A Close-Up Look at Fluid Flow

4.1

Fluids are substances that flow (**Figure 1**). You see water flowing from a tap when you wash your hands. You also see it flowing in a stream. But liquids are not the only substances that flow. What flows past your face when you ride a bicycle or around your arm when you stick it out a car window? Air, which is a gas, also flows. Both gases and liquids are fluids.

Fluids flow because some sort of force is exerted on them. A **force** is a push or pull that causes changes in movement. One of the most common forces is the force of gravity. Water runs downhill and ketchup pours from a bottle because of the force of gravity. Water can also be made to move by a mechanical force exerted by a pump. A pump can exert a mechanical force and cause water to move through a pipe. Water flowing through a pipe is slowed down somewhat by the force of friction between the water and the walls of the pipe.

Systems moving fluids are a concern for people in many professions and fields. How will a tower withstand a gusty wind? How do deposits on artery walls affect the flow of blood? How is an airplane affected by different kinds of airflow? Fluid flow involves both the movement of a fluid and the movement of an object through a fluid. How quickly a fluid flows in a given amount of time is called its **flow rate**.

Figure 1
Flow tests are conducted on fire hydrants to ensure there will be enough water in an emergency.

LEARNING TIP

Important vocabulary are highlighted. These are terms that you should learn and use when you answer questions. The terms are defined in the Glossary at the back of your student book.

TRY THIS: *Determining Flow Rate*

Skills Focus: measuring, recording, communicating

In this activity, you will find the rate at which water flows from the tap in your classroom or outside the school.

1. Pour water into a large bucket using a 1 L container, such as a plastic beaker. Mark the 10 L water level with a black waterproof marker. Empty the bucket.

2. Place a mark on the tap handle. How many turns of the tap (rotations of the black mark) are required to open the tap fully?

(a) When the tap is opened fully, how long does it take to fill the bucket to the 10 L mark?

(b) When the tap is opened halfway, how long does it take to fill the bucket to the 10 L mark?

(c) How does the result you obtained in question (a) compare with your result in question (b)? Is this what you expected to happen? Explain.

(d) The volume of liquid that flows in a second is called its flow rate. Calculate the flow rate of the tap in litres per second.

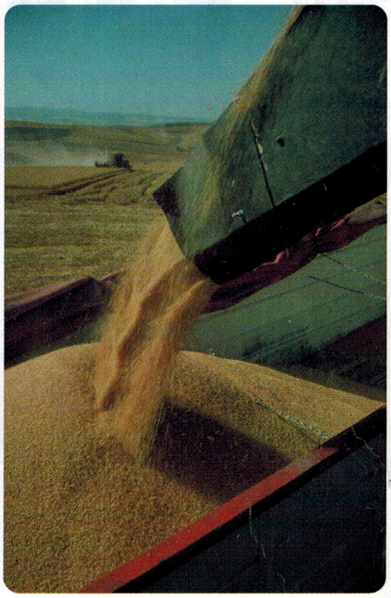


Figure 2
This material is not a gas or a liquid but appears to flow. Flour, sand, and wheat all appear to flow. Why are they not considered to be fluids?

Systems that involve movement, such as moving fluids, are said to be **dynamic**. Air or gas moving around solid objects is referred to as **aerodynamics** (*aero* means "air"). The motion of liquids (usually water) around solid objects is referred to as **hydrodynamics** (*hydro* means "water").

Solids That Seem to Flow

A fine powder, made up of a very large number of tiny solid pieces, can be poured from one container into another (**Figure 2**). But have you ever seen water form a pile, as flour does when you pour it?

Can you make a pile of milk, like you can make a pile of sand or wheat? The answer, of course, is no: only solids can be piled. Liquids take the shape of their container and have a level surface. Solids may also take the shape of their container, but they tend to pile up. Gases expand to fill the entire shape of whatever container they are in.

The Kinetic Molecular Theory

All matter can exist in three states—solid, liquid, or gas—and can change from one state to another. The **kinetic molecular theory** provides a model to help us understand how matter can change from one state to another.

The kinetic molecular theory states that

- all matter is composed of molecules or other types of particles
- particles are in constant motion
- there are forces of attraction among particles

Let us consider water, which exists in all three states and can be easily changed from one state to another. The change from one state to another is caused by either an increase or a decrease in the energy of the substance.

In solid water (ice), the particles have a low energy level and are close together (**Figure 3**). The force of attraction, therefore, is high and holds the particles together. The particles are still in motion, but they vibrate around a fixed position. Solids have a definite shape and volume.

