1.2 Investigating Matter

Matter is anything that has mass and volume. Solid, liquid, and gas are the three states of matter. The kinetic molecular theory describes how changes in the kinetic energy of particles can result in changes in state. All materials have physical properties you can observe. Pure substances can be classified as elements or compounds.

Words to Know

boiling point
conductivity
density
element
mass
melting point
state
volume

Figure 1.6 The Celebration of Light in Vancouver is a vivid display of light as well as chemical artistry.

Fireworks! The night sky lights up with a shower of colour, and the air crackles with explosive sounds. You have probably seen such spectacular displays in your community on holidays such as Canada Day. In Vancouver, the annual Celebration of Light competition brings the world's best fireworks to English Bay, as shown in Figure 1.6. Fireworks have an ancient tradition. The Chinese invented them more than 2000 years ago, and since then their use has spread around the globe. Fireworks displays have improved over the years as performance art has been blended with a branch of chemistry called pyrotechnics.

Fireworks are a dramatic display of matter. **Matter** is anything that has mass and volume. **Mass** is the amount of matter in a substance or object (often measured in grams). **Volume** is the amount of space a substance or an object occupies (often measured in litres).

Chemical Change

Fireworks designers achieve their colourful, noisy displays through chemical changes in the substances that make up the fireworks. A **chemical change** is a change in matter that occurs when substances combine to form new substances. For example, fireworks designers know that when certain substances are heated they will combine explosively to form new substances. When fireworks explode, gases form from the solids in the fireworks.

Designers also know that certain substances will change colour when they are heated. By adding substances made from barium and chlorine to a barrage-type firework, fireworks designers can create a huge sparkling green fan in the sky. When you light a sparkler, it glows a bright white colour. This is because sparklers contain magnesium, which burns bright white. Adding these types of substances to fireworks creates the spectacular fireworks you observe in the night sky.

Did You Know?

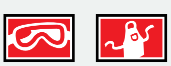
The word "pyrotechnics" refers to explosives used in displays or for other purposes such as smoke screens. The prefix "pyro" means fire, and "technics" refers to art.

1-2A Bag of Change

Find Out ACTIVITY

In this activity, you will mix three unknown substances together in a plastic bag and observe the changes that occur. Watch for changes in state (solid, liquid, or gas), colour, volume, temperature, and anything else you can detect.

Safety



- Be careful not to get any chemicals near your eyes or mouth.

Materials

- Chemical A—a white solid
- Chemical B—a white solid
- Chemical C—a blue liquid composed of a blue solid dissolved in water
- 2 small spoons for measuring A and B
- 50 mL graduated cylinder
- 2 resealable plastic bags per group
- water

What to Do

1. Describe and record the properties of chemicals A, B, and C. Observations may include the colour or state (solid or liquid) of the chemical.
2. Mix one spoonful of chemical A, one spoonful of chemical B, and 10 mL of chemical C into a plastic bag, and then quickly seal it up.
3. In the first 30 s, squeeze the bag in various places to mix the chemicals. Detect any temperature changes with your hand.
4. Record as many observations as you can.
5. When you are finished, wash all the chemicals down the drain and rinse out the plastic bag.
6. Clean up and put away all the equipment. Wash your hands.

What Did You Find Out?

1. List and describe changes you observed in the plastic bag.
2. Share your list with the class, and add to your list any new observations discussed in class.
3. If time and the quantity of chemicals permit, try to identify which two chemicals are responsible for each effect you see. To do this, mix just two chemicals together in the bag. You might wish to simply mix water and one of the chemicals. Your goal is to use the minimum number of chemicals to produce each effect.

Did You Know?

All particles have some kinetic energy, which is why scientists cannot lower the temperature of any substance to absolute zero. Absolute zero is the coldest possible temperature, −273.15°C.

Changes of State

Chemical changes involve substances reacting to form new substances. When **physical changes** occur, there may be a change in appearance but no new substances form. The change from solid to liquid shown in Figure 1.7 is an example of a change of **state**.

