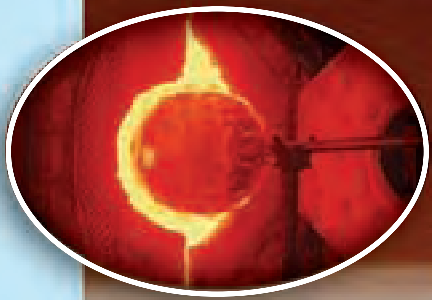
UNIT

3 Fluids

Pure oxygen in liquid form.

Key Ideas

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



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

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

Getting Started

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

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

Fluid or Non-fluid

Find Out ACTIVITY

How does a fluid differ from a non-fluid?

Safety

Materials

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

What to Do

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

What Did You Find Out?

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

Extension

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

Chapter 7

Viscosity describes a fluid's resistance to flow.

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

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

What You Will Learn

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

Why It Is Important

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

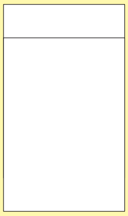
Skills You Will Use

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

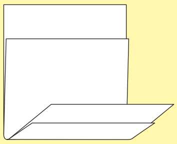
FOLDABLES™
Reading & Study Skills

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

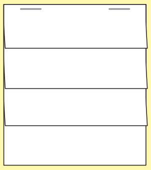
STEP 1 **Collect** 2 sheets of legal size paper and layer them about 2.5 cm apart vertically. Keep the edges level.



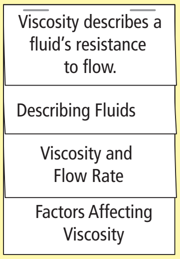
STEP 2 **Fold** up the bottom edges of the paper to form 4 tabs.



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



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



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

7.1 Describing Fluids

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

Key Terms

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

Go With the Flow

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

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

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

7-1A Magic Mud

Find Out ACTIVITY

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

Safety

Materials

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

What to Do

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

What Did You Find Out?

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

States of Matter and the Particle Theory

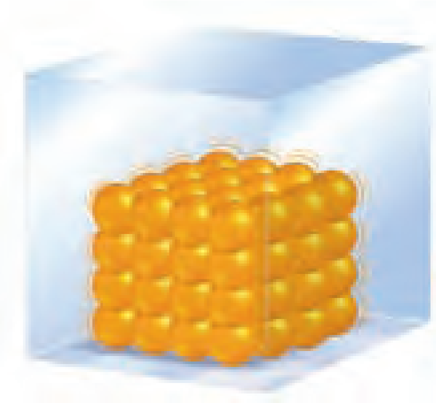
Oxygen, glass, and water are all examples of matter. There are three different states of matter: solid, liquid, and gas. As you have learned,

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

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

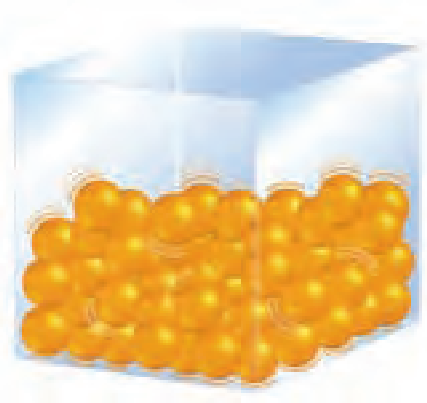
1. All matter is made up of very small particles.
2. All particles in a pure substance are the same. Different substances are made of different particles.
3. There is space between the particles.
4. The particles are always moving. As the particles gain energy, they move faster.
5. The particles in a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

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



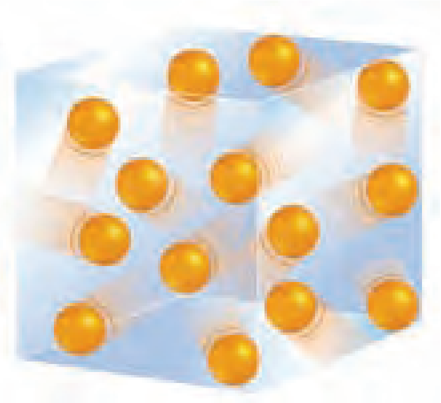
Solid

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



Liquid

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



Gas

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

7-1B Can Solids Flow, Too?

