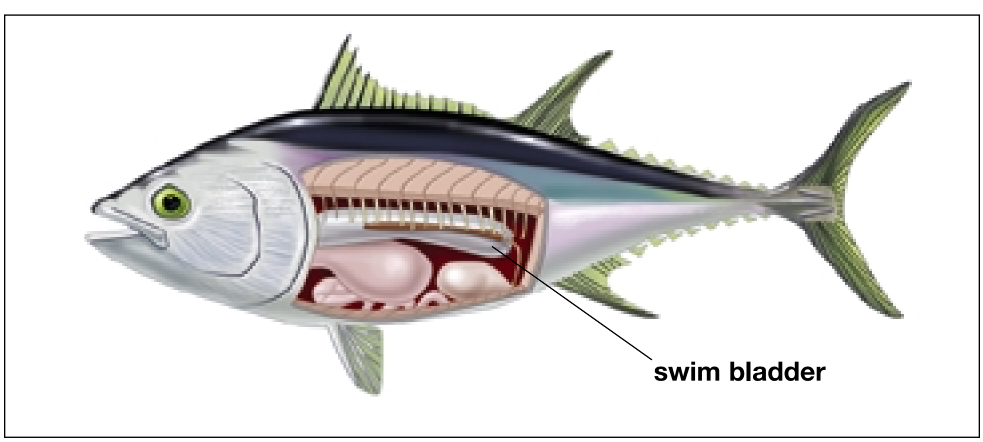


Figure 1.37 Cut-away drawing showing the swim bladder inside a fish

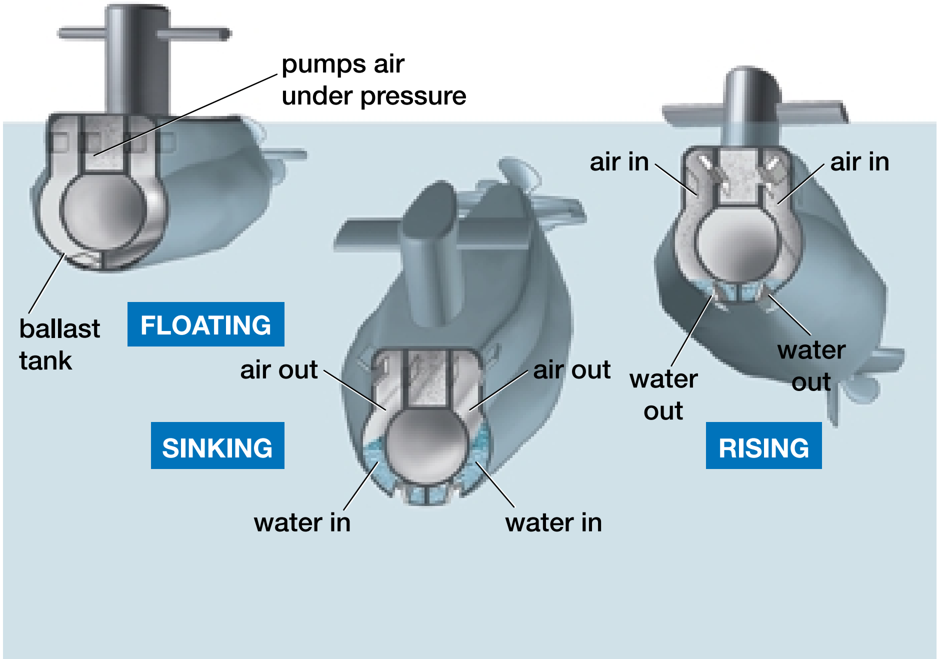


Figure 1.38 Cross section of a submarine

The buoyant force of air is much smaller than the buoyant force of water. Although air particles are extremely far apart, they are still close enough together to support some objects. The Goodyear™ blimp, shown in Figure 1.39, is one of the largest floating airships in the world. It can carry people as well as the substances that make up its structure. The giant airship is filled with helium gas, the second lightest 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. Ocean-going ships, hot-air balloons, and blimps all have huge volumes. The relationship between the size of an object and the buoyant force exerted on it was established long ago by a scholar named Archimedes.

Pause& Reflect

Imagine a contest in which you must drop a sheet of paper from a tower five storeys high, into a small box below. This contest would take place in an auditorium, so there would be no wind to affect the results. In your Science Log, explain why you would probably not succeed in winning this contest. Why can you not rely on an object such as a sheet of paper to land on a small target directly below you? Paper is made from wood. Do you think a wooden block would fall straight down? In your Science Log, comment on the difference between dropping a sheet of paper and dropping a wooden block. What could you do to help the paper hit its target? Why might that work?

Figure 1.39 The Goodyear™ blimp is often seen hovering over open stadiums during sports events. It captures a unique "bird's-eye view" of the action below.

Archimedes' Principle

The Greek scientist Archimedes made a brilliant discovery around 212 B.C.E. Hiero II, ruler of Syracuse, suspected that the royal goldsmith had not used pure gold to make his crown. The king asked Archimedes to determine whether the crown was made entirely of gold.

Archimedes knew that all he had to do was determine whether the density of the crown matched the density of gold. Recall that the formula for density requires only two values: mass and volume. Archimedes could measure the mass of the crown easily with a balance. How could he measure the volume of an object as irregularly shaped as a crown?

Archimedes solved the problem while at the public baths. He stepped into the almost-full bath, and water gushed all over the floor. The solution to the problem came to Archimedes in a flash — a solid object can displace water out of a container.

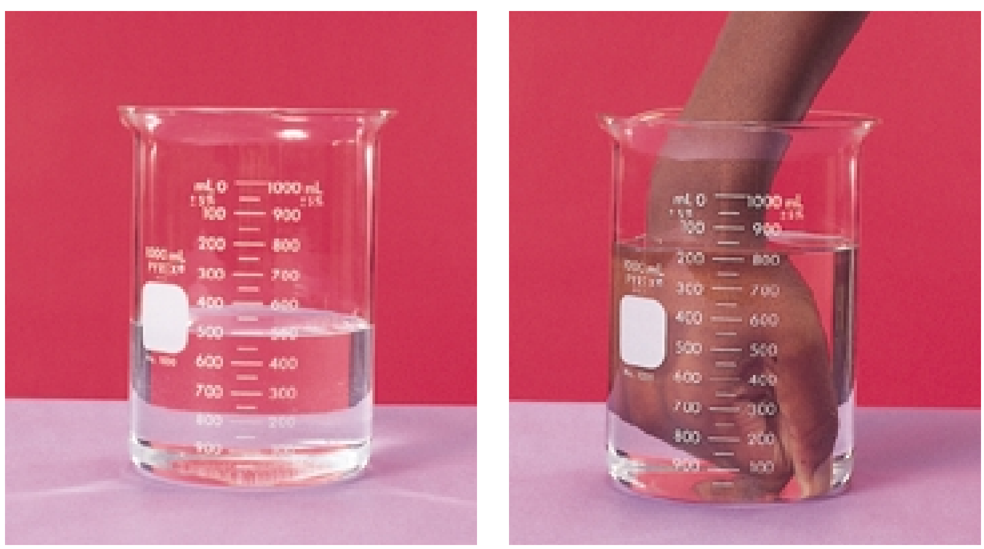


Figure 1.40 A solid object added to a container displaces the fluid.

Archimedes reasoned that the water that was displaced must have exactly the same volume as the volume of his body. Therefore, to find the volume of the crown, Archimedes would simply submerge the crown in a container full of water. He would then collect and measure the volume of the water that spilled out. When Archimedes carried out this test, he showed that the crown was made of a mixture of gold and silver. He concluded that the goldsmith who had made the crown had tried to cheat the king.

Archimedes applied his new ideas 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. He wondered why he would sink if he stepped into a bath-tub, but he would float if he stood in 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 (the weight) of the fluid that the object displaced.

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)*. When gravity equals buoyancy, this condition is known as **neutral buoyancy**. 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 it.

