CHEMISTRY

Explaining Physical Changes

Ideas you have met before

States of matter

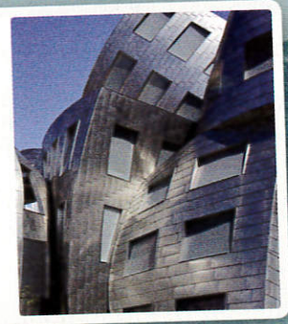
Solid, liquid and gas are the three main states of matter and most materials can be grouped into one of these.

When materials are heated or cooled, they may change from one state to another. Water freezes to become ice at 0 °C, and boils to becomes a gas at 100 °C.

In the water cycle, water evaporates to become a gas, condenses in clouds and forms water droplets. It falls back to Earth as precipitation.

Properties of materials

The properties of different materials affect their use. Some solids like metals and slate are very hard; paper and fabric are not. Some materials, like salt and sugar, dissolve in water; flour and talc do not. Only a few metals, such as iron and steel, are magnetic; most other metals are not. All metals conduct electricity and heat; non-metals do not. Some solids, such as glass, are transparent.



Reversible changes

Physical changes, such as changes of state, are reversible. Water can be frozen to make ice; this can melt to form liquid water.

Dissolving and mixing are also reversible changes – salt can be added to water, which can be evaporated to recover the solid salt.

In this chapter you will find out

3.1

Using the particle model to explain the states of matter

- The particle model explains why solids have a fixed shape and cannot flow, and why liquids and gases do not have a fixed shape, and can flow.
- Particles in solids, liquids and gases have their own internal energy – the energy of particles in a gas is far higher than the energy of particles in liquids and solids.
- The effect of temperature can be explained using the particle model. It can explain how changes of state take place and how solids, liquids and gases expand on heating.

Using the particle model to explain properties

- Brownian motion was the first description of how liquid particles move. From this observation, the theory of how particles behave was developed.
- Properties of materials can be explained in terms of the strength of the forces between the particles.
- Foams, gels and emulsions are different types of mixtures, involving different states of matter. They have special properties that can be explained using the particle model.
- We can explain differences in density, concentration and pressure using the particle model. These differences can account for why perfume spreads in a room and why astronauts need to wear space suits in space.

Particles in physical and chemical changes

- The particle model can be used to show how mass is conserved in physical and chemical changes. Using particles, we can explain why physical changes are reversible and why it is very difficult to reverse chemical changes.

Using particles to explain matter

We are learning how to:

- Recognise differences between solids, liquids and gases.
- Describe solids, liquids and gases in terms of the particle model.

Have you ever wondered why it is possible to put your hand through a liquid such as water, or a gas, such as air, but not through a solid wooden door? The answer lies in how the particles are arranged in these states of matter.

Particle arrangement

Anything that takes up space and mass is called 'matter'. All matter is made from **particles**. Particles vary in the ways they are arranged and behave. These are known as different states of matter. Figure 2.3.2a shows how particles are arranged in the three most common states of matter – solids, liquids and gases.

1. Name three solids, three liquids and three gases you are familiar with.
2. Describe how the arrangements of particles in solids, liquids and gases differ from each other.

Particles and internal energy

All particles above the temperature known as absolute zero (–273 °C) have internal **energy**. Particles in solids, liquids and gases have different amounts of energy.

- In solids, the particles vibrate in their fixed positions.
- Particles in liquids can move slowly from their positions, but are always in contact with other particles.
- Particles in a gas move about very fast, colliding with other particles.

Temperature affects how fast particles move. At higher temperatures, particles in a solid vibrate faster, while in liquids and gases particles move around faster.

3. Draw a cartoon to describe how the energies of the particles in solids, liquids and gases vary.
4. In which of the following do the particles have the most internal energy – ice, oxygen at room temperature or steam (over 100 °C)?

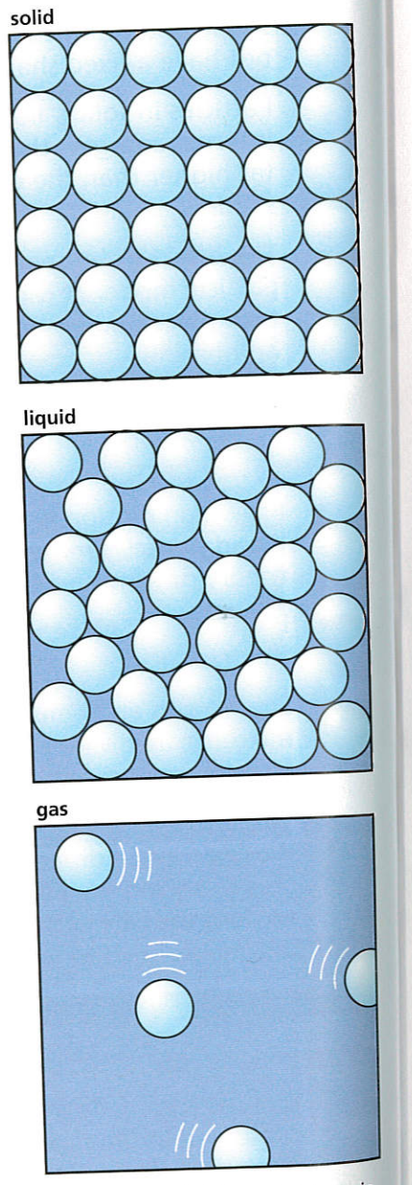


FIGURE 2.3.2a: Solid – particles are in fixed, regular positions.

Liquid – particles are close together and touching. They can move from their position.

Gas – particles have no fixed position and are far away from each other. They can move very fast.

Intermolecular forces

3.2

The particles in a solid have very strong, attractive **intermolecular forces** between them, which hold the particles in their positions. Between particles in liquids, the intermolecular forces are still strong, but not as strong as in a solid. This is why the particles are able to move about. The intermolecular forces between the particles of a gas are very weak.

FIGURE 2.3.2b: Which particles here have the strongest intermolecular forces?

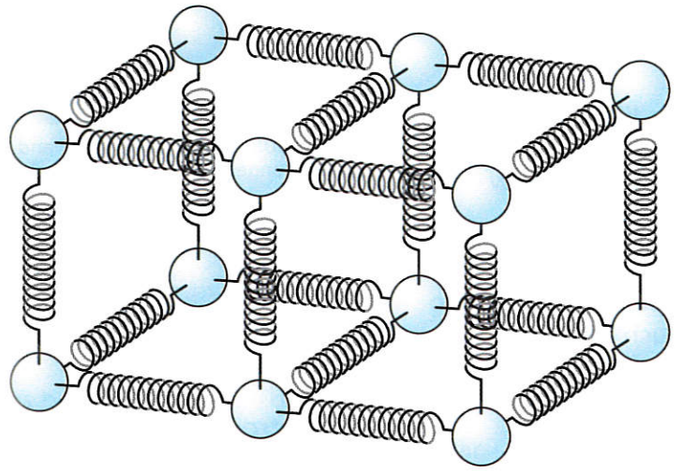


FIGURE 2.3.2c: Forces between particles can be represented by springs. How would you modify this particle model to show a solid with strong intermolecular forces and one with weak intermolecular forces?

Some solids, like metals, have very strong intermolecular forces between the particles – others, like paper, are not nearly as strong.

5. Use ideas about intermolecular forces to explain why you can put your hand through air but not through wood.
6. What can you say about the intermolecular forces between the particles of jelly compared with those of a metal?
7. Describe the relationship between the energy of the particles and the intermolecular forces holding them together.
8. What do you think is in between the particles of a gas?

Did you know...?

The most common state of matter in the Universe is called 'plasma'. It is known as the fourth state of matter, and is a form of gas.The Sun and space are made of plasma. We can make tools from plasma to cut strong metals.

Key vocabulary

particles

energy

intermolecular forces

Understanding solids

We are learning how to:

- Describe the properties of solids.
- Relate the properties and behaviour of solids to the particle model.

Some properties are common to all solids and help to define them. Differences between solids can be explained using the particle model.

General properties of solids

Except for mercury, all metals are solid at room temperature. They have high melting and boiling points, and all conduct heat and electricity well. A few non-metallic solids share these properties, but many others have very different properties.

Flow

Some solids appear as if they can flow, like sand. Seen under a microscope, such a solid is made up of many individual grains. None of the individual solid grains can flow – they do, however, flow over each other.

Changing shape

Some solids are **malleable** – they can be hammered into shape without being broken. Solids such as plastic are brittle – they will snap if hit. Metals are ductile – the layers of atoms are able to slide past each other, so they can be pulled into extremely thin wires.

Strength

Strength is the ability of a solid to withstand a force. Metals are generally very strong, but waxy solids are easily squashed.

Hardness

Hardness is a measure of how easy it is to scratch a solid – it is not the same as strength. Slate and concrete are very strong solids, but are easily scratched so they are not as hard.

Solubility

Some solids, salt for example, dissolve readily in water – they are **soluble**. Others, such as sand, do not dissolve and some, such as sodium, react chemically with water.

Conduction of heat and electricity

Metals will readily **conduct** heat and electricity, whereas non-metal solids, like plastic and rubber, will not. The only exception is graphite, which conducts electricity even faster than metals.

FIGURE 2.3.3a: The hardest and strongest material in the world

Did you know...?

Diamond has the strongest intermolecular forces of all solids. This makes it the strongest,hardest material in the world. Drills that cut through rock are tipped with diamonds.

TABLE 2.3.3: Put these solids in order of hardness.

Substance	Hardness
aluminium	3
carbon (diamond)	10
iron	4
silver	2.5
tin	1.5
copper	3

1. Which property is responsible for making copper wires?

2. Use the data in Table 2.3.3 to explain which material you would use on the end of drill.

3.3

What are alloys?

Alloys, such as brass, bronze and chrome, are mixtures of metals. They are often stronger than the individual metals they are made from. Different shapes and colours can be used to represent the different types of atoms in the particle model.

3. Duralumin is an alloy made from 96 per cent aluminium (very light) and 4 per cent copper (heavy). What might the particle model look like?

4. Use the particle model to explain why some alloys are less ductile than the metals they are made from.

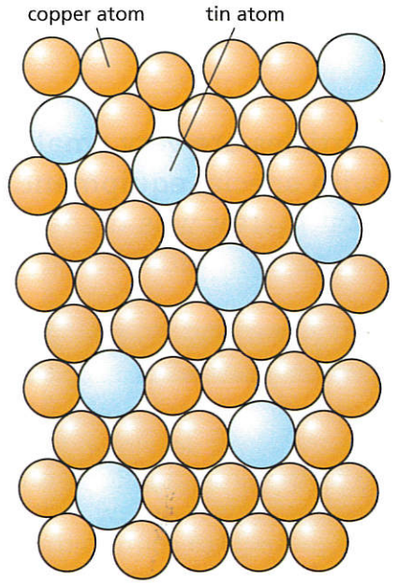


FIGURE 2.3.3b: Bronze is made up of 85 per cent copper and 15 per cent tin.

Explaining properties

Strength, shape and hardness all depend on the strength of the intermolecular forces between the particles in a solid.

Solubility also depends on intermolecular forces. In solids which dissolve, forces between the particles of the solid are weaker than the forces between the particles of the solid and the particles of the liquid. In insoluble solids, the forces between the particles of the solid are too strong to be overcome.