Find Out ACTIVITY

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

What You Need

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

What to Do

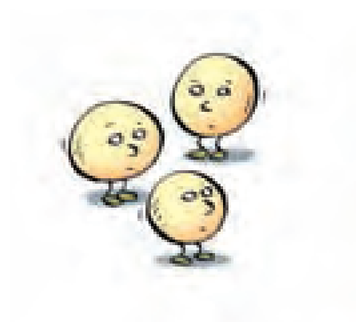
1. Place two large plates on a level surface. While holding your hands steady, slowly pour sand or sugar onto one of the plates. Draw the results in your notebook.
2. Again, hold your hand steady as you slowly pour 250 mL of water onto the second plate. Draw the results again.
3. Wipe up any spills and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

What Did You Find Out?

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

Particles in Solids

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



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

Particles in Liquids

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

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

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

Particles in Gases

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

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

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

Did You Know?

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

Reading Check

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

Changes of State

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

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

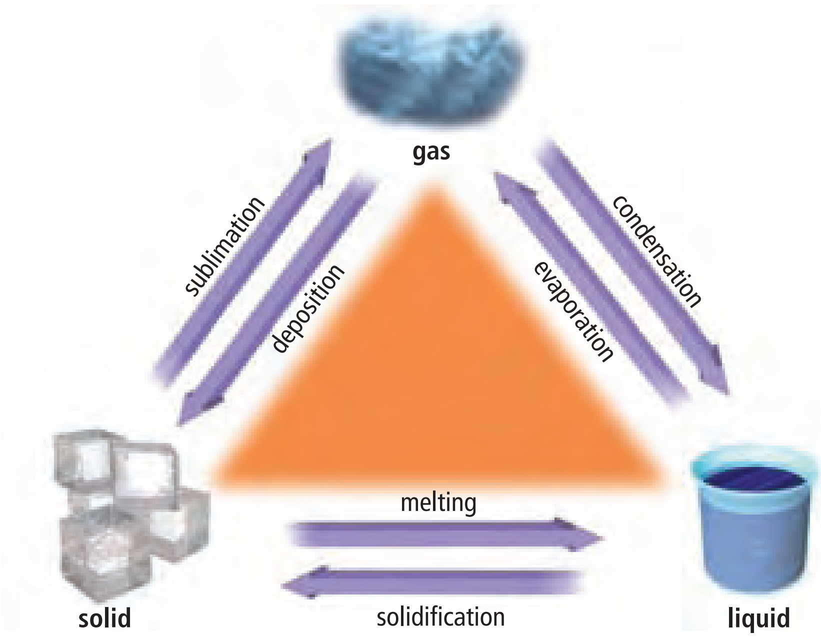


Figure 7.4 Changes of state.

Did You Know?

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

Did You Know?

