5.6 Characteristic Physical Properties

Figure 1 These liquids look identical but they are not. How can you tell them apart?

Figure 2 Unlike height, fingerprints do not change and are specific to the person. They are a characteristic physical property of a person.

characteristic physical property a physical property that is unique to a substance and that can be used to identify the substance

density a measure of how much mass is contained in a given unit volume of a substance; calculated by dividing the mass of a sample by its volume

If you had to identify a pure liquid, what types of tests could you perform on it? One option would be to test its chemical properties. You could mix it with substances such as vinegar and baking soda and see how it reacts. You would need to perform several tests to narrow down the possible choices. Mixing unidentified substances together can be dangerous. The liquid you are testing may change to form new products with each test. So, the number of tests you can perform is limited by the amount of liquid you have.

You could also examine the physical properties of the pure liquid. However, some physical properties are not useful for identifying a sample. Knowing the volume and temperature of the mystery sample is not a great help because these values are not unique to substances. However, determining properties that are unique, or characteristic, of the pure substance would be much more informative. You could identify the mystery liquid with confidence if you knew its unique physical properties, along with some of its chemical properties (Figure 1).

Certain physical properties are unique to each pure substance, like fingerprints are unique to each person (Figure 2). These physical properties are unique due to the composition and structure of each substance. These properties are called **characteristic physical properties**, and they can be used with confidence to identify a pure substance. Unlike chemical tests, characteristic physical properties can be determined without changing the composition of the sample, so the test sample is unchanged.

In this section, you will learn about three characteristic physical properties of pure substances: density, freezing/melting point, and boiling point.

Density

As you may recall from previous studies, the **density** of a substance is a ratio of its mass to its volume. The units of density are usually g/cm^3 (for a solid) and g/mL (for a liquid).

Density is the amount of matter per unit volume of that matter. A puffy marshmallow has the same mass as a squished marshmallow. However, a puffy marshmallow has a greater volume, so its mass–volume ratio is different, meaning its density is different. The particles in the puffy marshmallow are farther apart from each other. In other words, the puffy marshmallow is less dense than the squished marshmallow (Figure 3).

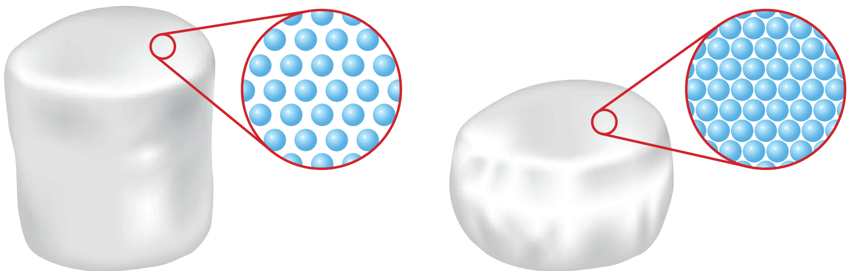

Figure 3 A greater mass of the same substance packed into a smaller volume has a greater density.

DID YOU KNOW?

Mass Spectrometers

Modern labs use advanced equipment, such as mass spectrometers, to identify substances. A very small sample is placed into the machine, which takes only several minutes to output the result. Two of the properties of a substance that a mass spectrometer analyzes are the mass of the particles present in the substance and how much of each particle is present in the substance.

SAMPLE PROBLEM 1: Identifying a Metal

SKILLS HANDBOOK 5.B., 5.D.

Calculate the density of a metal sample that is 18.00 cm long, 9.21 cm wide, and 4.45 cm high and that has a mass of 14.25 kg. What is the identity of the metal?