In earlier studies, you investigated the three states of matter:

- Solid is the state of matter that has a definite shape and volume. For example, the sugar you added to your breakfast cereal was a solid.
- Liquid is the state of matter that has definite volume, but its shape is determined by its surroundings. For example, the milk you pour into a glass has a definite volume, but the milk's shape is determined by the shape of the glass.
- Gas is the state of matter that has its shape and volume determined by its surroundings. For example, air blown into a balloon takes the shape of the balloon. Its volume is the volume of the balloon.

The Particle Model of Matter

Matter, chemical changes, and the states of matter are all part of chemistry. **Chemistry** includes facts and observations about matter, laws that summarize patterns of behaviour in matter, and theories that explain the patterns of behaviour. A *model* in science is a way to think about and interpret natural events and objects. Scientific models help us to visualize objects or processes that cannot be seen directly. A *theory* provides a scientific explanation based on the results of experimentation.

In earlier studies, you may have learned how the behaviour of matter can be described by using the particle model of matter. This model states:

1. All matter is made up of very small particles. The particles are much too small to observe with the naked eye or even with a light microscope.
2. There are spaces between the particles. The amount of space between the particles is different for different states of matter. For example, gases have much more space between particles than do solids.
3. The particles that make up matter are always moving.
4. The particles are attracted to one another. The strength of the attraction depends on the type of particle.

The particle model of matter is represented in Figure 1.8 on the next page. Notice the difference in the spacing of the particles in solids, liquids, and gases.

Figure 1.7 The water in this photo is changing state from solid water (the icicle) to liquid water.

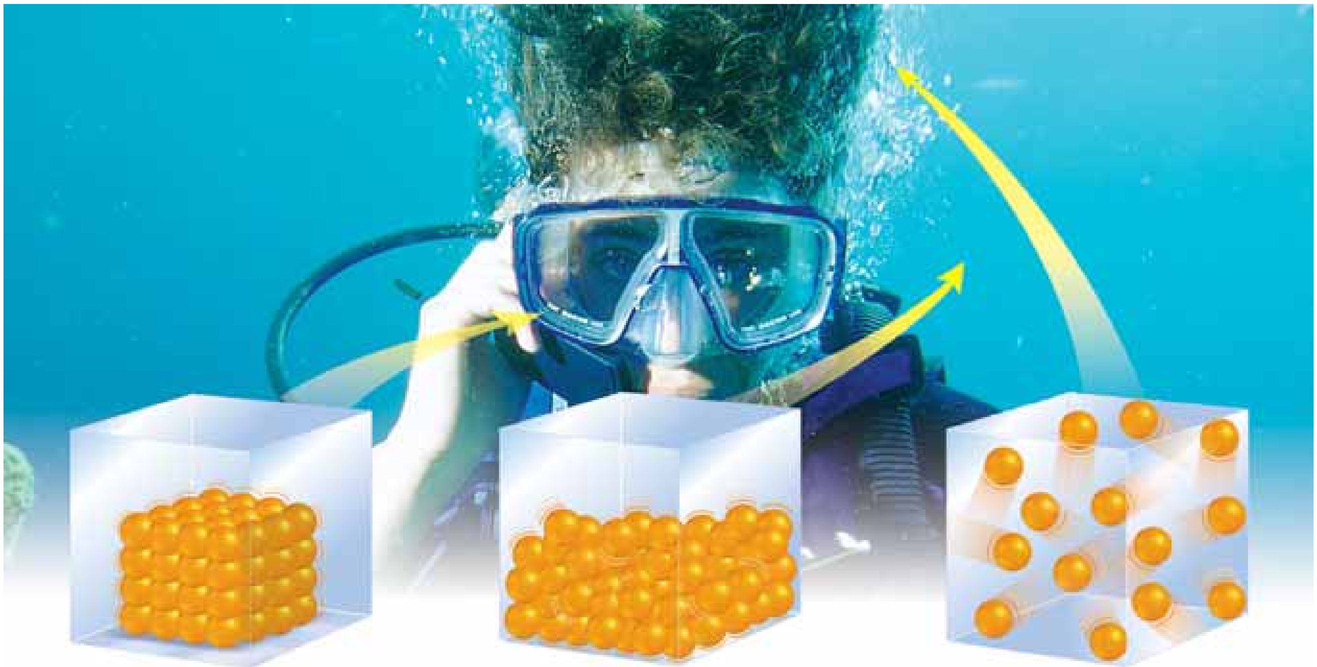


Figure 1.8A The particles in a solid are packed together tightly. This means that solids will hold a definite shape. Even though a solid does not appear to move, the particles are constantly vibrating in place.