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

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

Freezing, Melting, and Boiling Points

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

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

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

Reading Check

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

Wild, Weird, Wonderful

www Science

Spooky Change of State

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

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

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

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

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

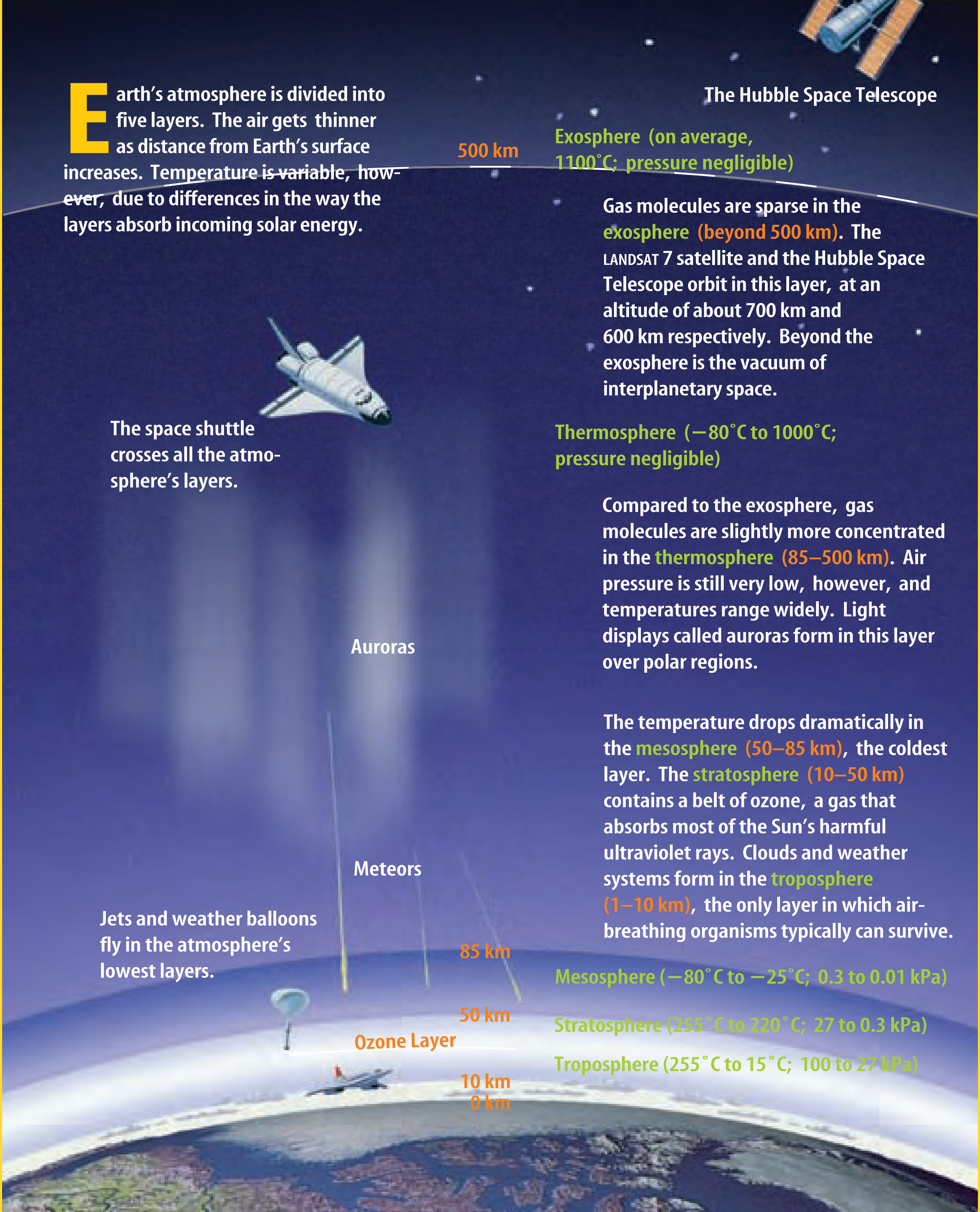
Be Careful Around Dry Ice!

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

NATIONAL GEOGRAPHIC

VISUALIZING ATMOSPHERIC LAYERS

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



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

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

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

Check Your Understanding

Checking Concepts

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

Understanding Key Ideas

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

Pause and Reflect

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

7.2 Viscosity and Flow Rate

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

Key Terms

flow rate
viscosity

Word Connect

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

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

Viscosity

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

Why Is Viscosity Important to Us?

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

Viscosity: A Taste Sensation?

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

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

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

Explore More

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

Viscosity in Everyday Products

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

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

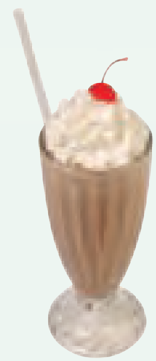
internet connect

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

7-2A The Value of Viscosity

Find Out ACTIVITY

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



What to Do

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

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

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

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

What Did You Find Out?

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

Did You Know?

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

Reading Check

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

Flow Rate

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

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

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

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

Suggested Activity

Conduct an Investigation 7-2B on page 282.