When Archimedes stepped into the bath, he sank because the amount of water that he displaced weighed less than he did. When he stepped into a boat, however, a larger volume of water was displaced. The weight of this water far exceeded the weight of the boat and Archimedes combined. Therefore, the buoyant force was greater and the boat, with Archimedes in it, floated on the surface.

Why would Archimedes and his boat not continue to rise, with such a large buoyant force pushing it upward? At the surface of the water, the fluid supporting the object is air. As mentioned earlier, the buoyancy of air is much less than that of water. Therefore, the upward motion stops at the water's surface.

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.* Archimedes' principle is useful in predicting whether objects will sink or float.

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 of the same volume, would experience the same buoyant force!

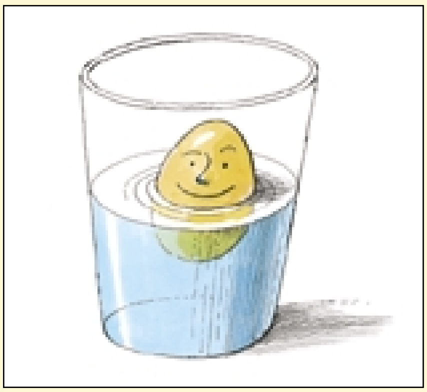
Find Out ACTIVITY

The Amazing Egg Hydrometer

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

Materials

glass or large bowl, teaspoon, water, salt, sodium bicarbonate, sugar, Epsom salts, fresh egg



Procedure

1. Place an egg in a glass or large bowl half-full of water and observe what happens. Record your observations.
2. Stir salt into the water one teaspoonful at a time; stop when the egg floats. Try to explain why the egg floats.
3. When the egg is floating, carefully pour more tap water into the glass until it is almost full. Add the water *slowly* and near the side of the glass so the fresh water and the salt water do not mix. Where does the egg float now? Sketch a labelled diagram of your floating egg. Suggest an explanation for your observation.
4. Repeat this experiment with sugar, Epsom salts, and sodium bicarbonate solutions.

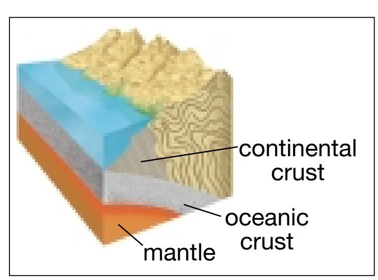
Off the Wall

The freshwater zebra mussel has the waterways of North America. This tiny mollusc sticks to underwater surfaces such as water-intake pipes and docks. Zebra mussels can attach themselves to buoys and ships' hulls.

Sometimes they form dense layered colonies of over 1 million mussels per square metre. Thus, they can alter the average density and the stability of floating objects. Buoys have been known to sink with the added weight of thousands of zebra mussels. An unbalanced distribution of zebra mussels can interfere with a ship's stability, especially when it is being tossed about in a storm.

Did You Know?

It is known that Earth's continents float on an endless mass of a denser, semimolten rock called the mantle. Although the mantle is more "liquid" than the solid crust, the mantle stays below the crust because its density is approximately 3.3 cm^3, while the density of Earth's crust is only about 2.8 cm^3. While this difference is enough to allow the continents to float, they ride low in the mantle, like a full barge.



How Buoyancy and Density Are Related

Think back to your density tower (page 60). Both water and oil are liquids, but they did not support the same objects. The buoyant force of a liquid does not depend on *physical state*, but rather on *density*. (This is also true for buoyancy in gases.)

As you observed in the previous Find Out 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. Salt water can support more weight per volume than 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! The relationship between buoyancy and density is the basis for the **hydrometer**, an instrument designed to measure liquid density. Figure 1.41 shows two kinds of commercial hydrometers. A hydrometer will extend farther out of a liquid if the liquid has a higher density, for example, water (1 g/mL). A hydrometer will sink lower if the liquid has a lower density, such as vegetable oil (0.9 g/mL).

Pause & Reflect

Would water solutions likely have a greater density than plain water? Use the particle model and the formula for density to explain your answer.

Figure 1.41 Commercial hydrometers

Many different hydrometers are available commercially, all designed for specific uses. Hydrometers are widely used in the food and beverage industries. Although they measure density, these instruments can be used to determine other values indirectly. For example, they can be used to determine the sugar content of canned fruit syrup, or the alcohol content of wine. Analyze how a hydrometer works in the next investigation.

INVESTIGATION 1-J

SKILLCHECK

- Initiating and Planning
- ✸ Performing and Recording
- ✸ Analyzing and Interpreting
- Communication and Teamwork

Measuring Buoyancy

Think About It

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. **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. **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.

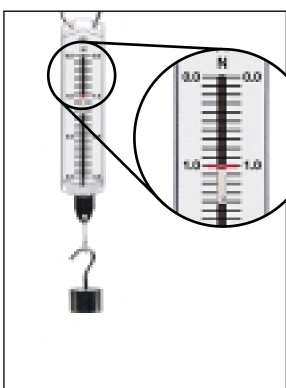
2. Using your calculations from step 1, list the liquids in order of the buoyant force they exert on the mass, from the greatest to the least.

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?

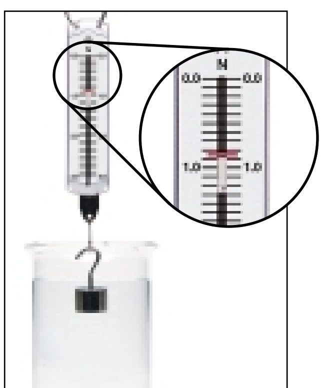
Analyze

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?

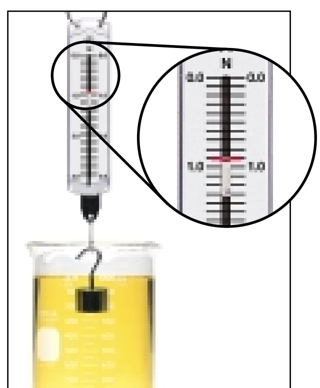
Set 1



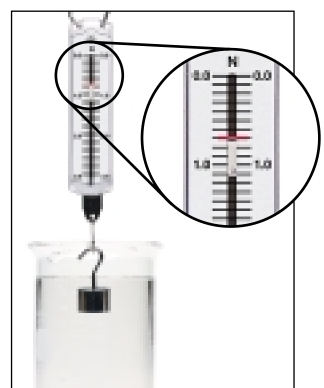
Weight = 1.0 N
100 g mass in air



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

Career CONNECT

Working Underwater

A number of careers involve scuba-diving in lakes, oceans, or other bodies of water. One example is underwater welding. As another example, the divers shown here are conducting research on marine life. How many other underwater careers can you think of? Brainstorm in a group to see how many diving-related careers you can list. The scuba gear that divers use includes masks, fins, air tanks, and weight belts. The word "scuba" comes from "**s**elf-**c**ontained **u**nderwater **b**reathing **a**pparatus." Search the Internet for information on scuba-diving or look in the Yellow Pages of your telephone book for companies that offer scuba training. Try to find out:

- how scuba gear helps you sink instead of float on top of the water
- how you are able to rise to the surface after your dive
- what determines how long a diver can stay underwater
- how much training is necessary before a beginning diver can dive without an instructor
- what careers involve scuba diving

TOPIC 6 Review

1. Explain how you could make plastic sink and steel float.
2. State Archimedes' principle.
3. Make a labelled drawing to show the most important design features of a hydrometer.
4. **Apply** A block of an unknown metal measures 5 cm x 3 cm x 2 cm. The block has a mass of 235 g. Of what metal do you think the block is made? Would this metal sink in mercury?
5. **Thinking Critically**
   (a) If the buoyant force is less than the weight of an object immersed in a fluid, what will happen to the object?
   (b) If the buoyant force equals the object's weight, what will happen to the object?
   (c) Give an example of what can happen when the buoyant force on an object is greater than the weight of the object.