As heat energy is added to ice, the motion of the particles increases and the forces of attraction among them are not as strong. The

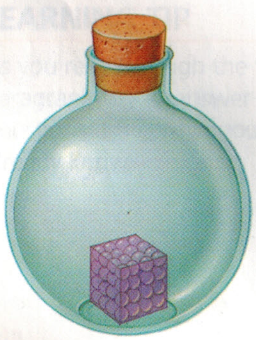


Figure 3
In a solid such as ice, the particles are close together and locked into a pattern

particles are now able to move around more easily and can slide past each other (**Figure 4**). The solid (ice) becomes a liquid (water). Liquids have a definite volume but do not have a definite shape. Liquids take the shape of the container in which they are placed.

The process of changing a substance from a solid to a liquid is called **melting**. You probably have observed icicles melting on a warm day. Ice melts at 0 °C.

If you continue to add heat energy to the liquid (water), the particles move even faster and farther apart. The forces of attraction among the particles becomes smaller and smaller. The forces of attraction are smallest on the particles near the surface of the liquid. If enough heat energy is added, individual particles break away from the surface of the liquid and become a gas (water vapour or steam) (**Figure 5**). Gases do not have a definite shape or volume. The particles of a gas spread out to fill a container of any size or shape.

Figure 4
In a liquid such as water, the particles are slightly farther apart.

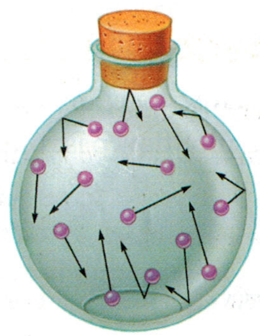


Figure 5
In a gas such as water vapour or steam, the particles are far apart.

The process of changing a substance from a liquid to a gas is called **evaporation**. You probably have observed rain puddles disappearing from the street as the water evaporates. Water can evaporate at any temperature above 0 °C. Water boils if enough heat energy is added to raise its temperature to 100 °C.

As heat energy is removed from a gas, the particles start to slow down. The gas becomes a liquid if enough energy is removed. This process of changing matter from a gas to a liquid is called **condensation**. Think about a glass filled with a cold drink. Water forms on the outside of the glass as the water vapour in the air touches the glass and changes to a liquid. Rain is another familiar example of a liquid that has condensed from a gas.

Removing even more heat energy can cause a liquid to change to a solid in a process called **solidification.** We generally use the term *freezing* to indicate water changing from a liquid to a solid. Water freezes at 0 °C.

Water can also change directly from a solid to a gas or from a gas to a solid without going through the liquid state. These processes are called **sublimation.** In sublimation, particles at the surface of the ice can escape directly into the air and become water vapour. Likewise, water vapour from the air can freeze to form a solid. Snowflakes and the frost on a car windshield are examples of water vapour changing directly from a gas to a solid (**Figure 6**).

Figure 6
Water vapour sublimates to form solid frost on a windshield.

Explaining Flow Using the Kinetic Molecular Theory

The kinetic molecular theory can also help us understand and predict fluid behaviour. The forces of attraction between particles are strong when they are close together and moving slowly. The particles in a solid are so close together and their forces of attraction are so strong that they cannot flow past one another. The particles in a liquid move more rapidly, so the forces of attraction between them are not as strong. Because the particles are not locked in a fixed arrangement, they move a little farther apart and can slide over one another. This explains why liquids are capable of flowing. In gases, the particles are so far apart from each other and the forces of attraction are so weak that the particles can move independently of each other. As a result, gases flow very easily.

4.1 CHECK YOUR UNDERSTANDING

1. How is the flow of air used in transportation?
2. What causes a substance to change its state?
3. Explain how the terms *evaporation* and *condensation* are related.
4. What is the opposite of each of the following terms: *evaporation*, *solidification*, *sublimation*?
5. Give an example of sublimation, other than those provided in the text.
6. Use the kinetic molecular theory to explain why solids do not flow.
7. Take another look at the word map you prepared in the Try This activity in the Unit Preview. Are any of your examples solids that seem to flow? Should they remain on the word map?

PERFORMANCE TASK

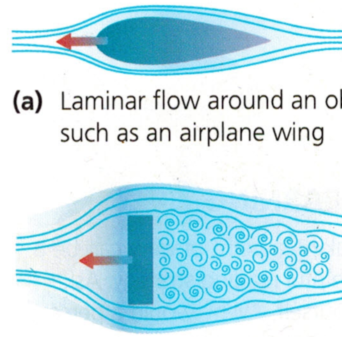
You will be using a fluid in the Performance Task. How will you consider the flow of that fluid during the design and testing of your model?