Given: $l = 18.00$ cm $h = 4.45$ cm
$w = 9.21$ cm $m = 14.25$ kg

Required: density of the metal (d)

Analysis: $\text{density} = \dfrac{\text{mass}}{\text{volume}}$

Solution:

$$\text{Volume of metal sample} = l \times w \times h$$
$$= 18.00 \text{ cm} \times 9.21 \text{ cm} \times 4.45 \text{ cm}$$
$$= 738 \text{ cm}^3$$
$$\text{mass of metal sample} = 14.25 \text{ kg} = 14\,250 \text{ g}$$
$$\text{density} = \frac{\text{mass}}{\text{volume}}$$
$$= \frac{14\,250 \text{ g}}{738 \text{ cm}^3}$$
$$= 19.3 \text{ g/cm}^3$$

To identify the metal, look up the value you obtained for density in Table 1.

Statement: The density of the metal is 19.3 g/cm^3. This metal is gold.

MATH TIP

Mass and Volume

Mass is a measure of the amount of matter in a substance. Volume is a measure of the amount of space a substance takes up.

The density of a substance is also related to the mass of the particles of which it is composed. A box filled with billiard balls is denser than an identical box filled with ping pong balls even though the volume of the boxes is the same. This is because the mass of the billiard balls is greater than the mass of the ping pong balls.

The densities of gases are closely related to their temperature and pressure. How closely particles are packed in gases depends on their temperature and pressure. For example, a gas at a higher pressure is denser than the gas at a lower pressure because the particles are packed closer together. Similarly, a gas at a higher temperature is less dense than the gas at the same pressure but at a lower temperature because the particles have more energy to move away from each other.

In liquids and solids, the particles are more closely bound, so changes in density caused by changes in temperature and pressure are minor compared with gases. For this reason, density is a characteristic physical property of pure liquids and solids. Still, temperature affects density, so values of density are often stated for a specific temperature.

Table 1 lists the densities of several common metals. For example, a piece of iron with a volume of 1 cm^3, approximately the size of a small sugar cube, has a mass of 7.87 g. A piece of aluminum of the same size has a mass of only 2.70 g—less than one-third the mass of the iron. Imagine how much less an aluminum car would weigh and how much less fuel you would need to drive it. Gold is more than seven times denser than aluminum. It is sometimes called a heavy metal, but it is more correct to call it a very dense metal.

Table 1 Densities of Common Metals (at Room Temperature and Atmospheric Pressure)

Metal	Density (g/cm^3)
aluminum	2.70
zinc	7.13
iron	7.87
copper	8.96
silver	10.49
lead	11.36
mercury	13.55
gold	19.32

Freezing Point, Melting Point, and Boiling Point

freezing point the temperature at which a substance changes state from a liquid to a solid; melting point and freezing point are the same temperature for a substance

melting point the temperature at which a substance changes state from a solid to a liquid

boiling point the temperature at which a substance changes state rapidly from a liquid to a gas

As Canadians, we know well that 0 °C is a significant temperature. It marks the difference between icy roads and rain puddles, and between skating rinks and fishing ponds (Figure 4). The **freezing point** is the temperature at which a substance turns from a liquid into a solid. It is the same temperature as the melting point of the same substance. **Melting point** is the temperature at which the substance turns from a solid into a liquid. For example, 0 °C is the freezing point of pure water and the melting point of pure ice. Different substances freeze and melt at different temperatures. The temperature at which a substance changes rapidly from a liquid to a gas is its **boiling point** (Figure 5). For example, the boiling point of water is 100 °C.

Figure 4 Water turns to ice at its freezing point, 0 °C.

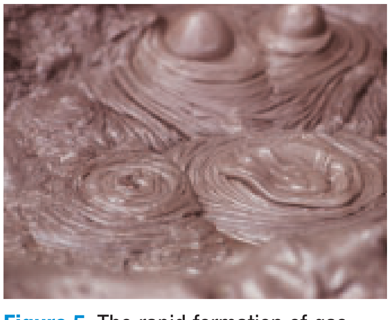

Figure 5 The rapid formation of gas bubbles throughout a liquid occurs only at the boiling point.