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

viscosity	weight	floating
flow rate	force	average density
density	gravity	neutral buoyancy
mass	buoyancy	Archimedes' principle
volume	buoyant force	hydrometer

Reviewing Key Terms

1. In your notebook, match the description in column A with the correct term in column B.

A

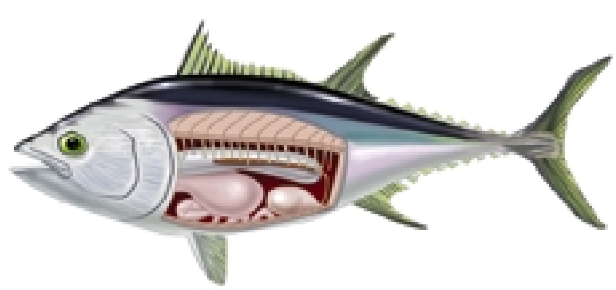
- the total mass of a substance divided by the total volume
- occurs when gravity equals buoyancy
- increases as the volume of a ship's hull increases
- the property that describes a liquid's thickness
- the pull of gravity on a mass
- the space occupied by an object
- opposes the force of gravity
- anything that causes a change in the motion of an object

B

- viscosity (4)
- force (5)
- density (5)
- average density (5)
- neutral buoyancy (6)
- mass (5)
- volume (5)
- flow rate (4)
- gravity (6)
- weight (6)
- buoyant force (6)

Understanding Key Concepts

2. Name three factors that affect the internal friction of a fluid. (4)
3. Name three industries in which measuring and controlling viscosity are important. (4)
4. Explain why the effect of temperature on the viscosity of gases differs from the effect of temperature on the viscosity of liquids. (4)
5. Compare the densities of the solid, liquid, and gaseous states of a substance. (5)
6. Explain how to measure the volume of a gas. (5)
7. State the formula for density, and include the units in the formula. (5)
8. Use the particle model to explain buoyancy. (6)
9. Restate Archimedes' principle in your own words. (6)



TOPIC 7 Fluid Pressure

Every time you lean against a wall, you are exerting pressure on the wall. Pressure is a measure of the force acting perpendicular to a unit area. When you press your hand against a wall, you are *applying pressure* on that particular *area* of the wall. If the wall were made of whipped cream, your hand would push right through the whipped cream, leaving a hand shape that is the outline of the area over which the force was applied. If the force is increased, the pressure will increase. What happens if the area is increased?

A Formula for Pressure

Pressure can be calculated by using the following formula:

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

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) in honour of his pioneering work with pressure. A **kilopascal** (kPa) is equal to 1000 Pa.

DidYouKnow?

Pascal demonstrated a talent for numbers and relationships at a very early age. By the time he was 16, he had published a geometry book, and by 19, had invented the first mechanical calculator. Turning his attention to physics, he was fascinated with fluids. He was the first to discover that the pressure exerted on a fluid (in a closed container) at one end could be felt, undiminished, at the other end of the container. This formed the basis for understanding how to use fluids to do work in large and powerful mechanical systems.

Blaise Pascal 1623–1662

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Proving the Pressure Equation

You need to apply force in much of the work you do. Mechanical devices have been designed and produced to make work easier. Can you identify where the pressure equation is applied?

Challenge

Examine a mechanical device (no electricity or fuel required) that requires an applied force, to see how the pressure equation, $P = \frac{F}{A}$, has been taken into consideration in its design. Using the existing mechanical device as a model, and the pressure equation, suggest a design change that will make the task easier, or the device work harder for you.

Materials

Suggestions only — you are free to choose your own device and construction materials: 3-hole punch, ruler, stapler, pencil, staple remover, sketch paper, fork, calculator, shovel, wood dowelling, cardboard, garden claw, glue gun, food chopper, hammer, nails

Design Specifications

You must be able to identify which variable(s) of the pressure equation will change in your design modification.

Plan and Construct

1. As a group, analyze the device you have chosen. Elect someone to draft a series of labelled sketches of its different parts. Identify on the sketches where the pressure equation variables apply.
2. Make area measurements (see Skill Focus 6, Estimating and Measuring) of the parts that are involved in the pressure equation. If the areas are too small to measure directly, suggest an alternate method for measuring them. Record your measurements directly on the sketches.
3. In terms of the pressure equation, explain in a summary paragraph how the device eases a task or delivers more force than possible without it.
4. As a group, discuss a design improvement, directly related to the pressure equation and how you would rebuild the existing device to include it.
5. Using simple materials, construct your prototype. You can reconstruct the entire device, or if possible, simply add the modification to the existing device.

Evaluate

1. How many design features in the original device were related to the pressure equation?
2. Calculate the amount by which your force output, or force input changes with the modification.
3. How could you improve your design modification?

Compression of a Gas

Figure 1.42 Mats in gymnastics, pistonlike devices in some bicycles, and Styrofoam™ packaging are all used to absorb the force of impact to reduce the amount of pressure felt.

Imagine being a stunt double and jumping out of a window in an action movie. Would you rather land on the hard ground or onto a huge, billowy air mattress? Why would the air mattress be a better choice? Something that compresses when you land on it absorbs the force of the fall gradually. Your body would feel only a small amount of pressure during the landing. The air mattress would work as a huge shock absorber.

How is the compression of a gas made possible? Consider these requirements:

(1) The gas must be enclosed in a sealed container with sturdy walls. Gas molecules distribute themselves equally throughout their containers.

(2) There is so much space between the particles that, even after the particles are squeezed closer together, they are still far enough apart to behave as a gas.

(3) An external, or outside, force is applied to the enclosed gas, to push the particles closer together.

Gases are compressible because their particles can be squeezed closer together into a smaller volume. Is this true for liquids and solids as well?

Figure 1.43 An applied force is transmitted from one particle to the next, in both solids and liquids. This is similar to dominoes falling in a row. The force moves along, but the dominoes stay in the same places.

Although there is empty space between the particles of solids and liquids, the spaces are already almost as small as possible. When a force is applied to a solid or a liquid, the particles cannot move much closer together. Because solids and liquids cannot be squeezed into a smaller volume, they are said to be almost **incompressible**. What happens to liquids and solids when an external force is applied? Instead of changing the volume of either the solid or the liquid, the applied force is transmitted (passed along), from one particle to the next, throughout the substance, somewhat like falling dominoes (see Figure 1.43). The particles themselves do not move in the direction of the force because there is no space to move. Only the particles that have space to move will move.

Figure 1.44 All-terrain vehicles have wide tires and are kept inflated to a specific pressure.

Some Advantages of Compression

Another useful property of gases is their ability to exert a force *back* (a counterforce) when they are compressed. This property can be used to cushion shocks. For example, the air in a car tire pushes back against the force exerted by the weight of the car. Otherwise, the car would simply sink to the ground. If the car hits a bump, the extra force compresses the air in the tires even further. This allows the effect of the force to be spread out over the entire tire, rather than being transmitted directly to the body of the car and its passengers. When the extra force is removed, the air returns to its original volume, and the tire resumes its original shape.

An air bag in an automobile is another device used to cushion shocks. Air bags are designed to be used in addition to seat belts. An air-bag system consists of one or more crash sensors, an ignitor and gas generator, and an inflatable nylon bag. The nylon bag for the driver is stored in the steering wheel, and the bag for the front-seat passenger is usually stored inside the dashboard. If a car hits something with sufficient force (speeds in excess of 15–20 km/h), impact sensors trigger the flow of electric current to an ignitor. The ignitor causes an explosive chemical reaction to occur, producing harmless nitrogen gas. The nitrogen gas propels the air bag from its storage compartment at the same time as the driver is forced forward, saving the driver from serious injury. The bag then immediately deflates. The entire process takes only 0.04 s!

Figure 1.45 Some running shoes contain pockets of compressed air. It is believed that compressed air is superior to plain rubber soles in shock absorption and bounce.

Figure 1.46 An air bag in an automobile uses compressed air to protect the driver in a collision.

Find Out ACTIVITY

Balloon Balance

Gases are made up of particles that have mass and, therefore, weight. Weight is the force of gravity pulling on a mass. Prove to yourself that a gas has weight.

Materials

2 balloons, uninflated
metre-stick
string, 1–2 m
scissors
hook or thumbtack
sharp pin

Safety Precautions

Be careful when handling sharp objects.