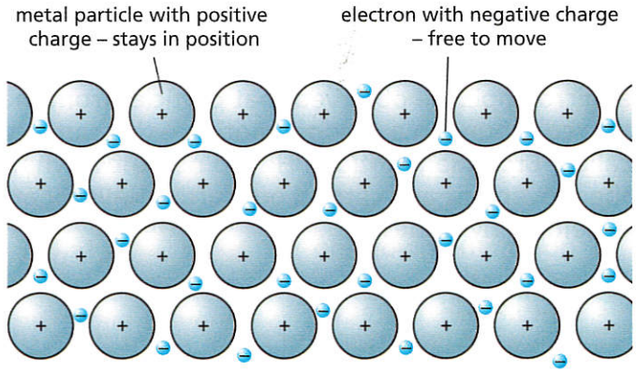


FIGURE 2.3.3c: Metals can conduct heat and electricity because they have negative particles that move freely.

The arrangement of particles in metals is special, accounting for their ability to conduct heat and electricity. This is shown in Figure 2.3.3c.

5. How would you modify the particle model to show a solid with strong intermolecular forces and one with weak intermolecular forces?

6. Explain as many differences in the properties of copper and wax as you can using appropriate particle models.

Key vocabulary

malleable
strength
hardness
soluble
conduct
alloy

Exploring Brownian motion

We are learning how to:

- Describe how theories develop.
- Describe and explain Brownian motion in terms of particles.

Particles are very small and cannot be seen except with special equipment. How did we first discover that matter was made from particles that can move in liquids?

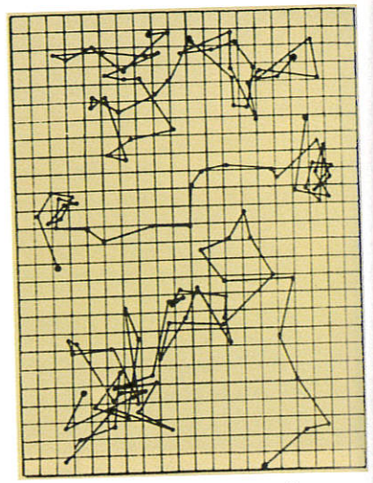


FIGURE 2.3.4a: Brownian motion

Making observations

Scientific theories are developed as a result of making observations, developing a **hypothesis** and testing this in further investigations. An important part of this process is 'peer review' – other scientists perform similar experiments to confirm the initial observations, or debate the findings of investigations based on their own research. The idea that particles move was developed in this way, but over many years.

In 1785 Jan Ingenhauz first noticed a random movement of charcoal dust in alcohol. In 1827, the Scottish botanist Robert Brown was studying pollen grains in water under a microscope. He observed that particles from the grains moved around in a random motion – this came to be called '**Brownian motion**'. He did not know what caused the movement and carried out further investigations to develop a hypothesis.

1. What is a hypothesis?
2. Why is it important for other scientists to confirm experimental observations?

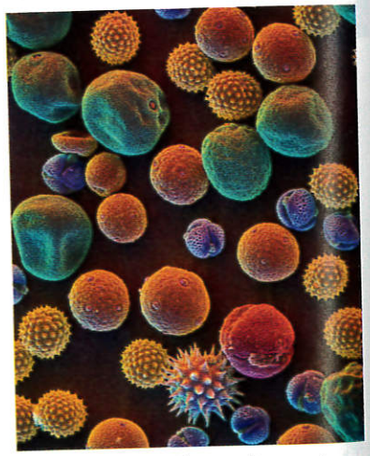


FIGURE 2.3.4b: Pollen grains can be seen to perform Brownian motion.

Developing hypotheses

Brown tested other pollen grains and found that smaller, more spherical grains had even more vigorous motion. He suspected that Brownian motion could have been produced because the pollen grains were living.

He then tested pollen from dead plants and found the same result. He wondered if there was some mysterious 'life force' at this miscroscopic level. He tested fossilised wood and dust from a stone that had been part of the Sphinx, an ancient Egyptian statue. Any material, dead or alive, produced this same random motion under the microscope. He could not explain this motion with the ideas established during his time.

3. Identify one hypothesis Robert Brown that had developed concerning his obeservations.
4. How did he test this hypothesis?

Using models and analogies to connect ideas

Fifty years later, scientists were developing the **kinetic theory**, which included the idea that matter was made of particles. The theory attempted to explain the properties and motion of particles in solids, liquids and gases. Scientists deduced that the Brownian motion shown by pollen in water was caused by the particles of the liquid colliding with the pollen grains – however, this conflicted with some existing ideas.

The kinetic theory was important to all chemists and physicists of the late 1800s. Albert Einstein was determined to resolve the problems. If Brownian motion could not be explained, the kinetic theory was in trouble.

Because individual particles could not be seen, the only **evidence** of them was from observations of their behaviour. Mathematical calculations were made from this and predictions developed.

In 1905,Einstein wrote an article in which he developed an analogy, comparing Brownian motion with osmosis. He found that the mathematical predictions between Brownian motion and his analogy were identical, proving that Brownian motion was due to the movement of the liquid particles colliding with the pollen grains. Amendments were made to the kinetic theory to fit this new evidence.

5. Why is it important for observations to fit in with an existing theory?
6. Why is it important to use models and analogies in developing theories?
7. Do you think a theory should be established by the evidence that supports it, or by the evidence that refutes it? Explain your answer.

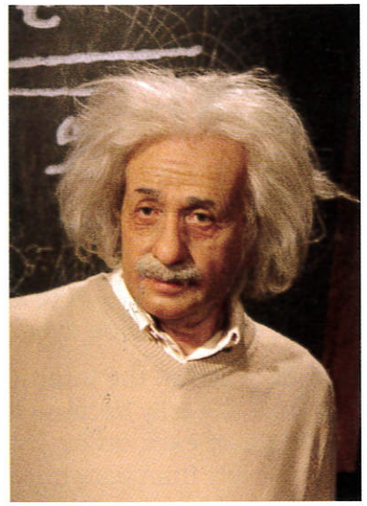


FIGURE 2.3.4c: Albert Einstein: a brilliant scientist and mathematician

Did you know...?

Einstein's 1905 article on Brownian motion is his most cited work by researchers. It has been instrumental in use by scientists working on aerosols and in investigating the properties of milk and paint.

Key vocabulary

hypothesis
Brownian motion
kinetic theory
evidence

Understanding liquids and gases

We are learning how to:

- Compare different properties of liquids and gases.
- Relate the properties and behaviour of liquids and gases to the particle model.

Oxygen cylinders, fish tanks, oil pipes and bicycle pumps all rely on important properties of liquids and gases.

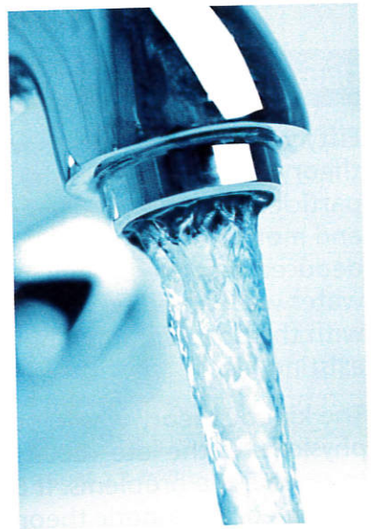


FIGURE 2.3.5a: Which material has particles with the stronger intermolecular forces?

Viscosity

Liquids and gases can be poured and can flow. This ability to flow is known as **viscosity**. Some liquids flow more easily than others. This is because the intermolecular forces holding the particles of a liquid in place are quite strong, but not strong enough to keep the particles in position. They are able to slide over and roll around each other.

Liquids in which the intermolecular forces are stronger do not flow as easily because it is more difficult for the particles to slide past each other. Think of oil and water – oil flows more slowly than water; it is more viscous.

1. Give three applications of liquids and gases that rely on their ability to flow.
2. You want to oil your bike. You decide to investigate three different brands to find out which spreads most easily in the cold.
   a) Which variables must you control?
   b) What values should you select for these control variables for this investigation?

Volume and compression

'Volume' is defined as the amount of space that matter takes up. A liquid will take up the same space, no matter which container it is placed in. There is no space between the particles in a liquid, so it cannot be **compressed**.

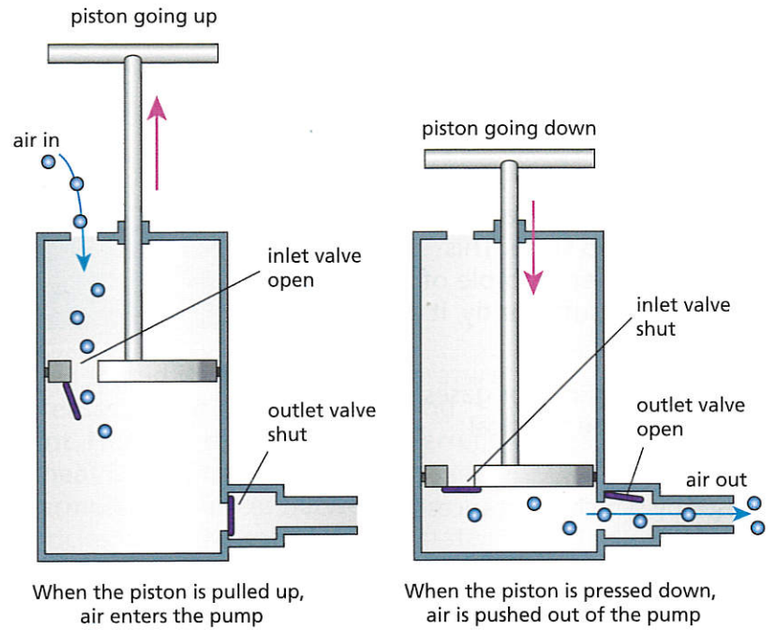
In a gas, the particles continue to move in a straight line, until they collide with the sides of the container or with other gas particles. This enables them to fill the space they occupy.

There is literally *nothing* in between the gas particles. They can, therefore, be easily pushed closer together, or compressed. When they are compressed a lot, the particles are forced very close together. If the gas is cool, the intermolecular forces become strong enough to change the gas into a liquid.

Did you know...?

In the longest experiment ever, scientists left tar pitch to drop from a funnel. After 70 years, one drop of tar pitch, finally, fell!

3. What is the advantage of compressing gases into liquids to fill containers?
4. Figure 2.3.5c shows a bicycle pump in operation. Use ideas about particles to explain what happens when the piston is lifted up and pushed down.



When the piston is pulled up, air enters the pump

When the piston is pressed down, air is pushed out of the pump

FIGURE 2.3.5c Which properties of a gas enable this device to work?

Effect of temperature on solubility

Figure 2.3.5d shows the effect of temperature on the **solubility** of different gases in water. When the intermolecular forces between particles of the gas and the water particles are stronger than those between the gas particles, then the gas will dissolve in the water. It is the same for liquids dissolving in water – a liquid will dissolve in water if the intermolecular forces between the liquid and the water particles are stronger than the intermolecular forces between the particles of the liquid.

5. Explain the differences between the graphs.
6. Develop a hypothesis for why temperature affects the solubility of gases in this way.
7. Use the graph to explain why environmental scientists monitor the temperature of rivers near factories.

3.5

FIGURE 2.3.5b: The cylinders contain gas which has been liquefied. When released, the change in pressure causes the liquid particles to become gas particles again.