Figure 1.8B The particles in a liquid are in contact with each other, but they are not nearly as close as in solids. In fact, the particles in liquids can slip and slide past one another, changing their position. This slipping and sliding means liquids do not hold a shape and instead take the shape of their container.

Figure 1.8C 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 to fill their container.

The Kinetic Molecular Theory

Kinetic energy is the energy of motion. All particles in every solid, liquid, and gas are always moving, so they have kinetic energy. Scientists have used the particle model to develop the **kinetic molecular theory** to explain what happens to matter when the kinetic energy of particles changes.

The main points of the kinetic molecular theory are:

1. All matter is made up of very small particles.
2. There is empty space between particles.
3. Particles are constantly moving. In liquids and gases, the particles are colliding with each other and the walls of their container.
   - (a) Particles of a solid are so tightly packed together that they cannot move around freely. They can only vibrate.
   - (b) Particles of a liquid are farther apart, and they can move by sliding past each other.
   - (c) Particles of a gas are very far apart, and they move around quickly.
4. Energy makes particles move. The more energy the particles have, the faster they can move and the farther apart they can get.

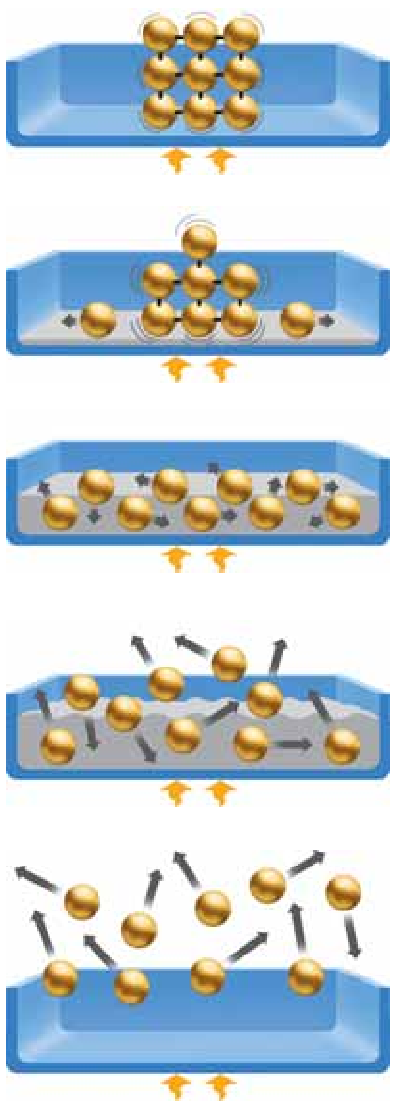
The Kinetic Molecular Theory and Changes of State

Imagine tossing an ice cube into a hot frying pan. The ice lands in the pan and slides easily across to the far side, riding on a sheet of liquid water. The cube quickly melts into a little pool of water. Soon the water begins to bubble, and then steam rises up from the pan. This example describes the three common states of matter on Earth: solid, liquid, and gas. Changes of state occur when matter changes from one of these states to another one.

The kinetic molecular theory helps explain changes of state, as well as the differences between solids, liquids, and gases. The particles in cold objects, such as ice cubes, have low kinetic energy, and their particles simply vibrate back and forth. The particles in warmer objects, such as liquid water or steam, have more kinetic energy and move faster (Figure 1.9).