Procedure ✷ Performing and Recording

1. Blow up the two balloons to the same size and tie them.

2. Assemble a "balloon mobile," as shown in the photo to the right.

3. While the mobile is hanging and balanced, pierce one of the balloons with the pin. Observe what happens to the metre-stick.

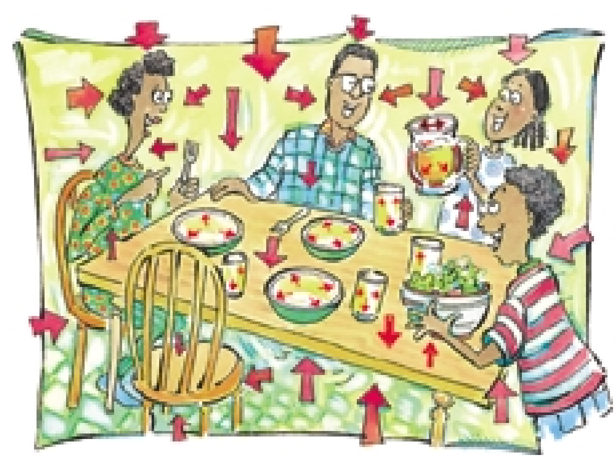
What Did You Find Out? ✷ Analyzing and Interpreting

1. Describe how the metre-stick moves after the balloon is popped. Does it move slowly or quickly? Why did it not move up or down before the balloon was popped?

2. Explain how this demonstration proves that carbon dioxide has mass and volume in addition to weight.

Atmospheric Pressure

Earth's atmosphere is approximately 160 km thick. Gravity keeps the envelope of air around Earth. Why don't you feel weighed down by air? The pressure of Earth's atmosphere is so well balanced by your body, both inside and out, that you hardly ever notice air pressure.



Just as water pressure changes with depth, air pressure changes with altitude. As you climb higher in the atmosphere, fewer air particles press against you on the outside of your body. The air pressure inside your body does not change as quickly, however. The number of particles pressing from the inside out is still the same at the top of a mountain as it was when you were at the base of the mountain. 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.

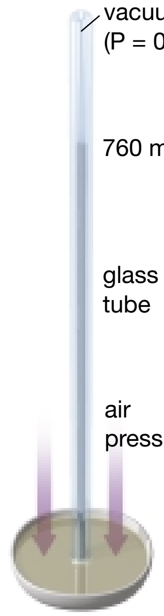


Figure 1.47 A mercury barometer

Measuring Air Pressure

The most common device for measuring air pressure is a **barometer**. The earliest barometers were made with mercury and are still used by many weather stations. Figure 1.47 shows how a mercury barometer works. First, a thin, strong-walled glass tube, sealed at one end and open at the other, is completely filled with mercury. It is then inverted (turned upside down) in a pool of mercury, allowing no air to enter. The mercury falls to a lower level in the tube, due to gravity, leaving a vacuum (no air, only empty space) at the top of the tube. Why does some mercury stay in and some come out?

As the air pushes down on the mercury in the pool, forcing it up the column, the mercury pushes down through the column and into the pool because of its weight. The mercury will stop moving when the force of the air pressure pushing it up equals the force of gravity pulling it down. Air pressure can support 760 mm of mercury (Hg) at sea level.

Balanced and Unbalanced Forces

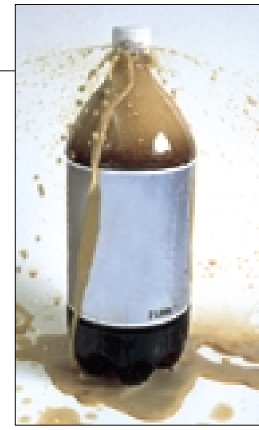
If the inside of a closed container experiences a lower air pressure than the air pressure pushing on the outside, the walls of the container will buckle and cave in. In other words, the lower air pressure inside the container does not balance the higher air pressure outside the container. This results in an unbalanced force. The force of atmospheric pressure pushes on the walls *toward the inside* of the container. You may have noticed this imbalance when drinking juice from a juice box. The straw makes such a tight seal that as you draw the juice up the straw and reduce the air pressure inside the juice box, the box buckles inward. The air pressure outside the juice box pushes the walls of the box together.

Pause& Reflect

Drink bottles are often made of flexible plastic. Have you ever taken a big sip from a plastic water bottle and seen the sides buckle? What about glass bottles? Do the sides of a glass bottle buckle when you take a big sip? At home, take sips from various types of bottles in which the openings are sealed around a straw, and record your findings in your Science Log. Try to explain your observations in terms of "low pressure," "high pressure," and "unbalanced force."

DidYouKnow?

Bottled pop on store shelves does not look carbonated because it has been bottled under pressure. To manufacture pop, carbon dioxide gas is forced to dissolve into the flavoured and sweetened water solution called the "syrup." The bottle cap is secured before the pressure is released, and the strength of both bottle and cap prevents a loss of pressure. If you open a bottle of pop quickly, however, the pressure inside the bottle is released suddenly and the carbon dioxide escapes rapidly from the solution, forming bubbles, or fizz. The more quickly you open the bottle, the more fizz is produced. Shaking the pop ahead of time, or warming the bottle in the Sun, gives the carbon dioxide particles more energy. Thus, more carbon dioxide escapes when the pressure is released than if the bottle were not shaken, or if the bottle were taken out of the refrigerator.



TOPIC 7 Review

1. Define pressure.

2. **(a)** What unit is used to measure pressure?
(b) What is another way to express this unit?

3. What is the difference between balanced and unbalanced forces? Which circumstance can exert pressure? Why?

4. In which direction is a force exerted in a fluid at rest?

5. **Thinking Critically** Mountain bike tires are kept inflated to a pressure of 550 kPa, while car tires are inflated to only 220 kPa. A car can support much more weight (the force due to gravity) than a mountain bike can. Use the pressure equation to justify the huge difference in inflation levels for each one.

DidYouKnow?

Earth's atmosphere does not have the same number of air particles at sea level as at the halfway or higher mark. The density of the atmosphere decreases as you move farther and farther away from sea level. That is why it is so difficult to breathe at the tops of very high mountains, such as Mount Everest. Every breath you take on the mountaintop contains a fewer number of oxygen molecules than at sea level. Since pressure decreases as the force (in this case, weight) pushing down on an area decreases, you would experience less air pressure higher up in the atmosphere.

pressure = about 57 kPa at the top of this mountain (5951 m)

pressure = 101.3 kPa at sea level

Air pressure decreases with increasing altitude.

TOPIC 8

Fluid Systems

DidYouKnow?

Ultraviolet light can damage cells and contribute to skin cancer. A layer of ozone gas in the upper atmosphere reduces the amount of ultraviolet light reaching Earth's surface. However, the ozone layer is damaged by the CFCs used in many fast-food cartons, cavity-wall insulation, and refrigeration and air conditioning systems. Ultraviolet light reacts with CFCs to produce chlorine, which in turn reacts with and breaks down ozone.

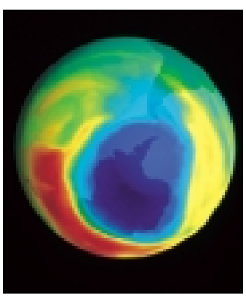


Figure 1.48 Liquids get pushed out with gases under pressure.

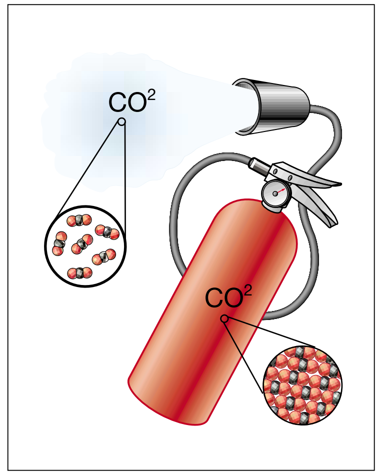
Aim, press, and apply! It is as simple as that with aerosol products, such as whipped cream, hairspray, hair mousse, paint, shaving cream, and bathroom cleaners. How does an aerosol work? Particles always flow from areas of high pressure to low pressure. When high-energy gas particles are squeezed inside strong-walled containers, they exit through holes or cracks with a great force. If a liquid is also present, the gas will push a fine foam or spray of the liquid particles as it exits (see Figure 1.48). Usually the openings are designed to help direct the spray; they can be tiny holes, which encourage a fine mist or spray, or elongated nozzles that help to direct the foam as it exits.