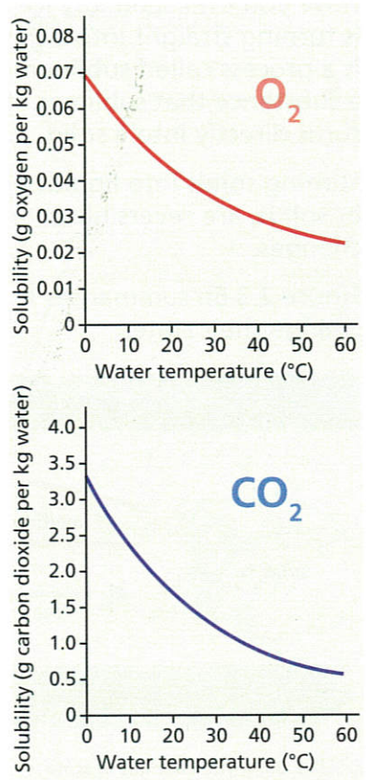


FIGURE 2.3.5d: The effect of temperature on the solubility of oxygen and carbon dioxide

Key vocabulary

viscosity

compressed

solubility

Changing state

We are learning how to:

- Recognise changes of state as being reversible changes.
- Use scientific terminology to describe changes of state.
- Explain changes of state using the particle model and ideas about energy transfer.

When you make ice or melt the frost from a windscreen, you are making use of changes of state. What is actually happening to the particles in these processes?

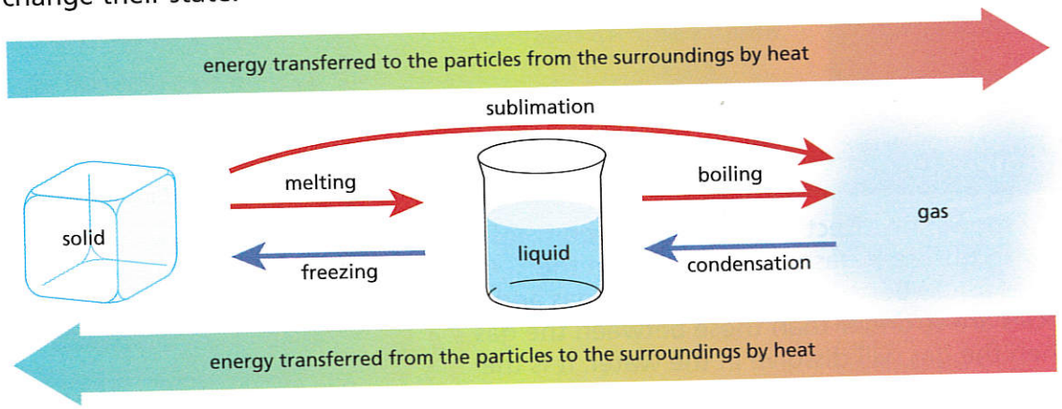
FIGURE 2.3.6a: Solid carbon dioxide is known as 'dry ice'.

Reversible changes

Have you ever seen 'dry ice'? It is solid carbon dioxide that is turning straight into a gas – there is no liquid state. This is a process called **sublimation**. Iodine is another example of a substance that sublimes. If the gas is cooled sufficiently, it turns directly into a solid.

Turning solids into liquids or gases, and liquids into or gases or solids, are reversible changes. They are called physical changes.

Figure 2.3.6b summarises the processes by which substances change their state.



FIGUE 2.3.6b: The changes of state

1. Describe how you could show that making water freeze is a reversible change.
2. Use Figure 2.3.6b to describe the meaning of the following words:
   a) melting **b)** condensing **c)** boiling
   d) freezing **e)** sublimation.

Changing state

3.6

The temperature at which a pure substance melts or freezes is fixed – it is called the **melting point** or freezing point, depending on the change taking place.

When a pure substance boils or condenses, this also occurs at a fixed temperature called its **boiling point**.

Different substances have different melting points and boiling points. These points depend on the strength of their intermolecular forces.

3. Aluminium melts at 660 °C but copper melts at a 1064 °C. Explain why.
4. At 0 °C, hydrogen is a gas, mercury is a liquid and water is a solid. What can you infer from this data? Explain your answer.

Did you know...?

Helium has the lowest melting point of all substances at –272 °C, whereas diamond has the highest melting point of 3500 °C.

Latent heat

When a solid is heated, its temperature increases until it reaches its melting point. Here, all the energy transferred by heat is used to overcome the strong intermolecular forces between the particles, until the solid changes state. There is no increase in temperature until all the solid has changed state, even though energy is still being transferred by heat. This 'extra heat' is known as the **latent heat**.

This concept also applies to a liquid. Latent heat energy is used to overcome the intermolecular forces between the particles of the liquid, changing it into a gas. The temperature remains constant until all the liquid turns into a gas.

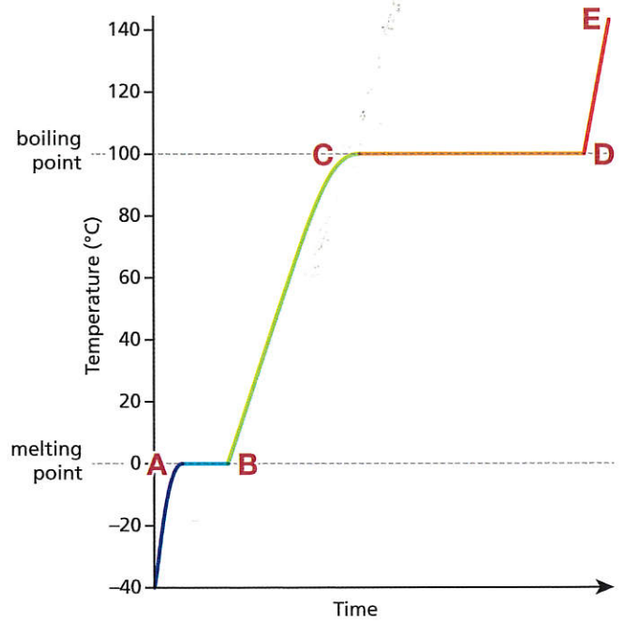


FIGURE 2.3.6c: How the temperature of ice changes with time

5. Look at the graph of heating ice (water). Identify what state the water is in:
   a) between A and B **c)** between B and C
   d) between C and D **e)** between D and E.
6. Why is there no temperature increase between C and D?
7. Do you think the latent heat energy will be the same for all substances? Explain your answer with two examples.

Key vocabulary

sublimation
melting point
boiling point
latent heat

Understanding evaporation

We are learning how to:

- Investigate factors affecting evaporation.
- Explain the differences between boiling and evaporation using the particle model.

Have you ever thought about what happens to the water particles when a puddle is left in the sunshine, or to the water produced when you sweat? The answer is the water has evaporated. What does this actually mean and how is it different from boiling?

Examples of evaporation

If you spill some water on a surface and leave it in the sunshine, after a few hours the water particles will no longer be present and there is no sign of the spill. The water has evaporated. The water particles have gained sufficient energy from their surroundings to become a gas.

When clothes are hung out to dry, the air particles in the wind transfer energy by movement (kinetic energy) to the water particles in the clothes. These gain enough energy to change from a liquid into a vapour.

Smells from perfumes are also an example of **evaporation**. The perfume particles gain enough energy by heat from the body, or by kinetic energy from air particles, to become a vapour.

1. Describe one other example of evaporation.
2. When we sweat, water evaporates from the surface of our skin. Where does the energy needed for evaporation to take place come from?

Differences between boiling and evaporation

Evaporation occurs at any temperature between the melting point of a liquid and its boiling point. It occurs only at the surface of the liquid. Some of the surface particles gain enough energy from the surroundings from heat, or from kinetic energy, to leave the surrounding particles in the liquid and become a vapour. Over time, all the particles at the surface will evaporate.

Boiling, however, occurs only at the boiling point, and the whole liquid changes into a gas. The water particles gain sufficient energy from their surroundings to leave the liquid.

FIGURE 2.3.7a: How is evaporation different from boiling?

3. Is evaporation more likely to take place at temperatures near the boiling point or near the melting point? Explain your answer.
4. What are the main differences between boiling and evaporation?

Factors affecting evaporation

Four factors that affect evaporation are:

Wind speed: in faster winds, air particles have more kinetic energy. More energy can therefore be transferred to the evaporating particles of the liquid.

Temperature: at higher temperatures, more energy can be transferred to the particles of the liquid by heat.

Surface area: evaporation occurs at the surface of a liquid. With a larger **surface area**, more energy can be transferred to the particles in the liquid from the surroundings.

FIGURE 2.3.7b: Salt being made in La Palma, one of the Canary Islands.

Strength of the intermolecular forces: some liquids, such as alcohol, have weaker intermolecular forces than others, such as water. Therefore, with the same amount of energy transferred from the surroundings, more alcohol particles than water particles will escape as a gas.

5. Look at the photo of salt production in Figure 2.3.7b. Explain the factors that affect the rate of evaporation in this process.
6. Which of the factors above are likely to have the biggest effect on the rate of evaporation? Explain your answer.

Did you know...?

Evaporation from oceans accounts for 80 per cent of water delivered as precipitation (rain, snow).

Key vocabulary

evaporation

boiling

surface area

Exploring thermal expansion

We are learning how to:

- Identify how heat affects the arrangement and movement of particles.
- Use the particle model to explain the effects of heat on expansion.

Heat has a significant effect on the particles in solids, liquids and gases. It causes materials to expand. Should the temperature of the seas and oceans increase by only 0.5 °C, the worldwide sea level would rise by 30 cm!

Examples of expansion

Heat causes solids, liquids and gases to expand. This means that they take up more room when they are hot than when they are cold.

The photos in Figure 2.3.8a show a brass ball before and after heating it. After heating, it will no longer fit through the ring. This is because the metal has expanded.

Think of a mercury thermometer. The liquid level rises when the temperature increases because the mercury particles move around more and become further apart. This causes the silvery liquid to take up more space overall, meaning that the level of the liquid rises.

Gases expand more than solids and liquids. If a balloon is placed over a bottle full of air (Figure 2.3.8b) and the air is warmed, the air particles will soon begin to fill the balloon as the air expands.

Expansion of gases is also made use of in steam engines, car engines and rockets.

before heating the ball

after heating the ball

FIGURE 2.3.8a: What do these photos tell you about the particles in the metal when it is heated?

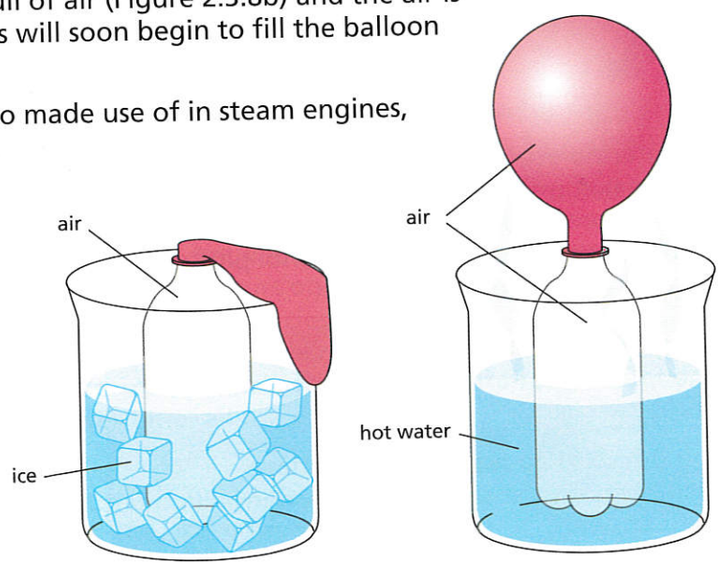


FIGURE 2.3.8b: If the air in the bottle was replaced with water, would the effect be the same?