The temperature at which a substance changes state depends on the particular composition and structure of the substance, and is thus unique to each substance. So, freezing/melting point and boiling point are characteristic physical properties of a substance. You can use these properties to distinguish between pure substances.

Figure 6 When an electrical circuit is dangerously overloaded, the metal wire in the fuse melts, breaking the circuit and preventing a fire. Sometimes low melting points are a good thing.

Applications of Melting Point

Knowing the melting point of metals is important when selecting a metal for a specific purpose (Figure 6). For example, incandescent light bulbs produce light when an electric current heats a metal wire filament. The hotter the filament is, the more light is given off. Of course, the light bulb will not work if the filament melts. Which metal would you select for the filament? Early inventors of incandescent light bulbs chose platinum for its high melting point. However, this metal is very expensive.

In the late 1870s, Thomas Edison experimented with carbon filaments that glowed well, but they were chemically reactive and produced a black deposit inside the bulb. In 1910, the element tungsten was chosen because of its very high melting point, its low chemical reactivity, and its wide availability (Figure 7). Table 2 lists the melting points of common metals.

Metals with low melting points also have important applications. Mercury is a metal that melts at –39 °C, which means that at normal room temperatures (25 °C), it has already melted. Mercury is the metal of choice in many thermostat designs (Figure 8). Several drops of liquid mercury flow to and from a contact point in the electrical circuit, turning the heater on or off in response to changes in room temperature. This design requires a metal that conducts electricity and is also a liquid at room temperature. Mercury is the only metal that meets both of these criteria. As you will learn in a later section, mercury is hazardous, and its use and disposal must be carefully controlled.

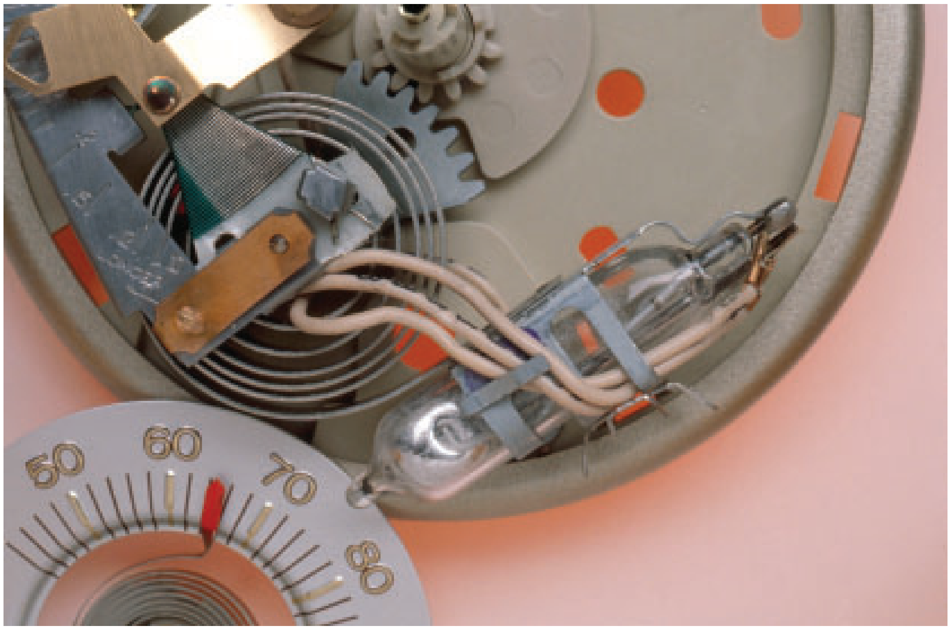

Figure 8 When the thermostat cools and tips the vial, mercury completes the electrical circuit and turns on the heat.

In the next section, you will take a closer look at how the characteristic melting point of a pure substance changes when other substances, or impurities, are added to it. This property can also be used to our advantage, especially during Canadian winters.

