What is stuff made of? Everything is made up of chemicals – the food you eat, the plastic in your phone… and you! But what are these chemicals like inside, and why do they behave the way they do?

In C1 you will learn about the atoms that make up everything on Earth… and beyond. You will explore how chemical reactions make vital materials, and provide energy for almost everything we do.

You already know

- Different materials have different properties.
- The different properties of different materials make them suitable for different uses.
- Many materials can exist in the solid, liquid, and gas states.
- The state of a material depends on the temperature.
- Changes of state are reversible.
- Melting, freezing, evaporating, boiling, and condensing are changes of state.
- Changes that form new materials are not reversible.
- Changes that are not reversible include burning, oxidation, and reactions of acid.

Big Questions

- What are materials like inside and why do they behave as they do?
- What are atoms and elements?
- How do scientists make new materials?

Making connections

In C1 you will learn about atoms and molecules and what happens when chemicals react.

In B1 you will learn about diffusion and how particles move between substances.

In P2 you will learn about energy transfer and energy conservation.

Can you solve this Picture Puzzler?

The first letter of each of these images spells out a science word that you will come across in this book.

Can you tell what this zoomed-in picture is?

Clue: It’s a cold and frosty morning.
Learning objectives
After this topic you will be able to:
- describe how materials are made up of particles
- use the particle model to explain why different materials have different properties.

What’s in a material?
Materials are made up of tiny particles. You cannot see the particles. They are too small. There are about 8 400 000 000 000 000 000 000 particles in a glass of water.

A State what materials are made up of.

Are all particles the same?
Many materials are mixtures. Wood is a mixture. So is milk, and the air. But some materials are not mixtures. They consist of just one substance. A substance has the same properties all the way through. Substances include gold, water, and oxygen.

B State what is meant by a substance.

What gives a substance its properties?
The properties of a substance describe what it looks like and how it behaves. Every substance has its own properties. The properties of a substance depend on its particles.
The table shows data for gold and water.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Relative mass of particle</th>
<th>Mass of 1 cm(^3) of the substance (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>gold</td>
<td>197</td>
<td>19</td>
</tr>
<tr>
<td>water</td>
<td>18</td>
<td>1</td>
</tr>
</tbody>
</table>

A gold particle has a greater mass than a water particle. This helps to explain why 1 cm\(^3\) of gold weighs more than 1 cm\(^3\) of water.

In liquid water, particles slide over each other. In an ice cube, the particles do not move around. This explains why you can pour water from a glass but you cannot pour water from an ice cube.

The properties of a substance depend on three things, or factors:
- what its particles are like
- how its particles are arranged
- how its particles move around.

C List three factors that give a substance its properties.

Table of data

<table>
<thead>
<tr>
<th>Substance</th>
<th>Relative mass of particle</th>
<th>Mass of 1 cm(^3) of the substance (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>gold</td>
<td>197</td>
<td>19</td>
</tr>
<tr>
<td>water</td>
<td>18</td>
<td>1</td>
</tr>
</tbody>
</table>

In a substance, every particle is the same. One gold particle is the same as all other gold particles. One water particle is the same as all other water particles. In the air, all oxygen particles are identical.

But gold particles are not the same as oxygen particles. Oxygen particles are not the same as water particles. Every substance has its own type of particle.

Summary Questions

1 Copy the sentences below, choosing the correct bold words. There are hundreds/millions of materials. Materials are made up of practicals/particles. A substance has the same/different properties all the way through. In a substance, all the particles are the same/different. The particles of different substances are the same/different. The properties of a substance describe its behaviour/particles.

(6 marks)

2 Use the data to estimate which is heavier, 10 cm\(^3\) of water or 10 cm\(^3\) of mercury. Show how you decided.

Data: relative mass of water particle = 18, relative mass of mercury particle = 201.

(2 marks)

3 Using all the key words, draw a visual summary to summarise and organise the information on this page.

(6 marks)

Fantastic Fact!
If people were the same size as gold particles, the world’s population would fit into a ball less than a thousandth of a millimetre across.

Gold is a single substance. All of its particles are the same.

The bridge cables are made from steel. Steel is a mixture.
Learning objectives

After this topic you will be able to:
- describe the properties of a substance in its three states
- use ideas about particles to explain the properties of a substance in its three states.