1. Why might heating the lid of a jam jar make the jar easier to open?
2. Explain why an inflated party balloon might pop if placed over a heater.

Expansion in different materials

Different solids and liquids vary in how much they expand for a given increase in temperature. Also, the more particles there are in a material, the bigger the expansion will be.

All gases expand by the same extent depending only on the temperature rise, not on the type of gas.

TABLE 2.3.8: Expansion of different solids

Material	lead	steel	aluminium	copper	glass
Expansion of 100 cm bar at 100 °C (cm)	0.29	0.11	0.23	0.17	0.09

3. Use the data from Table 2.3.8 to write the materials in order of which expands most to which expands least.
4. Copper is often used in making hot water pipes. What precautions should be taken when using this metal for this purpose?

Explaining the effect of heat

The particles in a solid are always vibrating. Transferring more energy by heat increases the frequency and amplitude of the vibration. As the particles vibrate more, each takes up more room. The amount of space increased by individual particles is very small, but over billions and billions of particles the overall expansion becomes measurable and significant.

The same is true for liquids. Because they have more kinetic energy than solids to start with, **thermal expansion** in liquids is significantly greater than in solids.

All gases expand to the same extent. This is because the intermolecular forces between the gas particles are very weak and do not play any significant role in the extent of expansion. Temperature is the only factor affecting the expansion of gases.

5. Why is a thermometer filled with a liquid and not a solid or gas?
6. Explain how global warming might increase flooding caused by the sea.

Did you know...?

The Eiffel Tower in Paris can grow in height by as much as 15 cm in very hot summer weather.

FIGURE 2.3.8c: The Eiffel Tower expands in the heat and contracts in the cold.

Key vocabulary

thermal expansion

Making sense of models

We are learning how to:

- Describe the concept of a 'good enough' model.
- Link the particle model to elements and compounds.
- Evaluate the strengths and weaknesses of the particle model.

A model is a way of representing something that cannot be seen. Particles are too small to be seen – so the particle model is a useful tool, allowing us to understand the properties and observations of solids, liquids and gases. However, it does not provide us with the full picture.

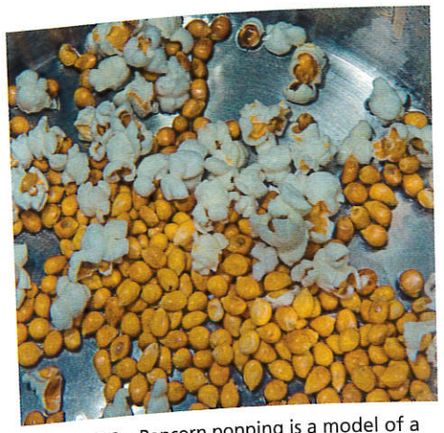


FIGURE 2.3.9a: Popcorn popping is a model of a change of state.

A good enough model

You already know about **atoms**, **elements** and **compounds**. All matter is made from atoms.

More advanced models are used to represent elements and compounds, compared with the model used to represent solids, liquids and gases. This is because the simplified **particle model** is 'good enough' for the purposes of explaining states of matter and changes of state.

1. List all the properties of solids, liquids and gases that the standard particle model can explain, making it a 'good enough' model.
2. Popcorn (Figure 2.3.9a) can be used as a model for explaining states of matter and changing states. How is this a 'good enough' model? Can you identify any problems with it?

Developing models further

Each element is made of only one type of atom. Compounds are made of two or more elements chemically bonded together.

Figure 2.3.9b shows the structures of two different solid compounds – aluminium oxide (Al_2O_3) and magnesium oxide (MgO). These adapted models can now explain more than just the state of matter a material is in. As you can see from the diagrams, both are solids but the atoms are organised in different ways.

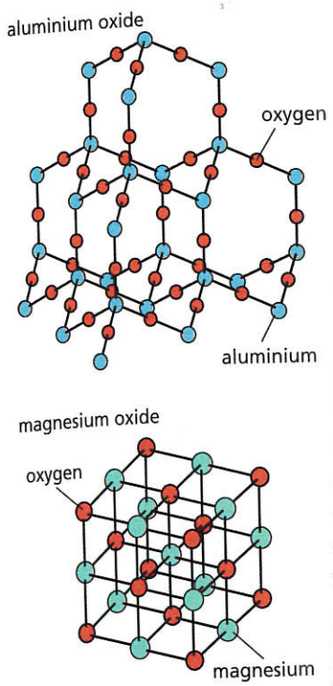


FIGURE 2.3.9b: What differences can be picked out between these two solids?

Look at the model of carbon dioxide gas and helium gas in Figure 2.3.9c. By adapting the model to show the relative sizes of the atoms, you can see why carbon dioxide is much heavier than helium.

3. Draw a model to show liquid water (H_2O) and liquid hydrochloric acid (HCl).
4. What does this model show that the standard particle model cannot?

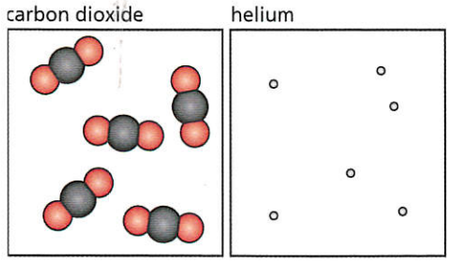


FIGURE 2.3.9c: Compare the molecules of carbon dioxide with helium gas. What does this model reveal that the model in Topic 3.2 does not?

Evaluating models

Figure 2.3.9d shows diagrams of water in the solid, liquid and gaseous states.

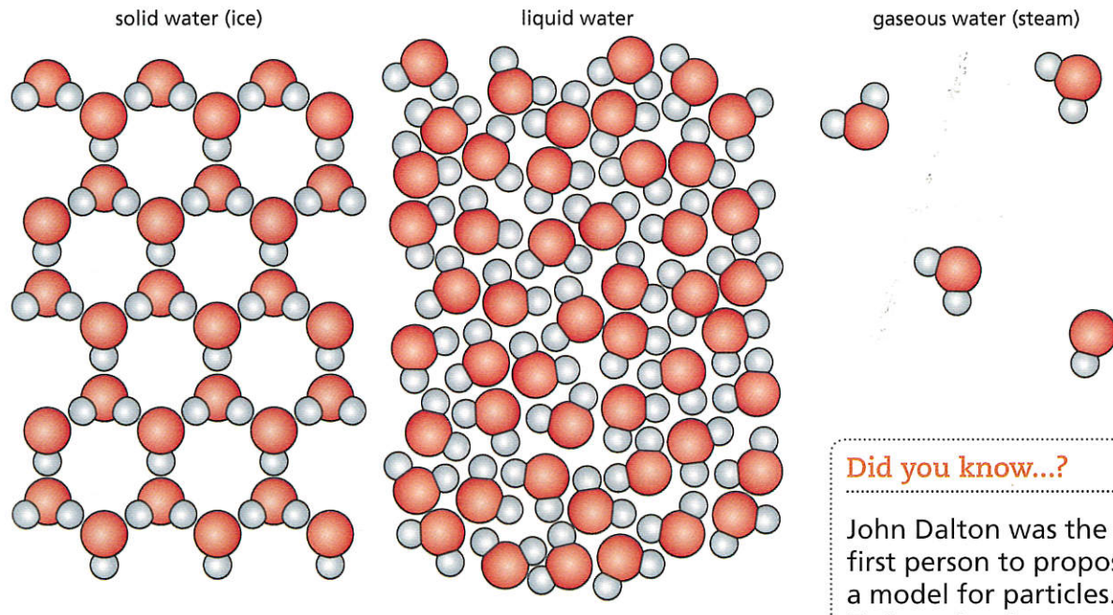


FIGURE 2.3.9d: The molecular structure of water in three states

The model shown here and the model in Topic 3.2 may be used to explain particular observations. You can compare how well they do this by evaluating the models. You need to be clear, when using models, about what they can explain and what their limitations are.

5. Which model can explain why steam diffuses faster than liquid water?
6. Which model is unable to explain the observed phenomenon that the same number of ice particles takes up *more* space than the same number of liquid water particles? Explain your answer.

Did you know...?

John Dalton was the first person to propose a model for particles. Today, scientists are still adapting and changing their ideas about particles as they learn more.

Key vocabulary

atom

element

compound

particle model

Applying key ideas

You have now met a number of important ideas in this chapter. This activity gives an opportunity for you to apply them, just as scientists do. Read the text first, then have a go at the tasks. The first few are fairly easy – then they get a bit more challenging.

Explaining heat packs

Self-heating packs have been around since about 1912. Electricity was used in early versions to transfer heat and help with pain relief. Since then, different chemical versions have been invented. An iron and charcoal pack relies on the heat produced from the reaction between iron and air. Unfortunately once used this has to be discarded because the iron is changed into iron oxide.

Calcium chloride produces heat when it is dissolved in water. Two separate compartments have to be built into self-heating coffee cups, and these must be completely sealed off from the drink to avoid contamination. Again, once used this cannot be used again.

Using changes of state to release heat has several advantages – the most important being that packs can be used over and over again.

Sodium acetate hot packs

Figure 2.3.10a shows a chemical called sodium acetate. It is dissolved in water until no further amount can be dissolved, forming a saturated solution. If the saturated solution is heated, the water expands creating more gaps into which more sodium acetate particles can be dissolved. This is known as a supersaturated solution.

FIGURE 2.3.10a: Sodium acetate can be used to warm your hands.

The supersaturated solution needs particles to trigger a change, converting from a liquid to a solid. This is done is by clicking a metal disc, which releases tiny particles of metal into the solution, on which new crystals can form. The sodium actetate solution changes visibly throughout, converting it from a liquid to a solid. Figure 2.3.10b shows this happening. It is a different process from freezing, but has the same effect.

FIGURE 2.3.10b: Changing from liquid to solid

Particles in a liquid have more energy than particles in a solid. When they change state, energy from the heat pack is transferred to the surroundings by heat, over an hour or so. This is a useful energy transfer enabling you to warm your hands. Once the heat pack has completely solidified, there is no more transfer of energy by heat. The sodium acetate must be re-dissolved to become a liquid again by heating it up. None of the sodium acetate has been lost or changed in any way. It can be used again and again.

Task 1: Solids and liquids

Compare the particles of the sodium acetate hand warmer when it is a solid and when it is a liquid. Use ideas about energy to help you.

Task 2: Drawing particle diagrams

Draw particle diagrams to show particles of sodium acetate changing from a liquid to a solid.

Task 3: Explaining changes of state

a) Use ideas about changing state to explain how the hand warmer is able to warm your hands.

b) Why does it need to be reheated in order to work again?

Use particle diagrams to support your explanation.

Task 4: Comparing hand warmers

a) Use your own particle diagrams to explain how heat is transferred from an iron–oxygen hand warmer and a calcium chloride hand warmer. Use the information from the text to help you. Include the term 'reversible change' in your explanation, where appropriate.

b) Discuss the advantages and disadvantages of iron–oxygen, calcium chloride and sodium acetate hand warmers.

Explaining the density of solids and liquids

We are learning how to:

- Use the particle model to explain density differences between solids and liquids.
- Use the particle model to explain anomalies between ice and water.

The particle model is very useful for explaining what density is. By understanding how to change density, we make it possible to explore the deepest ocean trenches and to float massive tankers on our seas.