Although aerosols no longer contain the chlorofluorohydrocarbons (CLOR-O-FLOOR-O-HYDRO-CAR-BONS), commonly referred to as CFCs, which damage the ozone layer, there are still dangers associated with aerosols. The liquid/gas mixture inside is under so much pressure that high temperatures could cause the energy of the particles inside to become stronger than the container, and cause the container to rupture. A rupture would allow the contents to escape suddenly and with a great deal of force, possibly causing an explosion. Puncturing, or exposing an aerosol can to a spark could also lead to an explosion. It is important, then, to keep aerosols in a cool place and away from flames.

Gases under pressure are ready to expand, because the particles have so much energy. If gases under pressure find a way to escape from a container — for example, through a nozzle or a hole — they exit the container with a great deal of force. That force can be used in many applications to carry, push, or move objects.

DidYouKnow?

Although fire extinguishers work under pressure, they operate a bit differently than aerosols. The common carbon dioxide (CO_2) fire extinguisher contains liquefied CO_2, which takes up much less volume than gaseous CO_2. Carbon dioxide exists as a liquid only at very cold temperatures. When the fire extinguisher is turned on, the CO_2 particles gain enough energy to become a gas again, which needs a lot more space. The CO_2 exits the tank with a great amount of force. The gas shooting out of the cylinder is still much colder than its surroundings, and helps to remove heat from the fire and extinguish it. As well, the CO_2 smothers the fire by not allowing oxygen to continue combustion.



Find Out ACTIVITY

Balloon Arm

Find out how squeezing a plastic bottle in one place can cause movement somewhere else.

Materials

strong elastic bands
small, flexible plastic bottle with a narrow spout
water
balloon
deep pail

Procedure

1. Fill the pail with water. Submerge the bottle and the balloon. Make sure all the air has escaped from both objects and has been replaced with water.
2. While holding both objects underwater, stretch the opening of the balloon over the opening of the bottle. You should have a completely enclosed and continuous liquid inside (no air). Use one or two strong elastic bands to make sure the balloon is securely fastened to the bottle.
3. Press the bottle and observe what happens. Record your observations.
4. Now press the balloon and observe what happens to the bottle. Record your observations.

What Did You Find Out? Analyzing and Interpreting

1. What makes the balloon arm move?
2. How could you use your balloon arm to move something else?

Cool Tools

An intravenous line, simply referred to as the IV, is a long, thin, flexible tube that is inserted into a vein so that medicine, food, or other substances can be pumped directly into the patient's bloodstream. If patients are unconscious or cannot eat on their own, they can be fed a nutrient solution through an intravenous line. Some treatments, such as chemotherapy or bone marrow transplants require substances to be pumped in and blood samples taken out on a regular basis. A catheter is placed into the large vein above the heart and the entire intravenous system becomes an extension of the patient's blood system.

Hydraulic Systems

Hydraulics is the study of pressure in liquids. Devices that transmit applied forces through a liquid to move something else, because of pressure, are called **hydraulic systems.** In most hydraulic systems, a force is exerted on a continuous, enclosed liquid. The applied force creates pressure that moves the liquid through a series of tubes, pipes, or hoses, which causes motion at the other end of the system. Try making a simple model of a hydraulic system in the following Find Out activity.

Find Out ACTIVITY

Simple Hydraulics

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

Materials

2 modified syringes

short piece of plastic tubing

beaker of water

Procedure

1. Fill the cylinder of one syringe (the "main cylinder") with water by inserting the cylinder tip into a beaker 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 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?

Analyzing and Interpreting

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

2. How would you expect your hydraulic system to work over a longer distance? How could you test it?

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Compression of Liquids and Gases

Using the same simple syringe you used in the last activity, find a method to determine the percent compression of air and water. You may develop your own method or use the one listed below.

Prediction

Make a prediction about the percent compression of liquids and gases.

Apparatus
simple plastic syringe, with tip cap
You may use items such as:
ruler, beaker, graduated cylinder

Materials
water

Procedure

1. Prepare a table with the following column headings:
   A. Distance from tip to edge of pulled plunger (mm)
   B. Distance from tip to edge of pushed plunger (mm)
   C. % Compression
   Air Water Water (after 10 min)
2. *Compressing Air*: Pull the plunger out the full length of the syringe. Place the cap on the tip of the syringe. Measure the distance from the tip to the plunger edge. Record this distance in the table under column A.
3. Holding the cap in place, press the plunger in as hard as you can. Measure in millimetres how far you are able to push the plunger. Record this distance in the table under column B.
4. Calculate the percent compression of air ($A - B \times 100\%$). Record the answer under column C.
5. *Compressing Water*: Fill the syringe with water by dipping the tip into the beaker of water and pulling the plunger to the top of the syringe. Hold the plunger with the tip up. Tap it until all of the air bubbles have reached the top of the syringe. Push the plunger until a bit of water comes out the tip. Place the cap on the tip and measure the distance from the tip to the plunger edge. Record this distance in the table.
6. Repeat steps 3 and 4.
7. Leave the plunger filled with water. After 10 min, examine the water-filled syringe very carefully. Record any changes. Repeat steps 3 and 4.

Analyze

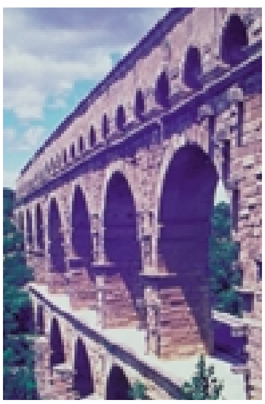
1. What was the manipulated variable(s)?
2. What was the responding variable(s)?
3. What was the control variable(s)?
4. How did your percent compressions compare?
5. What happened to the water-filled syringe after 10 min? How did the percent compression change?

Conclude and Apply

6. How close were your predictions to your experimental findings?
7. How would you explain the outcome of the water-filled syringe after 10 min?

Word CONNECT

An aqueduct is a raised canal that carries water from one place (the source) to another place some distance away. The water can flow only by gravity, so there must be a gradual decline the entire way. Research to find out the force used in the many aqueducts built throughout Europe during the time of the Roman Empire.



Hydraulics to Transport Fluids

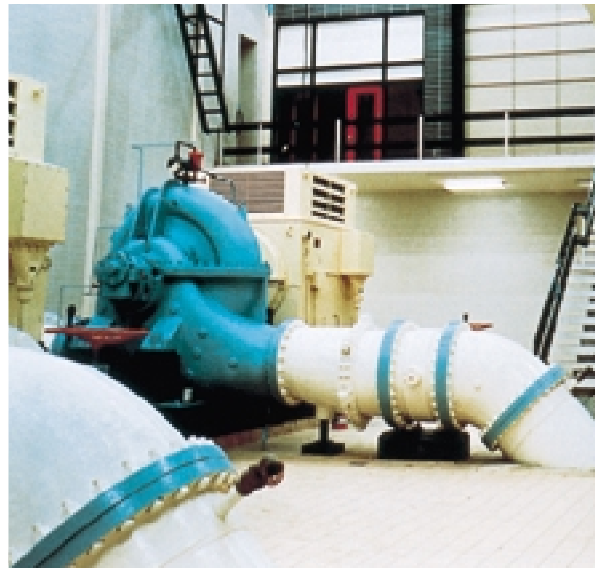


Figure 1.49 A water pumping station is needed to keep water flowing at a certain pressure through city pipelines.

Just as water gushes out of an open faucet, liquids under pressure flow away from the applied force in all directions. Hydraulic systems can be used to transport fluids over large distances. The ancient Romans constructed huge aqueducts to transport water from lakes to distant cities. Today, water, natural gas, and oil are typical examples of fluids transported in extensive pipelines. Pumps provide the force that pushes the fluid through the pipes. Why do the travelling fluids need to be placed under pressure?