Figure 1.9A Liquid gold

Changes of State in Gold



1. **Solid gold**
   Particles are very close to one another, fixed in position, and vibrate.
2. **Melting gold**
   As the temperature increases, the particles' kinetic energy increases. This motion results in the particles colliding with each other and making more space between them.
3. **Liquid gold**
   All particles are still close, but now have enough space to slide past one another.
4. **Boiling gold**
   As the temperature keeps on increasing, the kinetic energy increases and the particles bounce vigorously against each other, creating more space. Some particles gain enough energy to break completely free of the liquid gold.
5. **Gaseous gold**
   All particles are highly energetic and move freely to spread out in their container. Further heating gives particles even more kinetic energy, making the gas spread out faster and farther.

Figure 1.9B Energy (shown by the orange arrows) added to gold causes a change of state.

Temperature and Changes of State

Changes of state depend on a number of factors, such as temperature (Figure 1.10). When heat is added to a substance, its particles gain kinetic energy and vibrate faster. This causes them to move farther apart. If enough heat is added to a solid, it will melt. **Melting** is the change of state from a solid to a liquid. The temperature at which this change takes place is called the **melting poin**t. For water, the melting point is 0°C. **Boiling** is the change of state from a liquid to a gas. The temperature at which this change takes place is called the **boiling point**. For water, the boiling point is 100°C.

When heat is removed from a substance, the particles lose kinetic energy and vibrate or move more slowly. This causes them to move closer together. If enough heat is removed from a gas, it will change into a liquid. **Condensation** is the change of state from a gas to a liquid. Water condenses at the same temperature at which it boils: 100°C. **Solidification** or **Freezing** is the change of state from a liquid to a solid. Water solidifies at the same temperature at which it melts: 0°C.

Some substances can change directly from a solid to a gas and back again. Changing from a solid to a gas is called **sublimation**. Changing from a gas to a solid is called **deposition**.

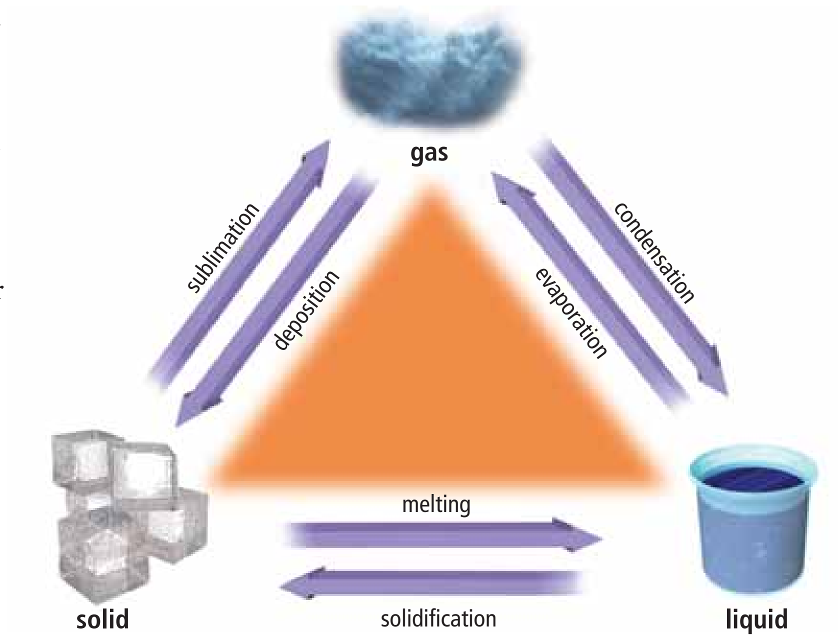


Figure 1.10 Changes of state

Reading Check

1. How is a liquid different from a solid in shape and volume?
2. How are gases and liquids similar in shape and volume?
3. How are solids and gases different in the amount of space between particles?
4. (a) How does the space between particles change as energy is added to the particles?
   (b) How does the space change as energy is lost?
5. (a) How does the behaviour of particles change as energy is added to particles?
   (b) How does the behaviour of particles change as energy is lost?
6. What happens during condensation?
7. What is the difference between sublimation and deposition?

Describing Matter

Think of a simple substance you have used recently—maybe sugar or salt or water. What colour was it, or was it colourless? What was its melting point or boiling point? When you answer questions like these, you are describing properties of matter. **Physical properties** are characteristics of matter that can be observed or measured. *Qualitative* properties are properties that can be described but not measured. *Quantitative* properties are characteristics that can be measured numerically. Table 1.1 lists the common physical properties used to describe matter.