What is density?

Density is defined by:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

The units of density are g/cm^3.

Solids are usually more dense than liquids and gases – there are more particles (and hence more mass) packed in the same volume. However, some liquids are more dense than some solids because of how the particles are arranged in a solid.

1. Use Table 2.3.11 to explain what would happen if you put the following materials together:
   a) paper and syrup **b)** iron and alcohol
   c) brick and honey **d)** baby oil and water
2. Much smaller amounts of sweeteners are needed in soft drinks than sugar. How does this explain why a can of sugar-free drink is less dense than a can of normal drink?

Factors affecting density

Temperature: as a solid or liquid is heated, the particles move about more because they have more kinetic energy, and can move further apart. The volume of the solid or liquid increases. The mass of the particles remains unchanged. The density of a hot liquid will, therefore, be lower than that of a cooler one, enabling it to **float** on top of the colder one.

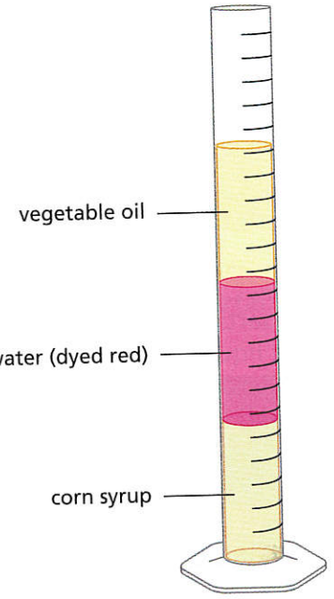


FIGURE 2.3.11a: Which is the most dense and which the least dense substance?

TABLE 2.3.11: The density of a selection of substances

Substance	Solid or liquid	Density (g/cm^3)
brick	solid	1.4
paper	solid	0.7
ice	solid	0.9
iron	solid	7.9
alcohol	liquid	0.79
baby oil	liquid	0.8
water	liquid	1.0
syrup	liquid	1.3
honey	liquid	1.4

Dissolved salts: if some salt is dissolved in water, the volume change is very small. This is because the salt particles fill the spaces between the liquid particles, so the overall volume does not change very much. In this way, more mass is added with little change in volume, so the density increases.

3. When a saucepan of liquid is heated, the hotter liquid at the bottom rises. Use ideas about density to explain why this happens.
4. The Dead Sea has a salt concentration ten times greater than in normal seas. It is possible for people to just lie and float on top of it, without effort – see Figure 2.3.11b. Explain why this is possible.

FIGURE 2.3.11b: Floating in the Dead Sea

Density anomalies: ice and water

Figure 2.3.11c shows the density of water at different temperatures. Ice and water are not typical in the way the density changes with temperature.

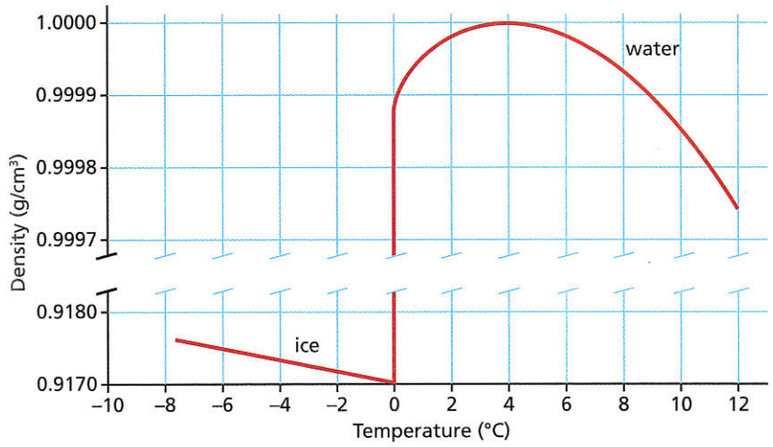


FIGURE 2.3.11c: At what temperature does water have the highest density?

Ice, instead of being more dense than cold water, is in fact less dense. Ice is made of water molecules. The bonds between the atoms of the molecules are very strong. However, *between* the water molecules, there are weak intermolecular forces which account for the spaces in the crystal structure shown in Figure 2.3.9d of Topic 3.9.

5. Look at the graph in Figure 2.3.11c.
   a) At what temperature does water have its maximum density?
   b) At what temperature does ice have its minimum density?
6. How is it possible for fish to survive at the bottom of a frozen lake?

Did you know...?

The world's largest floating iceberg is 295 km long and 37 km wide; it is larger than the island of Jamaica.

Key vocabulary

density
mass
volume
float

Explaining the density of gases

We are learning how to:

- Use the particle model to explain differences in the densities of gases.
- Evaluate a method of measuring density.

Have you ever wondered why helium balloons float or why carbon dioxide gas sinks? The answer lies in understanding the density of gases.

FIGURE 2.3.12a: How are more modern balloons adapted to be safer, so that the flames can burn for longer?

How dense are gases?

As for solids and liquids, the **density** of gases depends on the **mass** of the gas particles and the **volume** they occupy.

Table 2.3.12a shows the densities of different gases. All gases less dense than air will float in it, while gases with a density higher than that of air, like carbon dioxide, will sink in it.

TABLE 2.3.12a: Densities of different gases

Gas	Density (mg/cm³)
hydrogen	0.089
helium	0.18
air	1.28
carbon dioxide	1.977
ammonia	0.73
chlorine	3.2

1. Draw a graph to show how the densities of the gases in the table vary.
2. Which gases will sink in air?

Applications of gases based on density

Gases, just like solids and liquids, become less dense when heated. This principle was used in the development of hot-air ballooning. The air has to remain hot for the balloon to stay afloat. This led to many fires because early balloons were made from paper.

TABLE 2.3.12b: Density of air at different temperatures

Air temperature (°C)	Air density (g/l)
20	1.20
99	0.95
120	0.90

Nowadays air ballons use nylon (melting temperature 250 °C) and air at 120 °C. Most modern balloons use helium instead of air (density 0.18 g/l).

Carbon dioxide gas is nearly twice as dense as air. When it is released, it sinks to the floor, causing any air (and oxygen) to rise up above it. This is a useful property for fighting fires.

3. Why is it preferable to use helium in a balloon rather than hot air?
4. Look at Table 2.3.12a. Chlorine damages the lungs. It was used as a chemical weapon in World War I by firing it into the trenches. Why was this an effective method?

Working out density

We can work out the mass of different elements and compounds using the Periodic Table. We do this by finding the atomic mass of the element, multiplying it by the number of atoms of that element in one unit of the compound, and adding all the masses together.

For example, the atomic mass of N = 14 and the atomic mass of H = 1.

So the mass of one unit (one molecule) of the compound ammonia (NH_3) is (1 × 14) + (3 × 1) = 17 in atomic mass units.

Scientists discovered that if you work out the atomic mass of any gaseous element or compound, and scale it up from atomic mass units to grams, all gases occupy very nearly the same volume of 22.4 litres (at standard temperature and pressure).

So if you had 17 g of ammonia gas, it would have a volume of 22.4 litres. The approximate density can then be calculated as:

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{17}{22.4} = 0.8\,\text{g/l}$$

5. Use the Periodic Table to work out the approximate density of the following gases:
   a) oxygen (O_2) **b)** carbon dioxide (CO_2)
   c) sulfur dioxide (SO_2) **d)** camping gas – butane (C_4H_{10})

Did you know...?

The first human flight in a hot-air balloon took place in 1783 by the Montgolfier brothers in France.

Montgolfiers Luftballon, 1783.

FIGURE 2.3.12b

Key vocabulary

density
mass
volume

Explaining concentration and pressure

We are learning how to:

- Describe what is meant by concentration and pressure.
- Use the particle model to explain differences in concentration and pressure.

What is the difference between a strong drink of cordial and a weak one? Why can't we dive with ease to the bottom of the ocean? Why would our bodies explode if we went into space without a space suit? Ideas about concentration and fluid pressure can help to explain such things.

What is concentration?

Concentration is a term that generally applies to solutions. It is a measure of the number of solute particles in a given volume of solvent. When there are a high number of solute particles, we say the solution is **concentrated**. When the number is low, the solution is said to be **dilute**.

To increase the concentration of a solution, you would need to either add more solute or reduce the volume of solvent.

1. Look at the particle diagrams in Figure 2.3.13a. Rank the diagrams in order of concentration, with the highest first.
2. How would you decrease the concentration of a cordial drink? Explain your answer using a particle diagram.

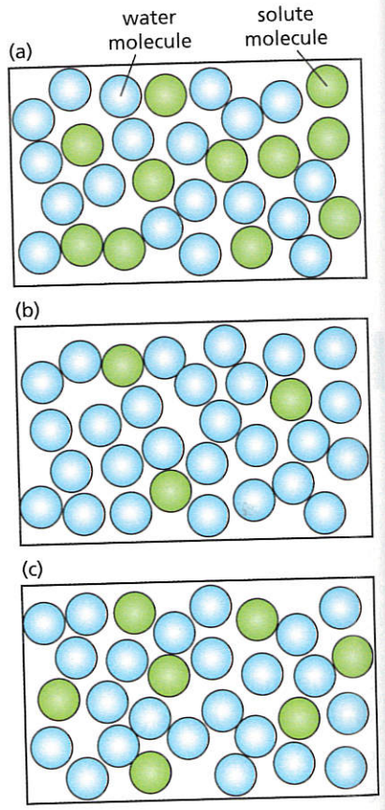


FIGURE 2.3.13a: What are the differences between these particle diagrams?

Working out concentration

We need to work out concentrations so we can determine the strengths of particular solutions for making medicines or chemical solutions. Concentration can be calculated according to how much solute is dissolved in a given volume of solvent. It is a measure of the mass of solute particles in a given volume.

For solids dissolved in liquids:

$$\text{concentration} = \frac{\text{mass of solute}}{\text{volume of solvent}}$$

The units for concentration are g/cm^3.

So if 30 g of salt were added to 100 cm^3 of water, we can calculate the concentration as:

$$\text{concentration} = \frac{30\,g}{100\,cm^3} = 0.3\,g/cm^3$$

Concentration can also be measured by 'volume per cent', which is more suitable for liquids dissolved in other liquids.

$$\text{concentration} = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%$$

The units for concentration in this case are % volume.

So if 20 cm^3 of alkali were dissolved in 200 cm^3 of water:

concentration = 20 ÷ 200 × 100% = 10%

3. Calculate the concentration of a solution of 25 g of sodium chloride added to 100 cm^3 of water.
4. Calculate the concentration of 10 cm^3 of acid in 90 cm^3 of water.

Explaining pressure in liquids and gases

When gas particles or liquid particles move, they have collisions between themselves and also with the sides of the container they occupy. The **pressure** is a measure of the average force of these collisions over the area of the container's sides. The standard units of pressure are **kilopascals** (kPa).

Higher pressure are applied when there are more particles and, therefore, more collisions with the sides of the container. Also, increasing the temperature causes the particles to move faster. The force of the collisions against the sides of the container is larger and the pressure is higher. The pressure of a gas is proportional to its temperature, as long as the volume remains constant.