Fluid Flow around Objects

4.2

The shape of an object determines how fluids flow around it. Consider the flow of water in a river. A deep river, with steep banks and no obstacles, flows fast and smoothly. The water travels in straight or almost straight lines. This is known as **laminar flow**. Now imagine a shallow river, with irregular rocks breaking the surface. The water is broken and choppy—unable to flow in straight lines. This is called **turbulent flow**, and it may result in rapids, eddies, and whirlpools.

The same thing occurs with gases in motion. As moving air meets objects, such as buildings or trees, the flow becomes turbulent. **Figure 1** illustrates laminar and turbulent flow.



(a) Laminar flow around an object, such as an airplane wing

(b) Turbulent flow around an object such as a water barrier

Figure 1

Shapes that produce a laminar flow have less air or water resistance than shapes that produce a turbulent flow. Resistance is referred to as **drag**. For cars and airplanes travelling at high speeds, less drag means better fuel consumption and less wind noise. Shapes that create a laminar flow are said to be **streamlined** or aerodynamic (**Figure 2**).

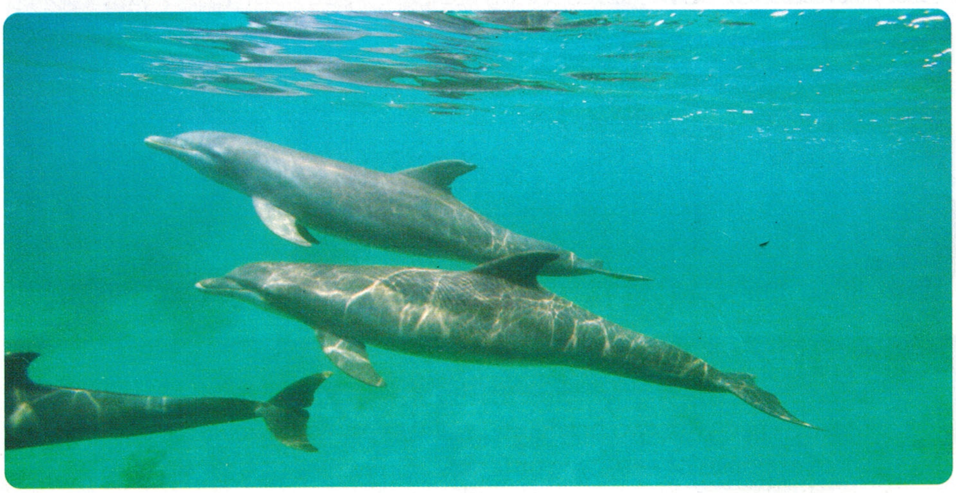


Figure 2
The body of a dolphin is streamlined for decreased water resistance. Notice the elongated shape with no narrowing at the neck, no protruding parts, and smooth skin. The tail fluke produces a laminar flow of water around the body.

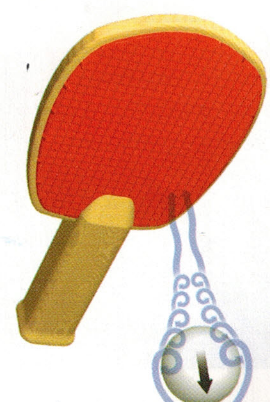


Figure 3
Turbulent and laminar flow can be used to control movement and direction. For example, the airflow around this ball becomes turbulent at the top and bottom of the ball. This helps to slow the ball.

A fluid moving relative to an object experiences resistance as its particles slam into the object. Water flowing under a bridge meets resistance as it passes the piers. Air meets resistance as it passes a flying airplane. Objects moving through the air are slowed down because of air resistance (**Figure 3**).

Wind Tunnels: A Closer Look at Gas Flow

Canadian Wallace Rupert Turnbull is credited with building Canada's first wind tunnel in 1902. He conducted experiments in the tunnel to test his propeller inventions.

A wind tunnel has a propeller at one end that propels (pushes or pulls) air into it. Smoke is often added to make the flow of air visible.

LEARNING TIP

Taking a point of view can be a helpful reading strategy. Ask yourself, "Why would a person buying a new car be interested in the information in **Figure 4**?"

Wind tunnels are widely used today. Engineers use them to test the airflow around aircraft wings and investigate how ice on aircraft wings affects airflow. Vehicles are examined in wind tunnels to determine how streamlined they are (**Figure 4**). By placing precisely designed scale models of tall buildings, bridges, and towers in wind tunnels, engineers can examine how high winds affect the structures.