Salt and Ice

How does salt "melt" snow and ice? As you know, pure water freezes at 0 °C. Any impurity that is added to ice interferes with the freezing process, and water does not become solid ice until the temperature drops even lower. As a result, adding any dissolved impurity such as salt lowers the freezing point of water. Instead of freezing at 0 °C, a mixture of 20 % salt in water stays a liquid until the temperature is as low as –16 °C. This means that, if you add enough salt, the roads will be ice-free even when the temperature dips below 0 °C.

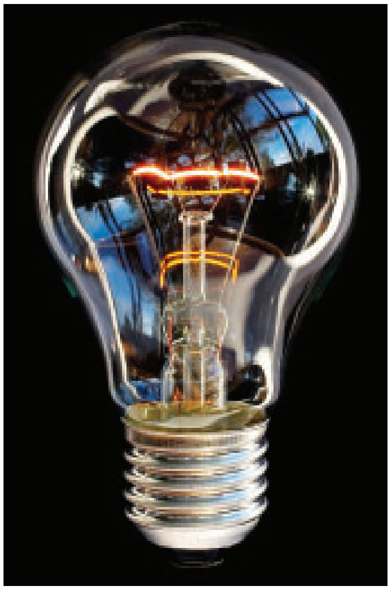

Figure 7 Metals need to be heated to extremely high temperatures before they give off a useful amount of light. Most metals melt before they reach these temperatures. Tungsten is an exception, which is why it is used as the filament in incandescent light bulbs.

Table 2 Melting Points of Common Metals

Metal	Melting point (°C)
mercury	–39
tin	232
lead	328
zinc	420
aluminum	660
silver	961
gold	1065
copper	1085
nickel	1453
iron	1535
platinum	1772
tungsten	3407

DID YOU KNOW?

Light Bulbs—A Canadian Invention

Canadian Henry Woodward invented an incandescent light bulb in 1874 and sold his U.S. patent to Thomas Edison, an American. This light bulb was very different from the one that was eventually sold commercially in the U.S.

TRY THIS WE SCREAM FOR ICE CREAM

SKILLS: Performing, Observing, Analyzing, Evaluating, Communicating

Ice cream has been a favourite treat for hundreds of years. It is simply frozen cream to which fruit or flavourings have been added. Before electrical refrigeration was invented, a mixture of ice and salt was used to achieve temperatures low enough to freeze cream. Just as we sprinkle salt on the roads to melt snow and ice, salt is mixed with ice to lower the melting point of ice. In this activity, you will make a small batch of ice cream.

Equipment and Materials: small sealable plastic bag; large sealable plastic bag; thermometer; one-half cup cream; 2 tbsp sugar; one-quarter tsp vanilla flavouring; 2 cups ice; 2 tbsp salt

1. Place the cream, sugar, and vanilla into the small bag and seal it securely.
2. Place the ice inside the large bag and use the thermometer to measure the temperature of the ice.
3. Add one tablespoon of salt to the ice and mix. Measure the temperature of the ice–salt mixture.
4. Add a second tablespoon of salt to the ice–salt mixture and mix. Measure the temperature again.
5. Place the sealed small bag inside the large bag and seal the large bag securely.
6. Shake the bags gently for about 10 min.
7. When the cream mixture is frozen, open the bags. Be careful to keep the salt and ice out of the ice cream.

A. What happened to the temperature of the ice after salt was added to it? T/I

B. What happened to the state of the ice after salt was added to it? T/I

C. What was the purpose of adding salt to the ice in this recipe? T/I

D. Salt is added to the ice and snow on the roads to keep the roads safe for driving. From what you have learned in this activity, what effect does salt have on snow? Why does spreading salt on roads in the winter improve road safety? A

E. Repeat the experiment, only this time omit the salt. What were the differences in your results? Give reasons for your answer. T/I

WRITING TIP

Finding the Main Idea

Read the first and last sentences of a paragraph to find its main idea. If you cannot find it, read them again and then the middle part of the paragraph. The nucleus of a paragraph is the main idea. You can assume that all paragraphs in a science textbook have a main idea. Your job is to detect it and translate it into your own words.