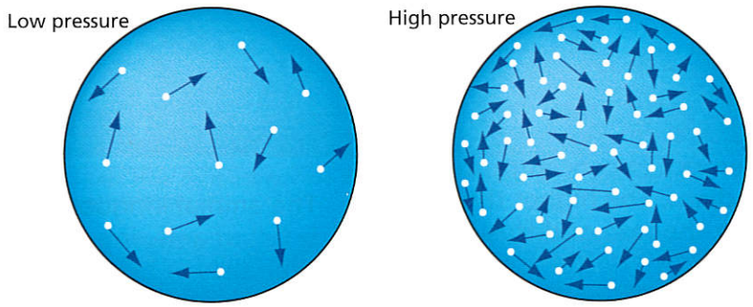


FIGURE 2.3.13c: What do we mean by pressure?

5. Suggest one reason why atmospheric pressure is lower on top of a mountain than at sea level.
6. Sketch a graph to show the relationship between pressure and temperature.

3.13

FIGURE 2.3.13b: How can the concentration of a solution be determined?

Did you know...?

The most toxic substance is called botulinum toxin. A concentration of just 0.000 000 001 5 g in 1 kg of body weight will kill a person. One sugar-bag size of this toxin would wipe out the human race!

Key vocabulary

concentration
concentrated
dilute
pressure
kilopascal

Exploring diffusion

We are learning how to:

- Use the particle model to explain observations involving diffusion.

Diffusion is a process in which particles move and spread out. Unsurprisingly, gas particles diffuse much faster than particles in other states of matter. What make diffusion so special?

Examples of diffusion

Diffusion occurs because of the movement of particles in a gas or a liquid. There is hardly any diffusion in solids because the particles cannot move freely. Gas particles move faster and further than liquid particles, so diffusion in gases occurs faster than in liquids.

All smells spread as a result of diffusion. When particles of a gas, like air freshener spray or odours from smelly socks, are released into the air, they spread out as far away from each other as possible. These gas particles move through the air – when they reach your nose they are detected as a smell. This is why we can detect smells from a long distance away.

1. Give another example of diffusion in everyday life.
2. Why do smells become weaker the further you are from the source?

Diffusion and the particle model

Concentration is a measure of the number of particles packed in a certain volume.

Diffusion occurs because particles move from an area of high concentration to an area of low concentration, until there is no overall change in concentration. We call this the point of **equilibrium**. The difference in concentration is known as the **concentration gradient**. The higher the concentration gradient, the greater the rate of diffusion, and the quicker equilibrium is reached.

Temperature affects the rate of diffusion because it affects the energy of the particles.The higher the temperature, the higher the kinetic energy of the particles, and the faster they move in such a way as to reduce the concentration gradient.

FIGURE 2.3.14a: If a drop of coloured ink is added to water, after several hours the colour will have spread through the water so that it is of equal concentration throughout.

Did you know...?

The animal kingdom is full of amazing examples of how animals make use of diffusion to smell odours. Elephants can detect water sources up to 20 kilometres away.

3. If a drop of ink is added to some pure water, and a similar drop of ink is added to some dilute ink solution, in which solution would diffusion happen fastest? Explain your answer.
4. Think about these examples of diffusion. Which will reach equilibrium first and why?

   a) Placing a spoonful of coffee in 50 cm^3 of hot water

   b) Adding a spoonful of cordial to 50 cm^3 of cold water

Explaining diffusion

Look at Figure 2.3.14b. Concentrated ammonia is placed at one end of the tube and concentrated hydrochloric acid at the other end. Particles of ammonia are smaller than particles of hydrochloric acid. When the particles diffuse, they meet and react, forming a white cloud of ammonium chloride.

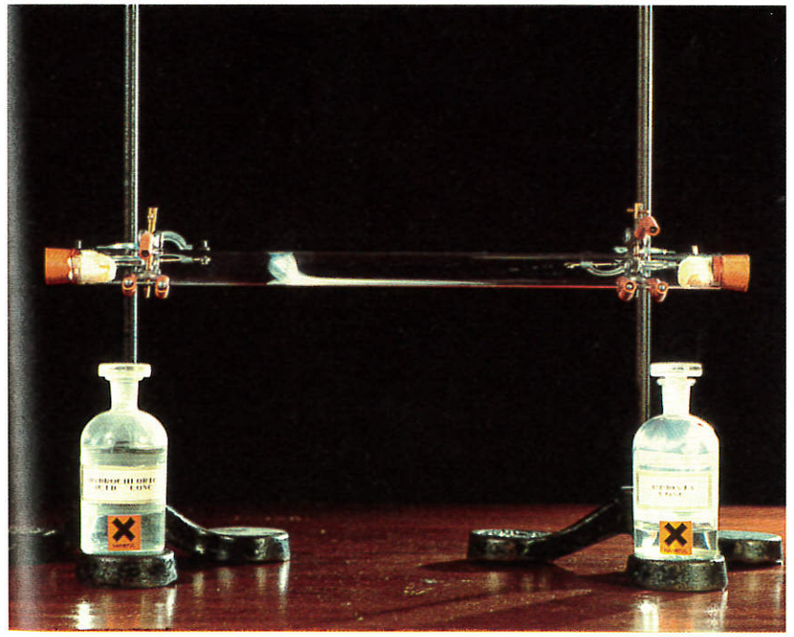


FIGURE 2.3.14b: How do the ammonia particles and hydrochloric acid particles reach each other to react?

5. What would happen if the concentrated solutions were replaced by dilute solutions of both ammonia and hydrochloric acid?
6. How else might the formation of the white ring be speeded up? Explain your answer.
7. Why doesn't the white ring in Figure 2.3.14b form in the centre of the tube?

Key vocabulary

diffusion

equilibrium

concentration gradient

Conserving mass

We are learning how to:

- Use the particle model to explain the Law of Conservation of Mass.

When a given amount of water is frozen to make ice, or boiled to make steam, what happens to the mass?

The Law of Conservation of Mass

In 1789, Antoine Lavoisier, a French chemist, first proposed the **Law of Conservation of Mass**. To do this, he had to carry out thousands of experiments, making very careful measurements. He found that in any **chemical reaction** or **physical change**, the total mass after the reaction was exactly the same as the mass before. His law can be summarised as follows:

'Matter cannot be destroyed, or created, just transformed.'

Notice the similarity between this and the conservation of energy – energy is never lost or created, only transferred by different processes to different places. Much later, Albert Einstein saw a fundamental link between mass and energy.

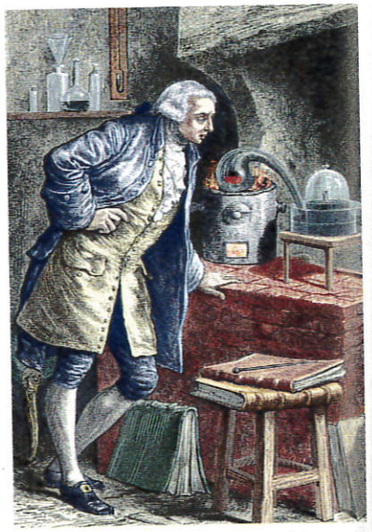


FIGURE 2.3.15a: Antoine Lavoisier first stated the Law of Conservation of Mass.

1. If 100 g of water was placed in a freezer overnight, how much ice will be made?
2. When water is boiled to make steam, why do the mass of the saucepan and its contents decrease over time?

Conservation of mass and solutions

When 50 cm^3 of water is added to 50 cm^3 of alcohol, you would expect the total volume to be 100 cm^3 – it is in fact less. When you weigh the liquids, you find that the mass of the water and alcohol before is exactly equal to the mass of the water and alcohol afterwards. What is going on?

Look at the particle diagrams in Figure 2.3.15b. You can see that exactly the same numbers of particles of water and alcohol are present before and after they are mixed. However, the mixture takes up less room. This is because the aclohol particles occupy the spaces between the water molecules. The total volume of the mixture is, therefore, less than their combined volumes. Mass, however, is conserved in the change.

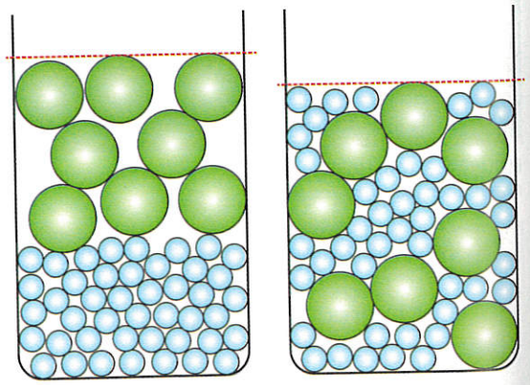


FIGURE 2.3.15b: Volume changes but mass is conserved.

3. You add 20 cm^3 of sugar and 80 cm^3 of hot water to a measuring cylinder. What is the total volume of the sugar solution formed? Explain your answer.
4. 20 cm^3 of sugar has a mass of 14 g. 80 cm^3 of water has a mass of 80 g. What is the total mass of the sugar solution? Explain your answer.

Efficiency of a process

Gold is found chemically uncombined in rocks. Many physical changes are involved in separating the gold from the rock. Figure 2.3.15c gives a simplified summary of these processes.

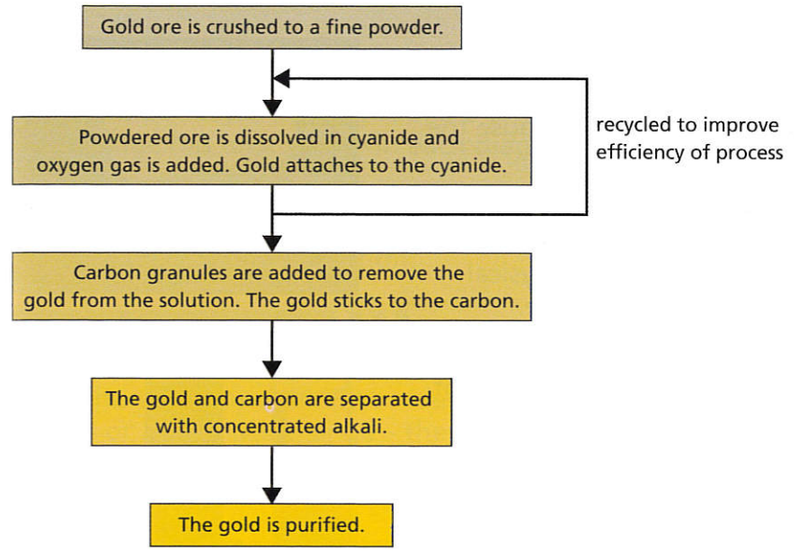


FIGURE 2.3.15c: Different processes in extracting gold

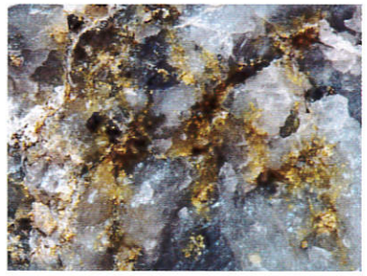
The Law of Conservation of Mass makes it possible to caculate how much gold you should be able to theoretically make.

We calculate the **efficiency** of a process as follows:

$$\text{efficiency} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

The processes used in the extraction are not 100 per cent efficient. This is because some of the gold particles remain in the rock, or in the cyanide, or on the machinery. It is very difficult to make a separation process perfectly efficient.

5. The overall process is thought to be 95 per cent efficient. What does this mean?
6. Dissolving gold in cyanide is about 50 per cent efficient. If 10 kg of gold ore were put through this process, how much gold would come out?