Reading Check

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

7-2B The Flow Rate of Liquids

Core Lab

SkillCheck

- Observing
- Recording data
- Calculating data
- Graphing data

Materials

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

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

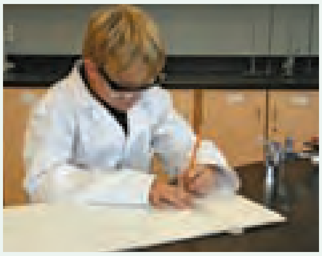
Question

How can you compare the flow rates of various liquids?

Safety

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

Procedure



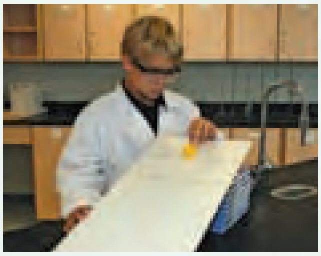
1. Draw a line across the width of the ramp, approximately 10 cm from the top. Draw a dot in the centre of the line and just above it. When you place the measuring spoon on the dot and rock the spoon forward, the lip of the spoon will touch the top line. This is the start mark.

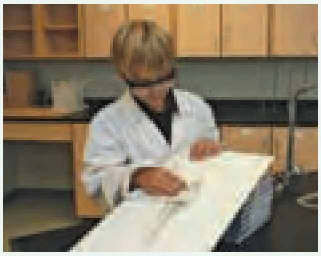
2. Draw a finish line 10 cm below the top line. Then assemble the apparatus as shown here.
   (a) Measure the temperature of the room and record it in your notebook.
   (b) Make a data table that looks like the following:

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

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

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





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

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

4. When the marshall says "go," the spoon student rocks the spoon quickly but gently to pour its contents down the ramp. At the same time, the timer starts timing.
5. When the marshall says "stop," the timer stops timing and records the time in the data table. Students clean and dry the ramp and measuring spoon to get ready for the next liquid.
6. Repeat steps 3 to 5 for the other two liquids. (Do this at least twice for each liquid.)
   (a) Wash your hands after this investigation.
   (b) Keep the flow rate ramp assembled so you can complete Activity 7-3A on page 287.

Analyze

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

Conclude and Apply

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

Wild, Weird, Wonderful

WWW Science

Superfluids

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

A superfluid offers no resistance to flow.

Superfluids have some amazing properties:

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

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

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

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

Check Your Understanding

Checking Concepts

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

Understanding Key Ideas

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

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

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

Pause and Reflect

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

7.3 Factors Affecting Viscosity

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

Key Terms

concentration
kinetic energy

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

Word Connect

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

Temperature and the Viscosity of Liquids

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

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

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

internet connect

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

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

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

Suggested Activity
Think About It Activity 7-3B on page 291

Temperature and the Viscosity of Gases

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

Suggested Activity
Find Out Activity 7-3D on page 294

7-3A Cool It! — Find Out ACTIVITY

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

What Did You Find Out?

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

Extensions

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

Did You Know?

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

Concentration and Viscosity

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

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

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

Suggested Activity

Investigation 7-3E on page 295.

Did You Know?

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

Attractive Force and Viscosity

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

Particle Size and Viscosity

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

Small and Fast

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

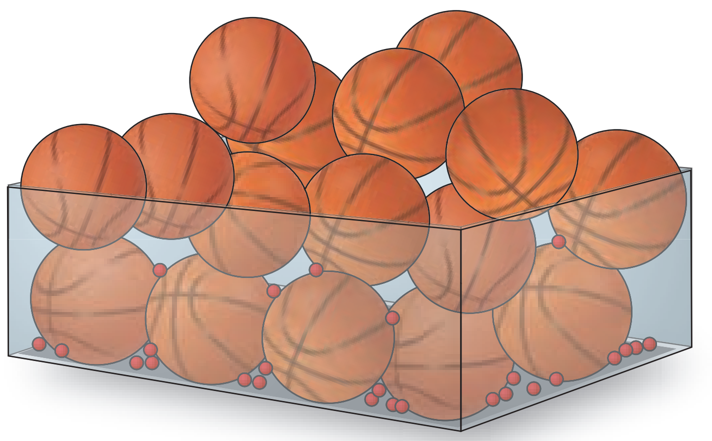


Figure 7.12 Small objects like marbles roll easily between basketballs and reach the bottom of the bin quickly. Similarly, if a fluid is made of small particles, it can flow faster and more easily than a fluid with large particles.