The Unusual Behaviour of Water

What can be odd about water? It is a most ordinary substance—clear, colourless, odourless, and tasteless. It freezes at 0 °C and boils at 100 °C. The Celsius temperature scale was designed to fit the boiling point and freezing point of water. Water is odd because its solid form floats on its liquid form; that is, ice floats on water (Figure 9)! Very few substances do this. Normally, the particles in a solid state are packed more closely together than they are in a liquid state. Therefore, a solid occupies less space and is denser than its corresponding liquid. A solid usually sinks in a liquid of the same substance.

Water particles are different. Due to their shape and the way they are arranged, water particles occupy more space when they are packed together into solid ice (Figure 10). As an analogy, picture a box filled with L-shaped building blocks. When these blocks are not connected, they can be poured as a fluid. The pieces overlap and each one fits into an empty space.

Figure 9 Water is an unusual substance because its solid form is less dense than its liquid form. This is why ice floats on water.

However, if each L-shaped block were connected end-to-end, in a solid shape, they would not be able to overlap, and would occupy a larger space.

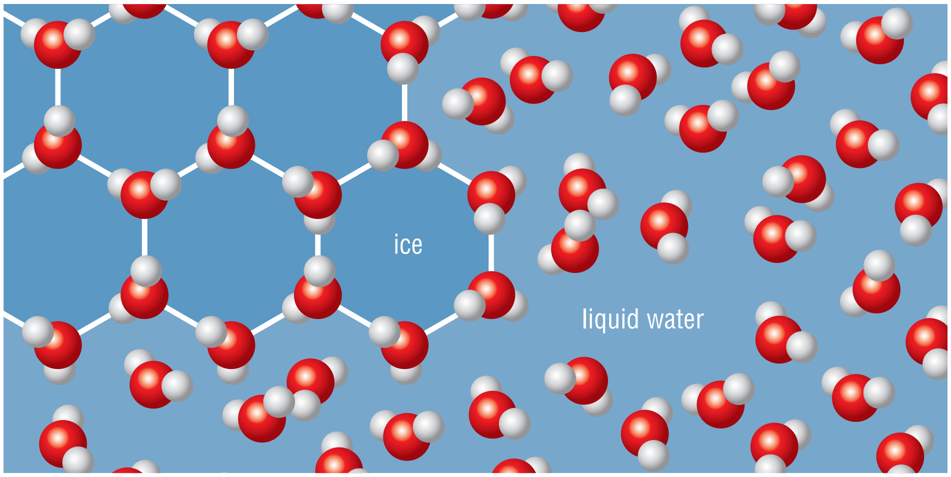

Figure 10 Ice is less dense than water because the particles in ice take up a larger volume than the same number of particles in liquid water. The mass of the particles remains the same.

We should be very grateful for this oddity of water. If water were like other liquids, its solid state would be denser that its liquid state. Water would become denser as it cooled, and sink. A lake would freeze from the bottom up! Luckily for the fish in the lake, this does not happen. Water becomes denser as it cools, but its density is highest at a temperature of 4 °C (Figure 11). Lake water at this temperature sinks but remains a liquid. As the temperature drops below 4 °C, surface water becomes less dense and stays at the surface. If the temperature drops to 0 °C, surface water freezes to form ice.

There are also negative consequences of this property of water. The force of expansion of water as it freezes can cause serious problems (Figure 12). Glass bottles of juice in a freezer can crack, and water pipes at a cottage can burst if the pipes are not emptied before winter.

DID YOU KNOW?