Do you like ice in cold drinks? An ice cube is made up of water particles. Ice is water in the solid state. Now imagine a steaming kettle. Steam is also made up of water particles. It is water in the gas state.

Water can exist in three states, as a solid, a liquid, or a gas. These are the states of matter. The particles of water in its three states are identical. But the properties of ice, liquid water, and steam are different. These pages explain why.

A Name the three states of matter.

How does state affect properties?

Most substances can exist in three states. The state of a substance depends on temperature. At room temperature, gold is solid. But if you make it hot enough, gold exists as a liquid or gas.

The table compares the properties of a substance in its three states.

<table>
<thead>
<tr>
<th>State</th>
<th>Can you compress (squash) the substance in this state?</th>
<th>Does the substance flow?</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>solid</td>
<td>no</td>
<td>no</td>
<td>fixed, unless you apply a force</td>
</tr>
<tr>
<td>liquid</td>
<td>no</td>
<td>yes</td>
<td>takes the shape of the bottom of its container</td>
</tr>
<tr>
<td>gas</td>
<td>yes</td>
<td>yes</td>
<td>takes the shape of the whole container</td>
</tr>
</tbody>
</table>

B Identify three differences between a substance in the solid and liquid states.

How do particles explain properties?

The particles of a substance do not change. All water particles are the same, in all three states. But the arrangement and movement of particles are different in each state.

The solid state

When a substance is in the solid state, its particles touch their neighbours. This explains why you cannot compress a solid. In the solid state, a substance’s particles are arranged in a pattern.

In the solid state, particles do not move around. They vibrate on the spot. This explains why solids cannot flow.

The liquid state

When a substance is in the liquid state, its particles touch their neighbours. This is why you cannot compress a liquid. The particles move from place to place, sliding over each other. This explains why liquids flow and why they have no fixed shape.

The gas state

In the gas state, particles spread out. So it is easy to compress a gas. The particles move throughout the whole container. This explains why gases flow.

C State why you cannot compress a liquid.

Express particle?

In 2010 a Chinese train became the world’s fastest passenger train. It reached a speed of 486 km/h (0.135 km/s). In the air, oxygen particles travel at about 500 m/s. Calculate which is faster – the train or the particles.
Learning objectives

After this topic you will be able to:
● use the particle model to explain changes of state involving solids and liquids
● interpret data about melting points.

Imagine an ice cube in your hand. What happens?
When a substance changes from the solid to liquid state, it melts. Melting is a change of state. Freezing is the change of state from liquid to solid. Liquid gold freezes if cooled to 1063 °C.

A Name the two states involved in freezing.

Explaining melting and freezing
What happens when an ice cube melts? As ice starts to melt it takes in energy, so its particles vibrate faster. Particles move away from their places in the pattern. They continue to move around. As more particles leave the pattern, more ice melts. When a liquid starts to freeze, its particles move more slowly as they transfer energy to the surroundings. The particles get into a pattern, and vibrate on the spot. Eventually, all the liquid freezes. The mass does not change when a substance melts or freezes. This is because no particles have been added or removed.

B Describe how particle movement changes when a substance melts.

What is a melting point?
The temperature at which a substance melts is its melting point.

Melting points give information about the states of substances at different temperatures. The melting points of gallium and gold are above 20 °C. So at 20 °C, gallium and gold are solid. You cannot work out the state of oxygen from the data in the table.

C List the substances in the table in order of increasing melting point.

Using melting points

Identifying substances
Jackson and Marcus are at university. They have three painkillers – paracetamol, aspirin, and ibuprofen. They do not know which is which. They use the Internet to find out their melting points. They record the data in the table shown on the right. The students measure the melting point of one painkiller. It is 136 °C. They conclude that it is aspirin.

Checking purity
A single substance has a sharp melting point. Stearic acid is solid at 20 °C. If you heat the acid, it stays solid up to 70 °C. Then it starts to melt. It stays at 70 °C until it has all melted. Then the liquid warms up.

What is a melting point?
The temperature at which a substance melts is its melting point.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Melting point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>gallium</td>
<td>30</td>
</tr>
<tr>
<td>gold</td>
<td>1063</td>
</tr>
<tr>
<td>oxygen</td>
<td>−218</td>
</tr>
<tr>
<td>water</td>
<td>0</td>
</tr>
</tbody>
</table>

A material that is a mixture of substances does not have a sharp melting point. Chocolate melts between 30 °C and 32 °C. This shows that it is a mixture.