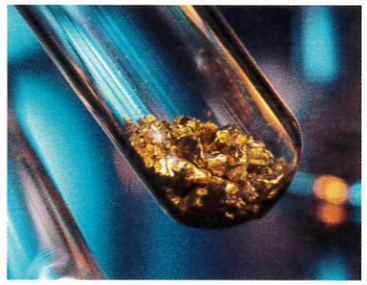


FIGURE 2.3.15d: Gold ore and purified gold

Did you know...?

As early as 490 BCE, Greek philosphers had formed the idea that 'nothing comes from nothing'. They believed, from observations, that matter could not just be created or destroyed, but must be just transformed.

Key vocabulary

Law of Conservation of Mass

chemical reaction

physical change

efficiency

Deciding between physical and chemical changes

We are learning how to:

- Use the particle model to explain the differences between physical and chemical changes.
- Recognise that mass is conserved in all changes.

The particle model can help to decide whether a physical change or a chemical change has occurred. What other signs are there of these changes?

Signs of a change

All changes of state are called **physical changes** because the atoms and molecules within do not change.

All physical changes are easily **reversible**, which means the orginal state can be achieved by reversing the change. The nature of the atoms and molecules involved in a physical change is not altered – chemically they are the same.

A few physical changes, like dissolving certain solutes, result in a temperature change, but most physical changes do not have an energy change associated with them.

All **chemical changes** are difficult to reverse. They occur as a result of a reaction between reactant chemicals to make new products – they can be summarised by an equation.

Observations that a chemical change has occurred include:

- There may be a colour change.
- A new substance may be formed that has a different state from the reactants. For example, a solid may be formed from two liquids or a gas may be released from reacting a solid and a liquid.
- There may be an energy change. Energy may be given out – this is an **exothermic** process, and there is an increase in temperature. Energy may be taken in – this is an **endothermic** process, and the temperature decreases. Energy transfers can also be caused by light.

1. Identify three common physical changes and three common chemical changes.
2. When colourless acid and alkali are mixed, a colourless solution remains. If indicator is added, there is a colour change. Is this a physical or chemical change?

FIGURE 2.3.16a: A physical change

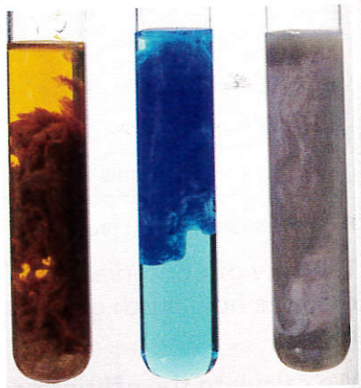


FIGURE 2.3.16b: Chemical changes

Did you know...?

Some chemical changes are reversible. The production of ammonia from hydrogen and nitrogen is an example. Under the right conditions, ammonia is made.

Using particle diagrams

3.16

Figure 2.3.16c shows some particle diagrams of different changes.

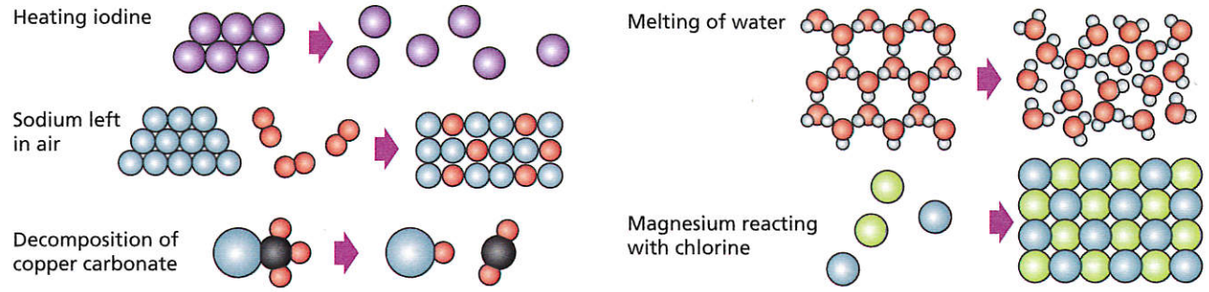


FIGURE 2.3.16c

3. Look at the changes in Figure 2.3.16c. Explain, using ideas about particles, whether a physical or chemical change has taken place in each diagram.
4. Draw two annotated particle diagrams to show a physical change and a chemical change. Write a word equation for your reaction.

Ambiguous changes

Some changes cannot easily be identified as a physical change or a chemical change – they show signs of both.

Adding ammonium nitrate to water gives a marked temperature decrease – it is an endothermic process. However, the ammonium nitrate is just dissolving. If the mixture is heated, the salt can be recovered – it has not changed chemically.

An alloy has different physical properties from both of its component metals. This might lead you to believe that making an alloy is a chemical change. However, the particles within the alloy have not been changed. Brass is made from 60 per cent copper and 40 per cent zinc. There is no such thing as a brass molecule, and the copper and zinc atoms have not formed chemical bonds.

5. Heating rubber causes changes in its physical properties, making it harder and more rigid. The mass of the rubber does not increase or decrease on heating. Is the change physical or chemical?
6. When sodium chloride is added to water, the solution is able to conduct electricity. Solid sodium chloride cannot conduct. Explain why adding sodium chloride to water is still considered to be a physical change.

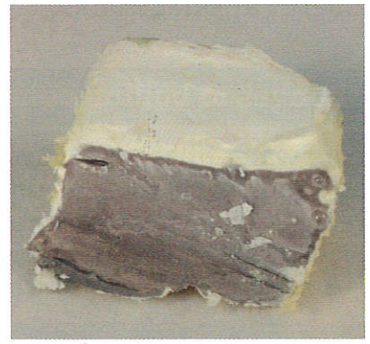


FIGURE 2.3.16d: The oxidation of sodium left in air

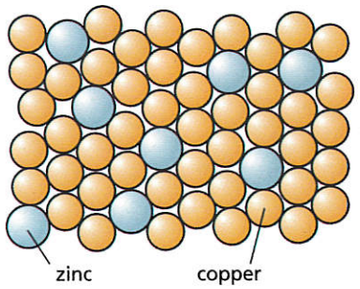


FIGURE 2.3.16e: Why might you think making an alloy is a chemical change?

Key vocabulary

physical change
reversible
chemical change
exothermic
endothermic

Explaining the properties of mixtures

We are learning how to:

- Use the particle model to explain the properties of mixtures.

Making mixtures is a physical process. This means that the atoms and molecules in the mixture are the same as before they were mixed. However, some of the physical properties of a mixture can be different from the original substances, resulting in useful applications.

Changes to boiling point and melting points

Pure water freezes at 0 °C and boils at 100 °C. If salt, sodium chloride, is added to liquid water, the temperatures at which water freezes and boils changes. Figure 2.3.17a shows a graph of how the freezing point is affected by the concentration of salt.

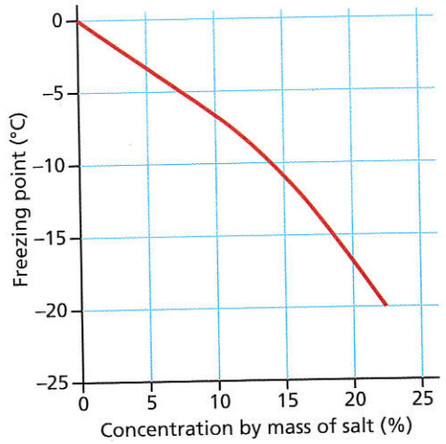


FIGURE 2.3.17a: How the freezing point of water changes with sodium chloride concentration

1. What is the freezing point of a 15 per cent salt solution?
2. How does this help to explain why salt is added to roads in the winter?

Emulsions

An **emulsion** is a mixture of two liquids (one water-based, the other oil-based) which do not normally mix. An emulsifier can be added to the mixture to change its properties. The emulsifier has a structure with a water-loving end and an oil-loving end. It allows the two different liquids to be in contact with each other, and they become evenly spread throughout the mixture. This is an important quality in many food products such as mayonnaise, milk, ice cream and salad cream – also in many other products such as paints, moisturising creams, butter and margarine.

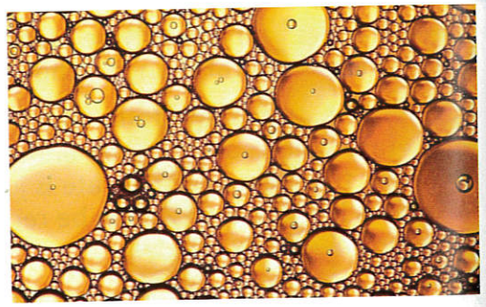


FIGURE 2.3.17b: An emulsion

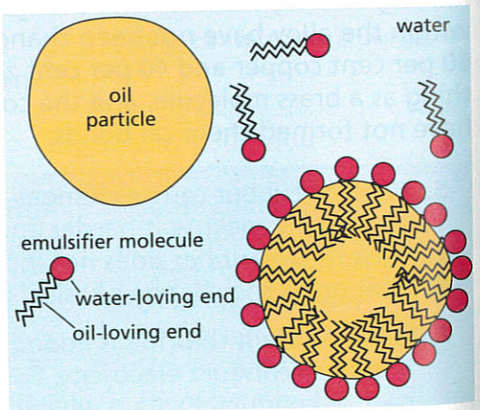


FIGURE 2.3.17c: This shows what is happening at a particle level in an emulsion

3. What would happen if the emulsifier was not present in Figure 2.3.17b?
4. Why is it important to use emulsifiers?

Explaining colloids

When different states of matter are dispersed together, this is known as a **colloid**. For example, in an aerosol there may be particles of liquid or solid spread about in a gas. When an aerosol is sprayed, the gas particles help to move the liquid or solid particles to where they need to be applied.

Foams are a mixture of gas bubbles trapped inside a liquid. Blowing bubbles is an example of making a foam.

Figure 2.3.17d shows some soap that has been made into a foam by heating it in a microwave. The particles of the soap have not been changed, but air and water vapour have been added to the soapy mixture.

FIGURE 2.3.17d: How are the soap foam and the bar of soap different?

Foaming changes the properties of the original liquid by making it much less dense and increasing the surface area. This has many useful applications. Foams filled with carbon dioxide gas are effective at preventing oxygen getting to a fire, because carbon dioxide is more dense than oxygen. Oil spill fires are treated using special foams.

FIGURE 2.3.17e: Fighting a fire with foam

A **gel** is a mixture of liquid particles floating in a solid. Examples include hair gel, jelly and gelatin. The liquid particles make the solid structure less rigid, and easier to spread more accurately. Some eye ointments are in the form of gels – they are easier to apply and do not run.

5. Describe two other uses each of foams, gels and aerosols.
6. Draw a particle model of a foam, an aerosol and a gel.

Did you know...?

'Aerofoam' is a gas–solid colloid. It was first made in the 1930s. It is the lightest solid known, and is the best solid thermal insulator.

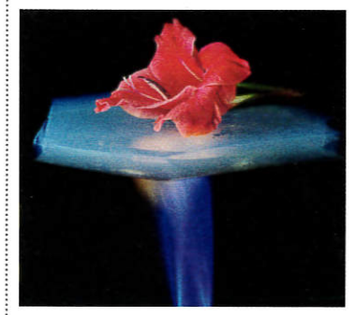


FIGURE 2.3.17f: With a blow torch underneath, the flower on top of the aerofoam does not burn.

Key vocabulary

emulsion
colloid
foam
gel

Using particle models

We are learning how to:

- Use 'good enough' particle models to explain different observations.