Think about the water that comes out of your faucet. How does water travel up to reach homes in highrise apartment buildings? To travel so high, water must be placed under pressure in order to move against gravity. There must be enough pressure in the pipes to transport the liquid over a large distance, but not enough to burst the pipes.

Friction in the pipes — caused by rough surfaces or numerous bends in the pipeline — can affect fluid pressure. Particles lose energy as they brush past each other in confined spaces and as they bump into the walls of the pipelines. Pumping stations are frequently needed to restore the pressure lost on long routes (see Figure 1.49).

DidYouKnow?

Natural gas in major transmission pipelines is compressed to 100 times atmospheric pressure by "spinning" pumps that are operated by engines similar to the ones used in jet airliners. The gas travels on average 40 km/h, which is about the speed of an Olympic sprinter. The gas can leave Alberta on a Monday and reach southern Ontario the following Sunday.

Pressure and Pneumatic Systems

Pneumatic systems are similar to hydraulic systems, except gases are used instead of liquids. The operation of most pneumatic systems is based on the fact that gases can be compressed. Therefore, **compressors** — devices that compress air — are needed. Air pressure builds up in these devices. As the pressure is released, the compressed air decompresses. In other words, the particles start to move apart suddenly, creating a strong, steady force that can perform powerful tasks. Many tools use pneumatics, from large tampers used to pack down dirt and gravel when building a road, to tiny precision drills used by dentists. As well, heavy trucks and buses rely on pneumatic brakes (also called air brakes) to stop quickly and smoothly.

In pneumatic systems, an enclosed gas can transmit a force, causing motion. Find out how a balloon can behave like a pneumatic system in the next activity.

PROBLEM-SOLVING

INVESTIGATION 1-M

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Make a Model of a Dentist's Chair

A dentist's chair can be lowered, raised, and tilted by means of a hydraulic system. Use your knowledge of hydraulics and some everyday materials to design and build your own working model of a dentist's chair.

Challenge

Create a working model that simulates the movement of a dentist's chair.

Materials

modified syringes; plastic tubing; water; jinx wood, plywood, stiff cardboard or corrugated plastic; masking tape; elastic band; glue gun; butterfly fasteners or paper fasteners; dowelling; thread spool; scissors or cutting knife; pencil or skewer for punching holes

Safety Precautions

- Be careful when using sharp tools such as scissors, knives, or skewers.
- A glue gun is hot and the glue remains hot for several minutes.

Design Specifications

A. Your team's model must use hydraulics to exert a large force, using minimal space.

B. Your model hydraulic system must transmit motion smoothly.

C. You must be able to operate your model with no breakage of parts.

Plan and Construct

1. Work with your team members to make initial concept sketches showing how your model will work. Draw a side view and a top view. Include all measurements and dimensions. Label the parts of your model.
2. Decide which materials to use as components. Select the materials to use as connecting parts or hinges in your model.
3. Assemble your model and test it to see if it works.

Evaluate

1. Does your team's model meet all the specified design criteria?
2. Did the members of your group work successfully as a team in designing and building the prototype? If not, how might problems or conflict be avoided next time?
3. Compare your team's model with those constructed by other groups. How would you rate your model compared to the others? Not as effective? As effective? Superior? Explain your rating.
4. In what ways might you improve your design?

Across Canada

Since the late 1980s, the Canadian Space Program, along with NASA (National Aeronautics and Space Administration), has been conducting scientific research in space. Recently, flight surgeons on the Neurolab mission have been investigating questions related to blood pressure, loss of sleep, orientation in space, and tiredness.

Canadian astronaut Dave Williams, M.D., is a member of this large team of scientific researchers. Dr. Williams has been trying to find answers to questions such as: How does the body's ability to regulate blood pressure change during and after spaceflight? He has discovered that over 500 000 North Americans suffer from disorders of the body's natural ability to regulate blood pressure and to keep blood flowing to the brain. These disorders often result in lightheadedness or fainting when people stand up quickly. For some reason, the body can no longer increase the blood pressure to boost the blood the extra height.


Dr. Dave Williams

Some astronauts experience similar symptoms after spaceflight. Fighter pilots and stunt pilots, too, sometimes nearly pass out when they force their planes into a tight turn. What is common in these cases? In every instance, the cardiovascular system (the heart and blood vessels) is stressed by gravity. Gravity forces the cardiovascular system to work hard to maintain the blood flow to the brain. The results of Dr. Williams's research in space will also benefit people experiencing this disorder on Earth.

TOPIC 8 Review

1. Define hydraulic system and give some common examples of hydraulics.
2. Define pneumatic system and give some examples of pneumatic devices.
3. Pipelines are used to transport liquids such as natural gas. Why are these pipelines made with few bends and kept free of dirt and rust?
4. Why do the sides of a juice box buckle when you suck the juice out through a straw?
5. **Apply** Which do you think would produce more fizz when opened: a bottle with a twist-off cap or one that has a bottle cap? Why?
6. **Thinking Critically** Would you be able to drink through a straw in outer space? Could you drink through a straw on the Moon? Explain your answers.

Wrap-up TOPICS 7–8

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

pressure
pascal
kilopascal
incompressible
barometer
hydraulics
hydraulic systems
pneumatic systems
compressors

Reviewing Key Terms

1. State whether each of these statements is true or false. If a statement is false, rewrite it to make it true.

(a) Pressure equals the area divided by the force. (7)

(b) Fluid pressure is exerted in all directions. (7)

(c) Attitude and depth can affect fluid pressure. (7)

(d) Hydraulic systems depend on air pressure. (8)

(e) Hydraulics is the study of pressure in liquids. (8)

(f) A dentist's chair is an example of a pneumatic system. (8)

(g) A barometer measures air pressure. (7)

(h) An air bag in an automobile uses hydraulics and pneumatics. (7)

(i) Pipelines with many bends lose pressure more quickly than straighter pipelines. (8)

(j) Liquids must be continuous and in an open system to transmit forces. (8)

Blaise Pascal 1623–1662

Understanding Key Concepts

2. Use the particle model to explain why your eardrums hurt when you swim deep underwater and "pop" when you travel up in a rapidly moving elevator. (7)

3. Explain, using the particle model, why gases can be compressed but liquids and solids cannot. (7)

4. How do (a) depth and (b) temperature affect pressure? (7)

5. What are the basic design requirements for a simple hydraulic or pneumatic device? (8)

6. Use the particle model to explain how air exerts pressure. (7)

7. (a) What unit is used to measure pressure? (7)

(b) What is another way to express this unit? (7)

8. Breanna's friends got her a helium balloon for her birthday with "Happy Birthday, Breanna!" printed on it. By accident, it slipped out of her grasp and rose higher and higher into the air until she could not see it any more. A few days later, she and her friends found it in a park. It had burst. Why do helium balloons eventually burst, or explode, as they rise higher and higher into the atmosphere? (7)

UNIT 1

Ask an Expert

Ever since Gamini Dassanayake was a child, he was interested in the environment. This interest led to his career as a civil engineer. Gamini has a masters degree and a Ph.D. degree in Water and Wastewater Engineering. He has worked in Sri Lanka, Thailand, Brazil, and Japan. He now teaches at the University of Calgary.

Q How is sewage treated?

A Generally, sewage continuously flows to a very large concrete tank. When we keep sewage in the tank for a few hours and supply air through air blowers or aerators, micro-organisms start to grow. Organic matter is food for these micro-organisms. When we supply enough air to the system, micro-organisms increase and eat almost all the organic matter present in the sewage.

Q Are the micro-organisms harmful?

A No. Since these micro-organisms are harmless, naturally occurring bacteria, we don't have to worry about harmful effects from them. However, sewage contains pathogens that originate from our bodies. After treatment, sewage is disinfected to get rid of the pathogens by adding chlorine, ozone, or being exposed to ultraviolet light. This treatment method is called the "activated sludge" system.

Q Is sewage treated with chemicals?