Suggested Activity

Conduct an Investigation 1-2C on page 24

Table 1.1 Physical Properties

Physical Property	Description
Qualitative	
State	Solid, liquid, gas
Colour	Colour
Malleability	Ability to be beaten into sheets
Ductility	Ability to be drawn into wires
Crystallinity	Shape or appearance of crystals
Magnetism	Tendency to be attracted to a magnet
Quantitative	
Solubility	Ability to dissolve in water
Conductivity	Ability to conduct electricity or heat
Viscosity	Resistance to flow
Density	Ratio of a material's mass to its volume
Melting/freezing point	Temperature of melting/freezing
Boiling/condensing point	Temperature of boiling/condensing



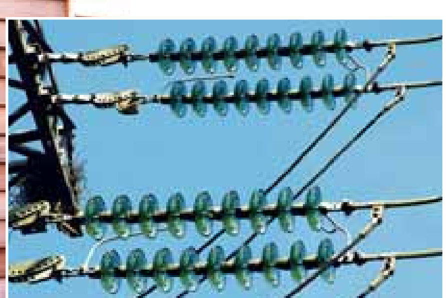


Figure 1.11 Works of art, windows, and electrical systems take advantage of the physical properties of glass.

The usefulness of a substance depends on which properties it has—and sometimes which properties it does not have. Common window glass, for example, does not form crystals and is not a good conductor of heat or electricity. But these "lacks" make it valuable. Because it is not crystalline, it can be easily bent and shaped when heated. It can be made into works of art, huge glass sheets called panes, and thousands of other glass products. Because it does not conduct heat or electricity well, it can be used for insulation. Figure 1.11 shows three results of glass's properties: a decorative glass object, double-paned windows, and insulators for power lines.

Pure Substances

A **pure substance** is a substance that is made up of only one kind of matter. Gold, water, and oxygen are all pure substances. There are two kinds of pure substances: elements and compounds.

- An **element** is a pure substance that cannot be broken down or separated into simpler substances. Gold and oxygen are both elements.
- A **compound** is a pure substance composed of at least two elements combined in a specific way. For example, water is a compound that is made up of the elements hydrogen and oxygen.

Explore More

Not all matter changes state in the usual manner. Find out about substances with unusual behaviour when they are changing state. Go to **www.bcscience9.ca.**

Reading Check

1. What property does malleability describe?
2. Would smell be a qualitative or a quantitative property?
3. How many kinds of matter are there in a pure substance?
4. What are the two kinds of pure substances?

1-2B A Chemical Family

Think About It

Elements that have properties in common are sometimes classified as a "chemical family." In this activity, you will determine whether aluminum and iron belong to the same chemical family as copper, gold, and silver.

What to Do

Scan the table below, and answer the questions below.

What Did You Find Out?

1. Three metals commonly used in coins—copper, silver, and gold—are considered to be a chemical family. List three arguments to explain why.
2. (a) List arguments in favour of including aluminum in the family of coinage metals.
   (b) List arguments against including aluminum.
3. (a) List arguments in favour of including iron in the family of coinage metals.
   (b) List arguments against including iron.
4. Do you think aluminum belongs to the same chemical family as iron? List arguments for and against.

Property	Elements				
	Aluminum (Al)	Copper (Cu)	Gold (Au)	Iron (Fe)	Silver (Ag)
Effect of acid on clean, bare, pure metal	Reacts with acid; hydrogen gas released	Unreactive with most acids	Unreactive with most acids	Reacts with acid; hydrogen gas released	Unreactive with most acids
Compound formed with oxygen	Readily	Not readily	Not readily	Readily	Not readily
Malleability	Very malleable	Very malleable	Highly malleable	Malleable	Very malleable
Electrical conductivity	Very good	Second best of all metals	Excellent	Good	Best of all metals

1-2C Modifying Metallic Properties

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Observing
- Classifying
- Controlling variables
- Working co-operatively

Safety

- Handle hot objects with care.
- Keep hair and loose clothing away from the flame.