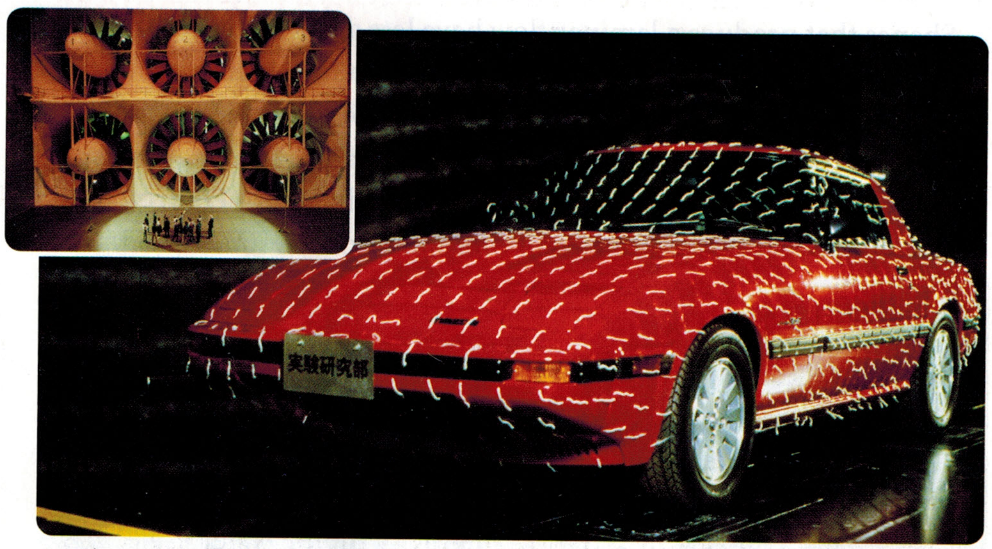
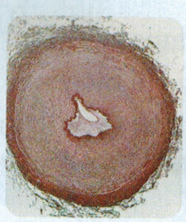


Figure 4
The wind tunnel (inset) helps designers create streamlined cars that are more energy efficient.

4.2 CHECK YOUR UNDERSTANDING

1. Make a chart with two headings: *Laminar flow* and *Turbulent flow*. List some examples of each type of flow.
2. Why might a car manufacturer change the shape of side mirrors on a particular model?
3. Which artery in **Figure 5** would produce more turbulent flow?
4. Why do scientists study airflow?



(a) Cross-section of a blocked artery

(b) Cross-section of a healthy artery

Figure 5

Viscosity: A Property of Fluids

4.3

Have you ever tried to pour ketchup out of a new bottle? It takes a lot of force to start the ketchup flowing (**Figure 1(a)**). Very little force is required to start maple syrup flowing (**Figure 1(b)**). That is because maple syrup has less resistance to flowing than ketchup. **Viscosity** is the resistance of a fluid to flowing and movement. The kinetic molecular theory helps us to understand that this resistance is due to the forces of attraction among particles. The attractive forces among the particles of a substance is known as **cohesion.** The stronger the cohesive forces among the particles, the greater is the resistance of the particles to flowing past one another. Different substances are composed of different particles and have different cohesive forces. This helps to explain why different fluids can have different viscosities.

When fluids are stationary, viscosity is not a concern. However, when a fluid is moving, or when something is moving through a fluid, the property of viscosity can be very important.

Another force comes into play when fluids are in containers or when they flow through a tunnel or pipe. The attractive force between the particles of a fluid and the particles of another substance is known as **adhesion.** Adhesion is the reason ketchup and syrup stick to the sides of the bottles. It is also the reason that water will "climb" up a paper towel even though we know that gravity is pulling down on the water. The adhesive forces between the water molecules and the paper towel are greater than the downward force of gravity on the water molecules.

In liquids, the attractive forces among the particles at the surface are greater than the attractive forces among the particles deeper in the liquid. This increased attraction among the particles at the surface is known as **surface tension.** The surface tension of water enables water striders to walk on the surface (**Figure 2**).

(a)

(b)

Figure 1
Ketchup **(a)** does not flow as easily as maple syrup **(b)**. We say that ketchup is more viscous than maple syrup.

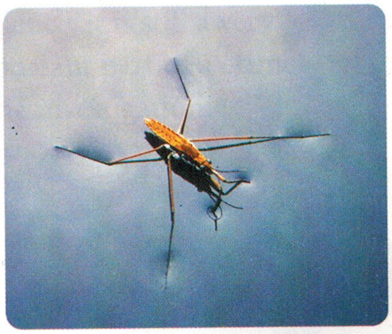


Figure 2
The surface tension is greater than the weight of the water strider. The water strider is able to walk on water.

Measuring Viscosity

If you tipped a water pitcher as quickly as a salad dressing bottle, you would find a puddle of water on the table! You handle the two fluids differently because you know that they have different viscosities.

We might use the words *thick* and *thin* to describe viscosity, but these words do not give enough information. We need some way of