Summary Questions

1 Copy the sentences below, choosing the correct bold words.
The change of state from solid to liquid is freezing/melting. As a substance melts, its particles vibrate slower/faster. The particles start moving around/upwards. The substance is now in the liquid/solid state. The melting point of a substance is the speed/temperature it melts at.

(5 marks)

2 A substance has a melting point of −7 °C. Tom says the substance is liquid at 20 °C. Ben says it could be liquid or gas. Explain who is correct. Use evidence to support your answer.

(3 marks)

3 Use the particle theory to explain in detail the difference between melting and freezing.

(6 marks QWC)
Learning objectives
After this topic you will be able to:
● use the particle model to explain boiling
● interpret data about changes of state.

Close your eyes. Imagine water boiling. What can you hear? What can you see? When a substance is boiling it is changing from the liquid state to the gas state.

Explaining boiling
When water boils, bubbles of steam form all through the liquid. In the liquid, water particles touch their neighbours. Inside the bubbles, the water particles are spread out. As water boils, the steam bubbles rise to the surface of the liquid. They escape into the air. The total mass of steam and water is the same as the mass of water at the start. Scientists say that mass is conserved in boiling.

Using boiling points
Identifying substances
You can use data about boiling points to help identify substances. Lucy has a colourless liquid. Her teacher tells her it could be water, ethanol, or propanol. Lucy notes the boiling points of these substances in the table below.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Boiling point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>100</td>
</tr>
<tr>
<td>ethanol</td>
<td>78</td>
</tr>
<tr>
<td>propanol</td>
<td>97</td>
</tr>
</tbody>
</table>

Lucy heats her liquid on an electric heater. She measures its temperature every minute. At 78 °C the liquid bubbles vigorously. It remains at 78 °C for several minutes. Lucy concludes that the liquid is ethanol.

Predicting states
If you know the melting point and the boiling point of a substance, you can predict its state at different temperatures. The melting and boiling points of silver are shown below.

At room temperature (20 °C), silver is in the solid state. At 961 °C, the melting point, silver exists as both a solid and a liquid. Between 961 °C and 2210 °C silver is a liquid. At 2210 °C, the boiling point, silver exists as both a liquid and a gas. Above 2210 °C silver exists in the gas state.

C Predict the state of silver at 1000 °C.

Fantastic Fact!
The boiling point of a substance depends how high above the Earth’s surface you are. At Mount Everest Base Camp (5364 m above sea level), water boils at 82 °C.
What happens to the water when you use a hairdryer to dry your hair? It changes state from liquid to gas without boiling. This is called evaporation.

Explaining evaporation
In a liquid, some particles have more energy than others. The particles with most energy leave the liquid surface. Then they move away from the liquid. The particles spread out, forming a gas. They mix with air particles. This is evaporation.

A substance can change from the liquid to the gas state by evaporating or boiling. The table below shows some differences between these two processes.

<table>
<thead>
<tr>
<th>Process</th>
<th>How particles leave the liquid</th>
<th>Temperature</th>
<th>Does the mass change?</th>
</tr>
</thead>
<tbody>
<tr>
<td>evaporation</td>
<td>Particles escape from the liquid surface.</td>
<td>happens at any temperature</td>
<td>no</td>
</tr>
<tr>
<td>boiling</td>
<td>Bubbles of the substance in the gas state form throughout the liquid. They rise to the surface and escape.</td>
<td>happens only at the boiling point</td>
<td>no</td>
</tr>
</tbody>
</table>

A State two differences between evaporation and boiling.

How is evaporation useful?
Why do you sweat? Sweating cools you down by evaporation. Sweat comes out of pores in your skin. Water from the sweat evaporates. The water particles need energy to move away as a gas. They take this energy from your skin. This cools you down.

What is condensation?
Is the inside of your bedroom window ever wet after a cold night? At bedtime, water particles were mixed with air particles. They were spread out, as a gas. During the night, water particles hit the cold glass of the window. They moved closer to other water particles, until they were touching. This formed liquid water. The change of state from gas to liquid is called condensation. It can happen at any temperature below the boiling point.

C Identify the state formed when a substance condenses.