Carbon Freezing

A bottle of carbonated water can be kept at temperatures much lower than 0 °C without freezing. The carbonation comes from forcing carbon dioxide gas to be dissolved in the water under pressure. What happens when the sub-zero-temperature carbonated drink is opened? Try it for yourself and find out. Cool an unopened bottle of carbonated water in a mixture of salt and ice, until it reaches about –8 °C. Then take the bottle out of the ice and open the bottle.

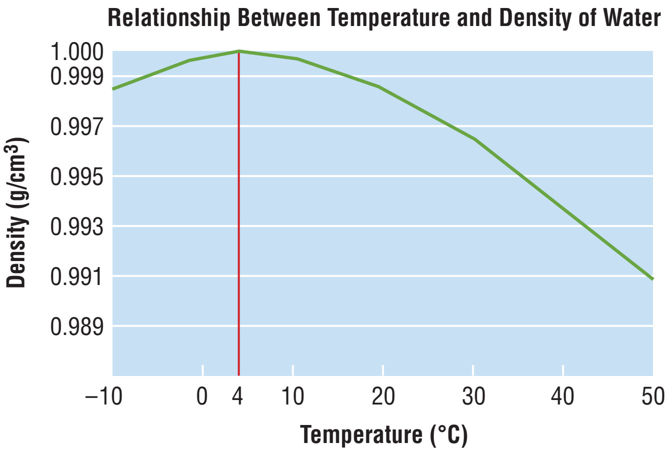

Figure 11 The density of water changes depending on its temperature.

Figure 12 Water that freezes but has no room to expand can cause damage.

UNIT TASK Bookmark

You can apply what you learned in this section about characteristic physical properties to the Unit Task described on page 286.

IN SUMMARY

- A characteristic physical property is a physical property that is unique to a pure substance and that can be used to identify the substance.
- Density is a measure of how much mass is contained in a given unit volume of a substance. It is calculated by dividing the mass of a sample by its volume.
- Melting point is the temperature at which a substance changes state from a solid to a liquid.
- Freezing point is the temperature at which a substance changes state from a liquid to a solid. Melting point and freezing point are the same temperature for a substance.
- Boiling point is the temperature at which a substance changes state rapidly from a liquid to a gas.
- Unlike other substances, water that is close to its melting point is less dense in the solid state than in the liquid state. Therefore, ice floats on water.

CHECK YOUR LEARNING

1. Explain why the boiling point of water is a characteristic physical property, but the temperature and the volume of a glass of water are not. K/U
2. Which properties of mercury make it a good material to use in a thermostat? K/U
3. If you could place a piece of solid silver into a container of liquid silver, would it float or sink? Explain your answer. K/U
4. A sample of pure iron has a mass of 5.00 g. Calculate its volume. T/I
5. A metal with a mass of 71.68 g occupies a volume of 8.00 cm^3. Calculate the density of the metal. Using Table 1 on page 193, determine the identity of the metal. T/I
6. A sample of pure copper has a volume of 3.75 cm^3. Calculate its mass. T/I
7. A metal with a mass of 1.00 kg occupies a volume of 370 cm^3. Calculate the density of the metal. Using Table 1 on page 193, determine the identity of the metal. T/I
8. A sample of pure zinc has a mass of 4.50 g. Calculate its volume. T/I
9. A metal with a mass of 15.00 g occupies a volume of 1.32 cm^3. Calculate the density of the metal. Using Table 1 on page 193, determine the identity of the metal. T/I
10. Calculate the mass of a gold bar that is 18.00 cm long, 9.21 cm wide, and 4.45 cm high. T/I
11. (a) Explain why water is said to exhibit unusual behaviour.
    (b) Describe some consequences of the behaviour of water. K/U
12. A drinking glass at a crime scene contains a clear, colourless liquid that may be water or alcohol. As the investigator, you know that the densities of alcohol, water, and ice are 0.79 g/mL, 1.0 g/mL, and 0.92 g/mL, respectively. Design a simple method to determine the identity of the mystery liquid. Explain your design. T/I A