A We only use naturally occurring bacteria and air. Therefore, this is an environmentally safe operation. This is called "aerobic treatment," since we use aerobic bacteria — bacteria that can only exist in the presence of air. We can also treat sewage by using anaerobic bacteria.

Q Are there big sewage tunnels and pipes under the city where the sewage flows?

A Sewage is collected from each area in smaller pipes of about half a metre in diameter. Bigger pipes are used farther from the pumping stations. People may be able to walk inside some of these pipes. In Sri Lanka, I have seen pipes of two to three metres in diameter.

Q What happens when inappropriate items are flushed in a toilet?

A A lot of solid items get into the sewage stream — toys, pieces of plastics, tiny household items, and even dead animals like rats get into the system. Before the sewage is pumped to the treatment plant, there are pre-treatment devices to separate solids, grit, and oil and grease. To remove most of the floating solids, treatment plants have coarse and fine bar screens. These screens trap and separate sewage from these items, which are disposed in a landfill or composting plant. Next, a grit removal chamber removes all sand and soil particles that get added during the flow of sewage to the treatment plant. Then, fat traps remove all grease and oils in the sewage. Sometimes shredders are also included to shred the remaining solid particles into tiny pieces. These three processes eliminate most of the undesirable elements in raw sewage before it is treated.

Math CONNECT

If the cost to treat sewage is about five cents a day per person in Calgary, how much does it cost to treat one day of sewage for the city? How much does it cost to treat a year of sewage for the city?

Q **Are garburators good or bad for the water treatment plants?**

A They are good and bad. They are good because all solids get shredded without causing blockages of pipes. However, once the particles are shredded, they get mixed with the sewage and have to be treated. If the solids are not shredded, they need to be separately collected as solid waste and landfilled. In a landfill, methane gas is produced and methane in turn contributes to global warming.

Q **Where does sewage go after it is treated?**

A Treated sewage can be disposed of in water bodies such as rivers and creeks. Once disposed, it gets diluted and does not cause harm to the people who use the water bodies. Treated sewage looks like water and does not contain any odour. Regulatory bodies, such as Alberta Environment, check on the quality of the treated sewage. These regulatory agencies are the ones who set effluent standards.

Q **How does Canadian sewage treatment compare to that in other countries?**

A The basic process of Canadian sewage treatment is the same as that of other countries. However, Canada uses far more sophisticated devises, such as ultraviolet (UV) disinfection. Calgary has the biggest UV disinfection plant in North America. Operating these UV systems is expensive. Pure oxygen is pumped in to improve the efficiency of activated sludge treatment. Other plants have filter presses for sludge thickening. In Calgary, the sludge is pumped to huge holding ponds to thicken. In summer, these ponds smell bad, causing people living around them to complain.

Q **About how much water is treated in a facility each day?**

A We use more water in Calgary than most cities in other countries. The average amount of sewage generated each day is about 565 litres per person. Since Calgary has a population of about 900,000, over 500 million litres of sewage has to be treated each day.

EXPLORING Further

Surprising Sewage

Make a few phone calls or research on the Internet to learn where and how sewage is processed in your community. If you are in a rural area, research how septic systems process sewage. When you are finished your research, write a brief summary of your findings. Include a flowchart showing the steps. What aspect of sewage treatment surprised you the most?

UNIT 1 PROJECT

A-Mazing Hydraulics

Use your knowledge of fluids and pressure to create and play a unique new game. It's unique because you have designed it to be as easy or as challenging as you want. Amaze friends as you guide a marble through your maze and its series of obstacles and dead ends, using only your own imagination and the power of hydraulics.

Challenge

Design a game that uses your knowledge of fluids and hydraulics to move a marble through a maze.

Materials

4 syringes (5 mL to 30 mL)
2 blocks of wood (about 15 cm x 15 cm x 1.5 cm)
100 cm jinx wood (1 cm x 1 cm)
15 cm dowelling
block of wood (5 cm x 5 cm x 5 cm)
50 cm clear plastic tubing
marble
various fluids: air, water, vegetable oil, and any others approved by your teacher
string, paperclips, and rubber bands
coping saw
mitre box
glue gun
hand drill or drill press

Safety Precautions

- Be careful when using hand tools such as coping saws and hand drills.
- A glue gun is hot and the glue remains hot for several minutes.
- Wash your hands after completing this project.

Design Specifications

A. Working in groups of two or three, design a maze on a sheet of wood 15 cm × 15 cm that is operated by 4 syringes working together to raise and lower the corners of the maze platform.

B. The maze should have only one exit point and the pathways should be wide enough to allow a marble to pass through them.

C. Use only the materials specified.

D. Prepare a written presentation of your project, including:
- a title page with the names of your group members and a picture presenting the game
- a design brief (see "Plan and Construct")
- a design proposal (see "Plan and Construct")
- a construction procedure
- a learning log and record of problem solving
- a catalogue that describes and promotes your toy, and a set of written instructions explaining to a new player how your game works
- an explanation of how your knowledge of fluids, pressure, and hydraulics helped you build and design your game

E. Be prepared to have your game played by other students. Students may wish to see whose design is the most difficult, the most creative, or the most enjoyable.

Plan and Construct

1. Prepare a design brief that does the following:
   - states what you are making and the materials you are using
   - states how your finished product is going to be used
   - states for whom you are making the marble maze
   - states where the image is going to be used

2. Prepare a design proposal. This should be a full-size sketch of your marble maze in 3-D, or a scale drawing of the maze pattern you design. Also include 1 top and 2 side-view drawings of the maze unit, including the base and the syringes.

3. Working with your group members, choose a maze pattern. Write a construction procedure, including:
   - cutting list for jinx wood and dowelling
   - drilling points on maze base (2 holes for syringes and 1 hole in the middle of the base)
   - gluing points
   - choice of fluid and reason for choice (your choice may change as you experiment with other fluids)

4. As you build your marble maze, keep a learning log of the steps you have taken. Record any difficulties and what you did to overcome them.

Evaluate

1. How well could other students play your team's marble maze game? Explain.
2. Were your team's written instructions clear and easy to follow? If not, how could you improve them?
3. Did your team's catalogue copy make the game sound fun to play? If not, how would you improve it?
4. If you could improve the design of your marble maze game in any way, what would you do?

MORE PROJECT IDEAS

Working in a group, organize a "Fluids Circus" in your classroom. Use what you have learned about the properties of fluids to set up demonstrations such as the "Cartesian diver" in Topic 6. Invite other students and teachers in your school to visit your classroom to enjoy the show!

UNIT 1 Review

Unit at a Glance

- The particle model of matter states that all matter is made up of very small, moving particles that are attracted to each other. The strength of the attractive force depends on the type of particle.
- Matter can be classified as pure substances and mixtures. All particles in a pure substance are the same. Mixtures contain two or more pure substances and can be heterogeneous (mechanical) or homogeneous (solutions).
- Forming a solution by mixing two or more materials together is called dissolving. A solute is the substance that dissolves in the solvent.
- Properties such as density, buoyancy, and viscosity are important in the selection and use of fluids. These properties respond to changes in temperature and pressure.
- The Workplace Hazardous Materials Information System (WHMIS) uses symbols to identify dangerous materials.
- Density is calculated by dividing mass by volume.
- Pressure is calculated by dividing force by area.
- Pneumatics is the study of pressure on gases. In a pneumatic system a gas can be compressed, then decompressed, or used as a cushion when another object presses against it.
- In a hydraulic system, a force is applied to a liquid in a closed container and transmitted undiminished through the liquid, causing something else in the system to move.

Understanding Key Concepts

1. Properties of a material can often help you to classify it as homogeneous or heterogeneous.
- **(a)** Give an example of a material that is definitely heterogeneous.
- **(b)** Give an example of a material that is definitely homogeneous.
- **(c)** Easily observed properties can sometimes mislead you. Give an example of a material that looks homogeneous but is actually heterogeneous.

2. Define the terms "mixture" and "pure substance." Give two examples of each.

3. Give examples of three common solutions. For each example, name the solute and the solvent.

4. Why is sugar more soluble in water than in canola oil?

5. The instructions on a package of jelly powder state the following: "Dissolve in 250 mL of boiling water." Why do you need to use boiling water?