What is sublimation?
Where does stage smoke come from? It comes from solid carbon dioxide. Carbon dioxide is solid at temperatures below −78.5 °C. At this temperature and above, solid carbon dioxide changes state to become a gas. It does not normally exist as a liquid. The change of state from solid to gas is called sublimation.

At first, the carbon dioxide gas is very cold. Water particles condense around carbon dioxide particles. Tiny drops of liquid water form. It is this liquid water that makes stage smoke.

D Name the change of state that occurs when a substance in the solid state changes into a gas.
Learning objectives
After this topic you will be able to:
● use the particle model to explain diffusion
● describe evidence for diffusion.

Do you wear perfume or deodorant? How does the smell reach your nose?
Perfume particles evaporate from your skin. The particles move around randomly. They mix with the air. As the perfume particles spread out, some enter your nose. Your nose detects the smell. The random moving and mixing of particles is called diffusion.

Summary Questions
1 Copy and complete the sentences using the words below.
particles randomly air diffusion energy faster
When food cooks, you can smell it because some ______ leave the food. The particles move ______ and mix with the ______. This is called ______. Particles diffuse because they have ______. The higher the temperature, the ______ the diffusion.
(6 marks)

2 Describe three pieces of evidence for diffusion.
(3 marks)

3 The air contains particles of argon, nitrogen, and other substances. Use the data below to predict which type of particle diffuses faster. Give a reason for your choice.
Relative masses of particles: nitrogen ~ 28 and argon ~ 40
(2 marks)

4 Explain in detail the different diffusion speeds through substances in the solid, liquid, and gas states.
(6 marks QWC)

Key Words
diffusion

Fantastic Fact!
At room temperature, particles in liquid water move at an average speed of 1600 km/h (444 m/s).

Why do substances diffuse?
Particles diffuse because they have energy. Perfume particles move randomly in the air, even if the air seems completely still. Ink particles spread through water by themselves. You do not need to shake or stir.

A State what is meant by diffusion.

What factors affect diffusion speed?
Diffusion does not always happen at the same speed. Three factors affect the speed of diffusion:
● temperature
● particle size
● the state of the diffusing substance.

Temperature
At higher temperatures, particles have more energy. They move more quickly. Perfume particles leaving warm skin travel faster than perfume particles leaving a cold bottle.

B Explain why particles diffuse more quickly at higher temperatures.

Link
You can learn more about diffusion in B1 1.4 Movement of substances
1.7 Gas pressure

Learning objectives
After this topic you will be able to:
● use the particle model to explain gas pressure
● describe the factors that affect gas pressure.

Why do balloons get bigger as you blow them up? When you blow up a balloon, you are filling it with air particles. The more air particles you add, the bigger the balloon.

Inside the balloon, the air particles move quickly from place to place. They bump into, or collide with, each other. They also collide with the rubber the balloon is made from. The collisions exert a force on the rubber. The force per unit area (every square metre) is the gas pressure.

Gas particles always exert pressure on the walls of their container, whatever the container is made from.

A State what is meant by gas pressure.

How does the number of particles affect pressure?
Rubber is stretchy. So when you blow more particles into a balloon, the balloon expands. But some containers cannot expand. Adding more particles causes more frequent collisions with the walls. The pressure inside the container increases.

B Explain why adding more air increases the pressure inside a container.

As the air in a balloon gets warmer, its particles gain energy. The particles move faster. They collide with the rubber more often. The pressure inside the balloon increases.

The higher the temperature, the higher the air pressure. At first the rubber stretches. As the temperature gets even higher, the rubber cannot withstand the greater pressure. Eventually, it cannot stretch any further and the balloon bursts.

Cooling down
Imagine a plastic bottle of air in a freezer. The air cools down and its particles lose energy. The particles move more slowly. They collide with the plastic less often. The pressure in the bottle decreases. The particles outside exert a higher pressure than the particles inside. The bottle collapses.

Now imagine taking the bottle out of the freezer. The air inside the bottle warms up. Soon, the air particles inside and outside the bottle exert the same pressure. The bottle returns to its normal shape.

C Explain why a bottle collapses in the freezer.