Materials

- 3 metal paper clips
- crucible tongs
- Bunsen burner
- heat-resistant pad
- beaker
- cold water

Blacksmiths use hardening and heat treatment to shape horseshoes and other metal objects in a process called tempering. In this investigation, you will demonstrate how these methods affect a smaller metal object—a paper clip.

Question

How do hardening and heat affect the properties of a metal?

Procedure

1. Take one of the paper clips. Bend it so you have almost a straight metal wire.
2. Bend the wire carefully at one point to make roughly a right angle. Now bend the wire at the same point, at a right angle in the other direction.
3. Count the number of times you can bend the wire before it breaks. Record the number.
4. Straighten a second paper clip. Bend it as you bent the first one but only half the number of times you took to break the first one.
5. Hold the second paper clip in your tongs and heat it in a Bunsen burner flame until it is glowing. Heat it for about 10 s more, and then hold it in the air to cool slowly. Place it on the heat-resistant pad and leave it to cool to room temperature. You will use this wire again in step 8.
6. Half fill the beaker with cold water. Using the third paper clip, repeat step 4. Heat this paper clip so it glows for about 10 s and then quickly put it into the cold water. Let it cool for about 1 min.
7. Retrieve the wire from the water, and count the number of right-angle bends you can make before it breaks. Record the number.
8. Use the wire from step 5. Count the number of right-angle bends you can make before this wire breaks. Record the number.
9. Clean up and put away your equipment.

Analyze

1. You compared the flexibility of a metal wire that was heated and allowed to cool slowly with the flexibility of another that was cooled rapidly.
   (a) Which treatment resulted in a wire that was hard and brittle?
   (b) Which treatment resulted in a wire that was more flexible?

Conclude and Apply

1. Write a short paragraph explaining the effect that hardening and heating can have on a metal.

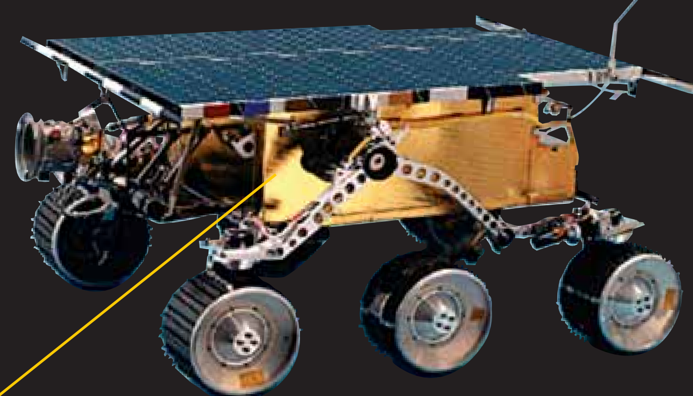
VISUALIZING ELEMENTS

Most of us think of gold as a shiny yellow metal used to make jewellery. However, it is an element that is also used in more unexpected ways, such as in spacecraft parts. On the other hand, some less common elements, such as americium (am uh REE see um), are used in everyday objects. Some elements and their uses are shown here.

▲ **ALUMINUM** Aluminum is an excellent reflector of heat. Here, an aluminum plastic laminate is used to retain the body heat of a newborn baby.

▲ **TUNGSTEN** Although tungsten can be combined with steel to form a very durable metal, in its pure form it is soft enough to be stretched to form the filament of a lightbulb. Tungsten has the highest melting point of any metal.

▲ **TITANIUM** (tie TAY nee um) Parts of the exterior of the Guggenheim Museum in Bilbao, Spain, are made of titanium panels. Strong and lightweight, titanium is also used for body implants.



▲ **GOLD** Gold's resistance to corrosion and its ability to reflect infrared radiation make it an excellent coating for space vehicles. The electronic box on the six-wheel Sojourner Rover, above, part of NASA's Pathfinder 1997 mission to Mars, is coated with gold.

▲ **LEAD** Because lead has a high density, it is a good barrier to radiation. Dentists drape lead aprons on patients before taking X rays of the patient's teeth to reduce radiation exposure.