You have learnt that the particle model is a 'good enough' model for explaining most changes of state. How good is it at explaining other phenomena and observations related to physical and chemical changes?

Explaining separation processes

You may remember using different separation techniques like filtration, chromatography and distillation. The **particle model** can be used to explain how these work, but some adaptations may be needed because it has some limitations.

The particle model cannot:

- distinguish between different types of particles, unless they are given different colours
- show what kinds of atoms are in the molecules
- show different intermolecular forces between particles.

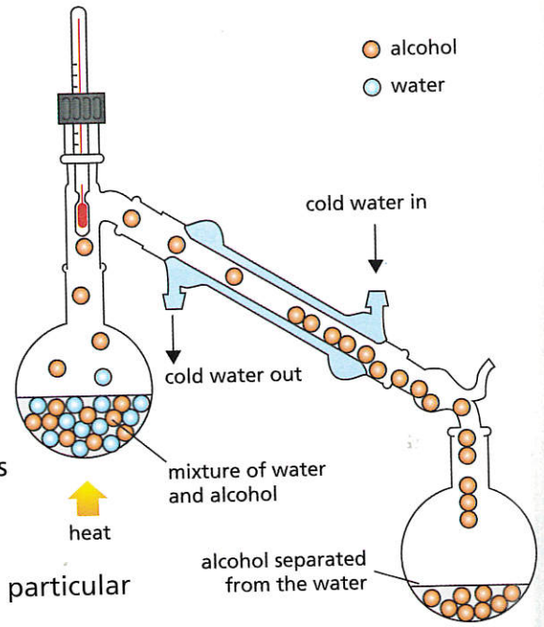


FIGURE 2.3.18a: Explanation of distillation using the particle model

The particle model needs to be adapted to explain particular phenomena – so it can be a 'good enough' model.

Figure 2.3.18a shows the process of distillation, which separates liquids. The particle model has been adapted to explain distillation.

1. How has the particle model been adapted to make it a 'good enough' model?
2. Use a 'good enough' model to explain how filtration works.

Explaining solubility

It is clear that some substances are more soluble than others. As it stands, the particle model is not a 'good enough' model to explain this and needs adapting.

Solute particles have forces of attraction between themselves and between the solvent particles. When the forces of attraction between the solute and solvent are stronger than between the solute particles, then the solute will dissolve. The solute particles fill the spaces between the solvent particles. When all the spaces are filled up, the solution is said to be saturated, because no more solute can be dissolved.

If the temperature is increased, the solvent particles move with more energy, moving further apart and creating more space. More solute can be dissolved at the higher temperature because as there are more gaps that can be filled.

3. Adapt the particle model to explain why some solids are more soluble than others.
4. Can the particle model be used to show how temperature affects solubility? What are the strengths and limitations of the model?

Did you know...?

Evidence for the existence of particles began to emerge in the 1800s. We have come to understand so much more about particles that we have very different models nowadays.

Explaining chemical changes

When calcium carbonate is added to hydrochloric acid, a gas, carbon dioxide, is formed. A chemical change takes place. Models that involve representations of the atoms must be used to explain this. Notice that the same number of atoms must be on both sides of the equation, ensuring that mass is conserved.

Certain standard colours can be used for particular elements as shown in Table 2.3.18.

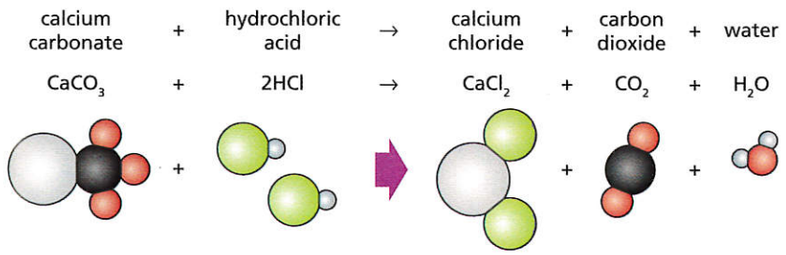


FIGURE 2.3.18b: This shows a 'good enough' particle model to demonstrate the changes when calcium carbonate is added to hydrochloric acid.

5. Use particle model colours from the table to show what would happen when magnesium metal is added to hydrochloric acid (HCl), making magnesium chloride ($MgCl_2$) and hydrogen (H_2). Write a word equation for the reaction first. Think about the conservation of mass.
6. Lead nitrate ($Pb(NO_3)_2$) solution reacts with potassium iodide (KI) solution to make lead iodide (PbI_2) and potassium nitrate (KNO_3). Write a word equation for the reaction. Think about the conservation of mass and use a particle model to show the reaction.

TABLE 2.3.18: Colours for elements in the particle model

Common elements	Colour for atom
hydrogen	white
oxygen	red
carbon	black
chlorine	green
nitrogen	blue
bromine	brown
sulfur	yellow
iodine	purple
metals, e.g. sodium, calcium	grey

Key vocabulary

particle model

Checking your progress

To make good progress in understanding science you need to focus on these ideas and skills.

- Compare the properties of solids, liquids and gases.
- Draw circle diagrams to demonstrate the differences between the arrangement of particles in solids, liquids and gases, and describe their different properties.
- Use particle diagrams to explain the differences in energy and forces between the particles in different states of matter, accounting for differences in their properties.
- Recognise how theories are developed.
- Use observations to develop hypotheses.
- Change hypotheses in the light of new evidence and use this evidence to develop theories.
- Use correct terminology and the particle model to describe changes of state, including evaporation.
- Interpret and explain data relating to melting and boiling points.
- Use the particle model to explain latent heat and how impurities affect melting and boiling points.
- Describe how solids, liquids and gases behave when heat is applied to them.
- Describe applications and problems caused by thermal expansion.
- Use the particle model to explain expansion in solids, liquids and gases.
- Describe a model that can be used to represent particles.
- Apply and adapt models to make them more suitable for use.
- Evaluate the strengths and limitations of particle models.
- Make predictions about floating and sinking using ideas about density.
- Use the particle model to explain density differences between gases and calculate the density of solids.
- Use the particle model to explain factors relating to density.

- Make predictions about floating and sinking using ideas about density.
- Use the particle model to explain the density differences between gases and calculate the density of solids.
- Use the particle model to explain factors relating to density.
- Describe what is meant by the terms 'concentration' and 'pressure'.
- Calculate concentrations of solutions.
- Use ideas about particles to explain the effects of pressure.
- Describe how diffusion occurs in liquids and gases.
- Explain observations relating to diffusion in terms of particles.
- Make predictions, using ideas about particles, about factors affecting the rate of diffusion.
- Describe features of physical and chemical changes, recognising how mass is conserved.
- Use ideas about particles to describe separation processes.
- Apply the particle model to explain physical and chemical changes, taking conservation of mass into account.
- Describe different types of colloids.
- Explain the properties of different colloids using the particle model.
- Evaluate the particle model in its ability to explain colloids and their properties.
- Use particle models to describe different separation processes.
- Use particle models to explain how the solubility of solids and gases changes with temperature.
- Evaluate the effectiveness of the particle model in explaining physical changes.

Questions

Questions 1–7

See how well you have understood the ideas in the chapter.

1. Which of the following statements is true? [1]

a) Particles in a solid have more energy than particles in a liquid.
b) Particles in a gas have weaker intermolecular forces than particles in a liquid.
c) Particles in a liquid have more internal energy than particles in solids and gases.
d) Particles in a solid do not have any internal energy because they do not move.

2. What does diffusion depend on? A difference in: [1]

a) temperature **b)** state **c)** concentration **d)** mass

3. Which of these relates to a physical change and not a chemical change? [1]

a) The change is reversible. **b)** New chemicals are made.
c) Colour changes are seen. **d)** Mass is conserved.

4. A foam is a mixture of: [1]

a) a liquid and a solid **b)** two solids
c) two liquids **d)** a gas and a liquid

5. Describe the evidence that Robert Brown collected which led to the theory of Brownian motion. [2]

6. Describe, using ideas about particles, how temperature affects the viscosity of liquids. [2]

7. Explain, using ideas about particles, what is unusual about the change in density of water as it freezes. [4]

Questions 8–14

See how well you can apply the ideas in this chapter to new situations.

8. Iron has a melting point of 1535 °C and a boiling point of 2750 °C. At which temperature will iron be a liquid? [1]

a) 2752 °C **b)** 2751 °C **c)** 1534 °C **d)** 1536 °C

9. The density of water is 1 g/cm^3 and that of syrup is 1.3 g/cm^3. Which of the following statements is false? [1]

a) In a mixture of syrup and water, the water will float on top.
b) The syrup is more dense than the water.
c) In a mixture of syrup and water, the syrup will float on top.
d) There is more mass per unit volume in syrup than in water.

10. Figure 2.3.20a shows the particles of different substances. Which particle diagram represents a shaving foam aerosol? [1]

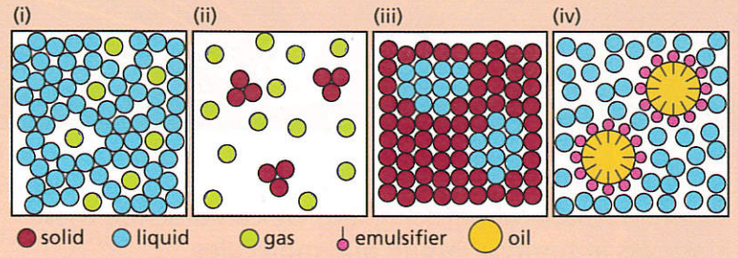


FIGURE 2.3.20a

11. Which of the following is *not* a reason for using carbon dioxide gas in fire extinguishers? [1]

a) It is more dense than air. **b)** It is not flammable.
c) It sublimes. **d)** It can flow.

12. A particular type of hand warmer uses calcium chloride and water. Energy is transferred in the process by heat. How would you prove this is a physical change and not a chemical change? [2]

13. Ammonium nitrate and water can be used to make fertiliser. Tomato plants require a concentration of 20 mg/l. You have 250 cm^3 of water. How much ammonium nitrate should you add? [2]

14. Aerosol cans have a warning on them to prevent their use on fires. Explain reasons for this, using ideas about particles. [4]

Questions 15–16

See how well you can understand and explain new ideas and evidence.

15. Butane (C_4H_{10}) is camping fuel. Its boiling point is –1 °C. Hydrogen (H_2) is also a fuel, with a boiling point of –252 °C. Both fuels are transported under pressure, turning them into a liquid so that more particles can be carried. Explain which fuel will be easier to transport in this way and why. [2]

16. Figure 2.3.20b shows how the temperature changes over time for a new substance called xmenium.

a) What information about this new material does the graph provide?
b) Xmenium is going through trials to see if it can be used in a heat pack (see Topic 3.10). Use the graph to explain whether it is suitable or not, and what could be done to improve its properties. [4]

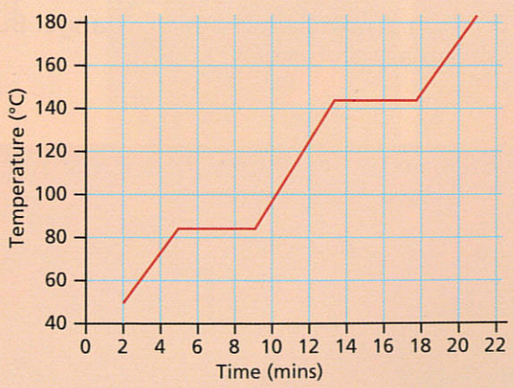


FIGURE 2.3.20b