6. How do you distinguish between a fluid and a non-fluid?

7. How can you demonstrate that finely ground solids are not fluids?

8. Some foods taste better if their viscosity is high; others taste better if their viscosity is relatively low. Name two foods that you would place in each category.

9. In your own words, explain what density means.

10. Explain why solids can support objects more easily than fluids can.

11. The density of molten lava increases as it cools and hardens. List other examples of natural changes in density.

Developing Skills

12. Design Your Own Explain how you would separate each of these mixtures:
- **(a)** oil and water
- **(b)** paper clips and pennies
- **(c)** sawdust and sugar

13. **(a)** Describe the steps you would take to recover pure water from dirty dishwater. What is the name of the process?

    (b) Would this process be practical for conserving water in your home? Explain your answer.

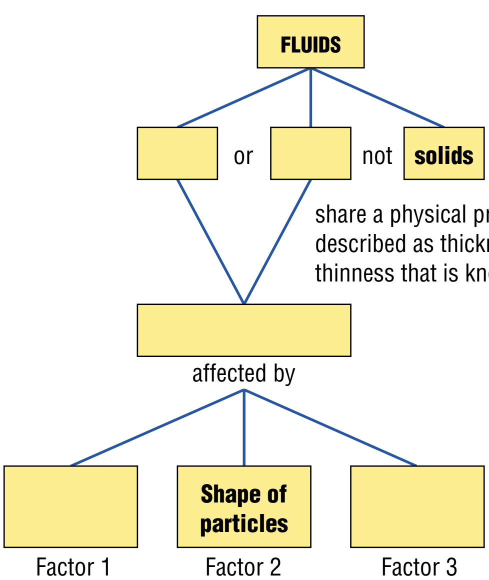
14. **(a)** Human activities add harmful materials to our water. Name five such activities and explain why water is used in each.

    (b) Choose one of these activities, and suggest how the same result could be accomplished without polluting our water supply.

15. **Design Your Own Logo** You are given two samples of water, one from Lesser Slave Lake and one from the Pacific Ocean. Somehow the labels have fallen off. Design an experiment, other than tasting, to determine which is which.

16. The Dead Sea is much saltier than ocean water. Design an experiment to show whether a sample of water from the Dead Sea is saturated or unsaturated with salt.

17. Copy and complete the following concept map using key ideas you have learned in this chapter.



18. 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).

    (a) Which substance is the most viscous? Which one is the least viscous?

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

    (b) Which substance is a solid at room temperature (about 20°C)?

    (c) Infer why the values for substance 2 are so similar.

19. Make a collage of the fluids that are used in one of the following industries:
    cosmetics — cooking
    construction — petroleum refining
    graphic design

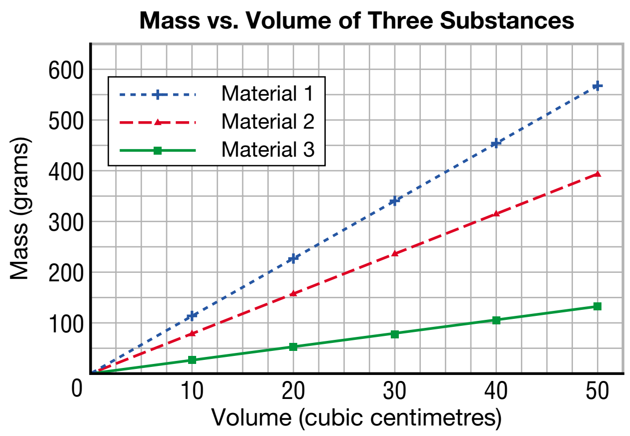
20. Formulate your own question related to viscosity, and design a fair test to explore possible answers.

21. The graph on the next page shows the density of three different substances. (5.2)

    (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 of the lines in the graph.



22. **(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)
15.74	15.74	
39.35	39.35	
55.09	55.09	
82.96	82.96	
94.44	94.44	

(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 1.5 on page 52.

(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.

23. When you press the button on a drinking fountain, a jet of water shoots upward into the air. Formulate your own question about this observation, based on what you know about the properties of fluids. Design an experiment that could provide an answer to your question.

24. Arrange to visit an automotive service garage. Make note of all the hydraulic and pneumatic mechanisms a mechanic uses, and which ones are needed and must be checked regularly in a car. What do these mechanisms look like? How do they work?

Problem Solving/Applying

25. In this unit, you classified several mixtures as either homogeneous or heterogeneous.

(a) How would you classify a soft drink when the sealed bottle is on the store shelf? Use the particle model to support your answer.

(b) How would you classify the soft drink when it is poured into a glass? Use the particle model to support your answer.

26. Suppose you have been given a jar of water that includes some salt and sand. Explain the steps you would take to remove each substance.

27. Imagine you have been asked to create a milkshake for a well-known fast-food restaurant. How would you design a straw to match the viscosity of your new milkshake? What factors (variables) would you take into account?

28. Design and conduct an experiment to determine the density of a 25-cent coin. Based on your results, what metals do you think are used in these coins? (Refer to Table 1.5 on page 52.)

29. 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.

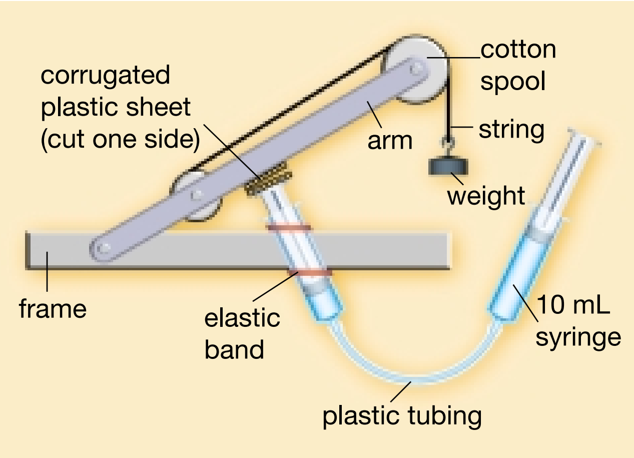
30. **(a)** How can you make a substance that is less *dense* than water sink? Explain.

(b) How can you make a substance that is denser than water float? Explain.

31. Design and make one or more of the following using simple hydraulic systems:

- a jack-in-the box
- a door closer
- a toy with blinking eyes
- a moving miniature billboard
- a simple puppet with moving parts
- a robot arm that moves up and down

32. Examine the simple hydraulic device shown below and explain how it works. Use the words "force," "cylinder," "pressure," "transmitted," and "hydraulics" in your answer.



Critical Thinking

33. Callia says that salt and water make a heterogeneous mixture. Mike says that it cannot. Decide who is right, explain why, and give evidence to support your answer.

34. You learned in this unit that water can be a pure substance. How is it possible that the water from one source tastes different than water from another source?

35. Fats and oils are not soluble in water. Why do greasy dishes become clean when you wash them?

36. Some substances are sensitive to heat treatment. If they are heated for too long or to very high temperatures, they will become very thin. Keeping internal friction in mind, can you suggest how such a substance might have changed at the particle level?

37. In fresh water, an ice cube floats with about nine tenths of its mass below the surface. Is this true for an iceberg in seawater? Explain.

38. 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 model to suggest an explanation.

39. 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.

40. Marco always struggles to open a pickle jar or any food jar, for the first time. He has tried many methods, including hitting the lid with a knife and using a rubber pad specially designed to give a good grip on the lid. However, he still has to wrench the lid open with as much strength as possible. One day his brother told him to use a small spoon to simply pry the lid slightly apart from the glass lip. Explain why this simple method works.

41. What do you think would happen if a container such as an aerosol spray can that has been sealed under pressure were exposed to extremely high temperatures? (This is similar to what happened during the Great Molasses Flood described in this unit.) Explain your answer.

Pause & Reflect

Return to the focussing questions on page 4. How would you answer each question now? How has your knowledge of fluids grown? Record your answers to the focussing questions in your science notebook.