Summary Questions
1 Copy the true sentences below. Write corrected versions of the false sentences.
Gas particles collide with the walls of their container.
Colliding gas particles exert pressure on the inside of the container.
The more particles in a container, the lower the pressure.
The higher the temperature, the lower the pressure.
(4 marks)

2 Jack was camping. He put a can of baked beans on his campfire, without opening the lid. The can exploded. Use ideas about particles to explain why.
(3 marks)

3 Plan a talk that you could give to another class to explain what happens to an inflated balloon when you put it in a warm room and when you put it in a fridge.
(6 marks)

A The more particles you blow into a balloon, the bigger the balloon.

In the fridge, the air pressure inside the bottle decreases.

Fantastic Fact!
Racing-car tyres reach 100°C. Before a race, technicians pump tyres to a lower pressure than they need in the race. The air pressure in the tyre increases as it heats up.

A The air pressure in racing-car tyres increases during a race.

A The air pressure in racing-car tyres.

Key Words
collide, gas pressure

Particle performance
Read the Fantastic Fact before you do this task.
Racing-car tyres are pumped full of air. Write a script for particles in a racing-car tyre. What do they say as the car goes faster and the air gets hotter? Then perform your script.

New style to come at next proof
C1 Chapter 1 Summary

Key Points

- Materials are made up of tiny particles.
- A substance is a material that has the same properties all the way through.
- The properties of a substance describe what it looks like and how it behaves.
- The properties of a substance depend on what its particles are like, and how they are arranged.
- There are three states of matter—solid, liquid, and gas. For a certain substance, the particles never change. But in different states, the particles move differently, and have different arrangements.
- In the solid state, you cannot compress a substance, or make it flow.
- In the liquid state, you cannot compress a substance, but you can make it flow.
- In the gas state, you can compress a substance, and make it flow.
- The change of state from solid to liquid is melting. A substance melts at its melting point. Pure substances have sharp melting points.
- A substance changes from the liquid to the gas state by evaporating or boiling. A substance boils at its boiling point.
- A substance changes from the solid state to the gas state. This is sublimation.
- Diffusion is the random moving and mixing of particles. Gas particles collide with the walls of their container. The collisions cause gas pressure.

End-of-chapter questions

1. The diagram shows some particles in solid gold. Draw another diagram to show particles of gold in the gas state. (2 marks)

2. Describe the arrangement and movement of particles in the liquid state. (2 marks)

3. The table shows the melting points and boiling points of six substances.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Melting point (°C)</th>
<th>Boiling point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bromine</td>
<td>−7</td>
<td>59</td>
</tr>
<tr>
<td>krypton</td>
<td>−157</td>
<td>−152</td>
</tr>
<tr>
<td>mercury</td>
<td>−39</td>
<td>357</td>
</tr>
<tr>
<td>neon</td>
<td>−249</td>
<td>−246</td>
</tr>
<tr>
<td>platinum</td>
<td>1769</td>
<td>4530</td>
</tr>
<tr>
<td>silver</td>
<td>961</td>
<td>2210</td>
</tr>
</tbody>
</table>

4. Read the statements about particles in a substance in the solid state.
   A. The particles touch other particles.
   B. The particles are in a pattern.
   C. The particles do not move around from place to place.
   D. The particles vibrate.
   a. Write down the letter of the statement that best explains why you cannot pour a solid. (1 mark)
   b. Choose one of the other statements and explain why it does not explain why you cannot pour a solid. (1 mark)

5. Olivia says that gas pressure is the result of particles colliding with each other. Is Olivia correct? Explain your answer. (2 marks)

6. Write a few paragraphs to compare the processes of boiling and evaporating. (6 marks QWC)

Maths Challenge

Up in the air

The air is a mixture of substances. The table shows the percentages of the substances in the air.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Percentage of substance in dry air</th>
</tr>
</thead>
<tbody>
<tr>
<td>nitrogen</td>
<td>78.08</td>
</tr>
<tr>
<td>oxygen</td>
<td>20.95</td>
</tr>
<tr>
<td>argon</td>
<td>0.93</td>
</tr>
<tr>
<td>others, including carbon dioxide</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Task

Draw a bar chart, a scatter graph, and a pie chart to represent the data in the table. Decide which type of chart is best, and explain why.

Key Words

material, particle, mixture, substance, property, solid, liquid, gas, states of matter, melting, change of state, freezing, melting point, boiling, boiling point, conserve, evaporation, condensation, sublimation, diffusion, collide, gas pressure