Big and Slow

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

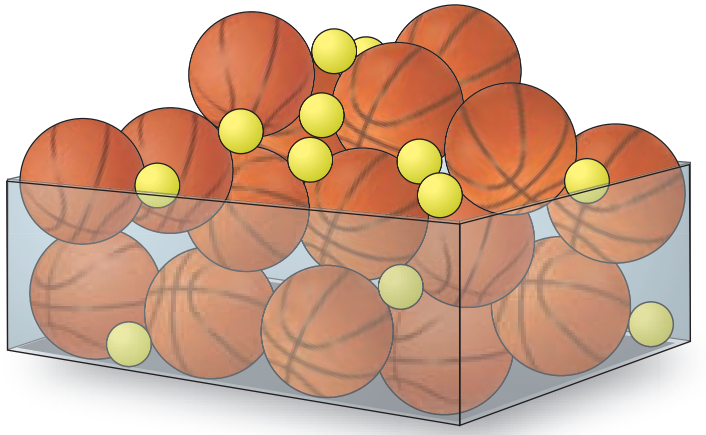


Figure 7.13 Tennis balls can only get between the basketballs one at a time. They sometimes get stuck between the basketballs. In fluids, larger particles flow past each other more slowly than smaller ones.

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

Reading Check

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

7-3B Flowing Fluid Floods City

Think About It

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

What to Do

Read the following true story and then answer the questions.

What Did You Find Out?

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

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

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

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

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

7-3C Viscosity Plunge

SkillCheck
- Measuring
- Classifying
- Graphing
- Evaluating information

Safety

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

Materials

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

Question

How does temperature affect viscosity?

Hypothesis

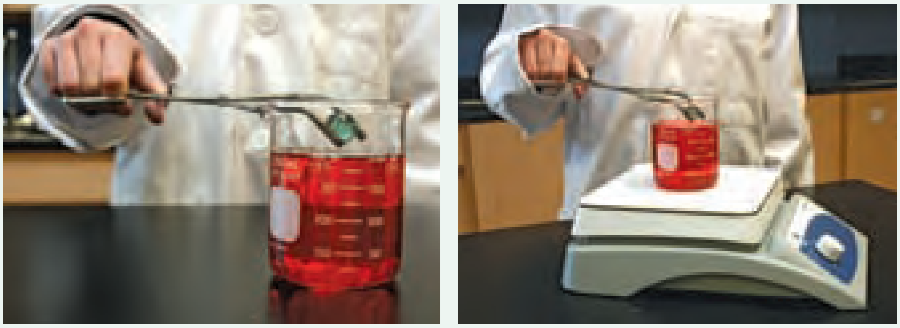
Write a hypothesis about the effect of temperature on viscosity.

Procedure

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

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

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



Step 5

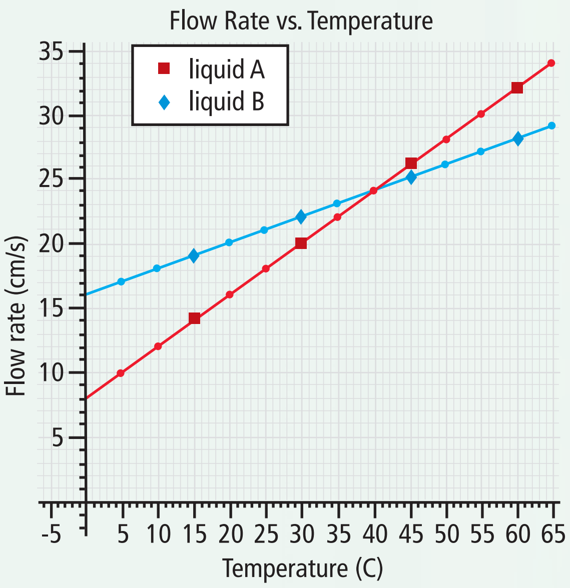
6. Turn on the hot plate to a low-medium setting. During heating, stir the corn syrup very slowly, being careful not to create bubbles.
7. Watch the temperature carefully. Every time the temperature increases by 3°C, repeat steps 4 and 5 (note the temperature, release a marble, and record the time).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