◀ **AMERICIUM** Named after America, where it was first produced, americium is a component of this smoke detector. It is a radioactive metal that must be handled with care to avoid contact.

Wild, Weird, Wonderful

www Science

Liquid Crystals

Have you ever worn a mood ring? These fun pieces of jewellery have been available since the 1960s, and many people think that the changing colours of the ring express the wearer's emotions. Does the ring change colour with a person's mood?

Mood rings respond to temperature, not mood!

The secret to mood rings is a thin layer of reflective liquid crystals under the glass of the ring. These special liquid crystals change shape as temperature changes, which affects how the layer absorbs and reflects different colours. Therefore, as the temperature of your finger (not your mood!) changes, so does the colour of the ring.

This man's back has been sprayed with temperature-sensitive liquid crystals. The very uneven colours indicate he has a back injury.

When you think about it, the term "liquid crystal" might not seem to make sense. How can something be liquid and crystallized? Liquid crystals are a unique group of substances that have properties of both liquids and solids. Liquid crystals behave like solids in the sense that their particles are organized in crystal-like fashion. But unlike a solid, the particles can slide past each other as in a liquid.

Imagine being on a very crowded subway platform, with people so tightly packed that it is impossible to bend, walk, or sit down. This packed arrangement is like particles in a solid. But when a train arrives, the people can twist their bodies, move, and even switch places. Now the people are behaving more like particles in a liquid. Liquid crystal substances behave in a similar way.

The fascinating thing about liquid crystals is that they can be made to move. Some liquid crystals will respond to electricity. By arranging liquid crystals in a very thin layer on an organized electrified grid, we can create a liquid crystal display (LCD). If you are wearing a digital watch, it probably has an LCD. Electricity applied to selected sections makes the liquid crystals twist and line up in such a way that light cannot pass through. This creates the dark areas you see as numbers.

Digits on the watch are due to liquid crystal response to electricity.

Today's LCD technology is responsible for the colourful displays we have in laptops, cellphones, and other flat screen devices. For example, an LCD TV screen has millions of carefully arranged, electrically controlled, tiny areas called pixels. Each pixel allows colours of light to pass through by controlling liquid crystals. Considering the advantages of liquid crystals, we can be thankful they do not strictly obey the rules of solids or liquids!

Questions

1. Compare the behaviour of particles in (a) solids, (b) liquids, and (c) liquid crystals.
2. How do liquid crystals respond to temperature changes?
3. How does a digital watch LCD work?

Check Your Understanding

Checking Concepts

1. Matter can be defined as anything that has two particular physical properties. What are these properties?
2. What happens in a chemical change?
3. What happens in a physical change?
4. Explain the term "change of state."
5. What two things happen to particles in a substance when the substance is heated?
6. What are the three most common states of matter on Earth?
7. Why does a liquid take the shape of whatever container it is in but does not expand to fill the container completely?
8. A certain pure oil solidifies at 5.0°C. What temperature does it melt at?
9. What happens to the particles in liquid water when the water boils into steam?
10. Describe the connection between kinetic energy and the movement of particles in a substance.
11. What does each of the following terms mean?
    (a) malleability
    (b) boiling point
    (c) ductility
    (d) conductivity
    (e) solubility
    (f) crystallinity
    (g) viscosity

Understanding Key Ideas

12. Which physical property is the ratio of the mass of a substance divided by its volume?
13. Select any four of the physical properties listed in Table 1.1 on page 22 and use them to describe:
    (a) gold
    (b) sugar
    (c) water
14. Mercury is a metal with a melting point of –39°C and a boiling point of 357°C. What is its state at:
    (a) 0°C?
    (b) 500°C?
    (c) –1°C?
15. List the four statements of the kinetic molecular theory.
16. The melting point of silver metal is 962°C, and its boiling point is 2162°C. Draw diagrams that show how the particles appear in silver at 900°C and at 3000°C.

Pause and Reflect

In this section, you have investigated the properties of matter. Why is it important to be able to describe the properties of various types of matter?