Analyze

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

Conclude and Apply

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



7-3D Cool Contraction

Find Out ACTIVITY

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

Safety

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

Materials

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

What to Do

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

What Did You Find Out?

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

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

7-3E The Effect of Concentration on Viscosity

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Measuring
- Predicting
- Observing
- Evaluating information

Safety

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

Materials

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

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

Question

How does concentration affect the flow rate of a liquid?

Procedure

1. Prepare the flow rate ramp as in Conduct An Investigation 7-2B on page 282.
   (a) Measure the temperature of the room and record it in your notebook.
   (b) Make a data table that looks like the following:

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

   (c) With your group members, hypothesize which of the three concentrations will flow fastest.
2. For the first sugar solution, add 20 g of sugar to 100 mL of water and stir until it has all dissolved. For the second sugar solution, add 45 g of sugar to 100 mL of water and stir until it has all dissolved. Be sure to label each mixture with its concentration in grams of sugar per millilitres of water.
3. Test one mixture at a time, starting with just water. The "spoon student" will pour enough, liquid into the clean, dry measuring spoon so that it is level, then place the spoon at the start mark on the ramp.
   (a) another group member, the timer, will work the stopwatch
   (b) A third group member, the marshall, will say "go" and will call "stop" when the liquid reaches the finish line.

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

Analyze

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

Conclude and Apply

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

Check Your Understanding

Checking Concepts

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

Understanding Key Ideas

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

Pause and Reflect

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

Chapter Review

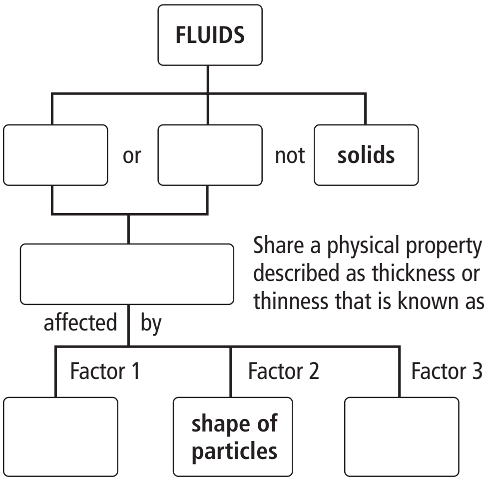
Prepare Your Own Summary

In this chapter, you explored fluids by examining the factors that increase or decrease their viscosity. Create your summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. Use the following headings to organize your notes:

1. The Particle Theory of Matter
2. Changes of State of Matter
3. Measuring Flow Rate of Fluids
4. Effects of Temperature on Fluids and Their Viscosities
5. Effects of Temperature on Gases and Their Viscosities

Checking Concepts

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

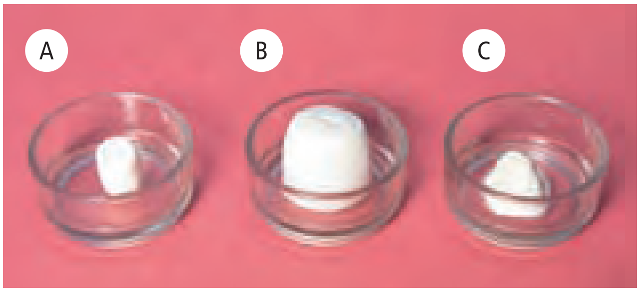


9. Explain why liquids kept in the refrigerator flow more slowly than liquids kept in a cupboard.
10. Define kinetic energy.

Understanding Key Ideas

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

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



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

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

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