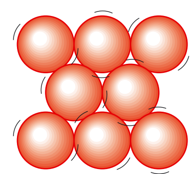
1.1 Particle model

All substances can theoretically exist as a solid, liquid or gas; it just depends on the temperature. For example, nitrogen – the gas that makes up 70% of the air around you – will become a liquid when it is cooled to –200 °C.

● **Figure 1** A steaming bowl of food. What solids, liquids and gases can you see around you every day?

Scientists believe that everything is made from very tiny particles. They use this idea, called **particle theory**, to explain what happens to solids, liquids and gases when they are heated and cooled.

Particles are not static, they all have some kinetic (movement) energy. One of the key differences between the states of matter (solid, liquid or gas) is how quickly the particles are moving, and this links to how close the particles are to each other.

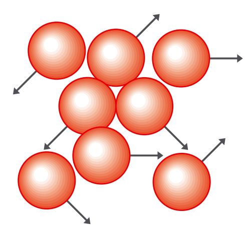


● **Figure 2** Particles in a solid

→ The three states of matter

Solids

- Solids have a fixed shape and a fixed size.
- The particles are very close together and held in place by strong forces (bonds).
- Their particles cannot move around, but they do vibrate.
- Because the particles cannot move around, a solid has a fixed shape.



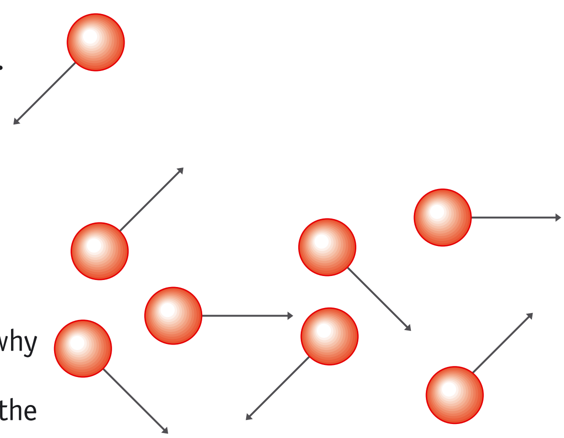
● **Figure 3** Particles in a liquid

Liquids

- Liquids do not have a fixed shape but they do have a fixed volume.
- The particles are very close together. Most of the particles touch each other.
- The particles can move around.
- A liquid can flow and take the shape of its container.

Gases

- Gases don't have a fixed shape or a fixed volume.
- The particles move around all the time and spread out. This is why a gas fills its container.
- A gas can be compressed into a very small space – this pushes the particles closer together.



● **Figure 4** Particles in a gas

→ Explaining expansion

As the solid is heated, its particles gain more energy. This makes the particles vibrate faster and they move further apart. The solid expands.

The particles themselves don't expand – their size stays the same. Their mass stays the same too.

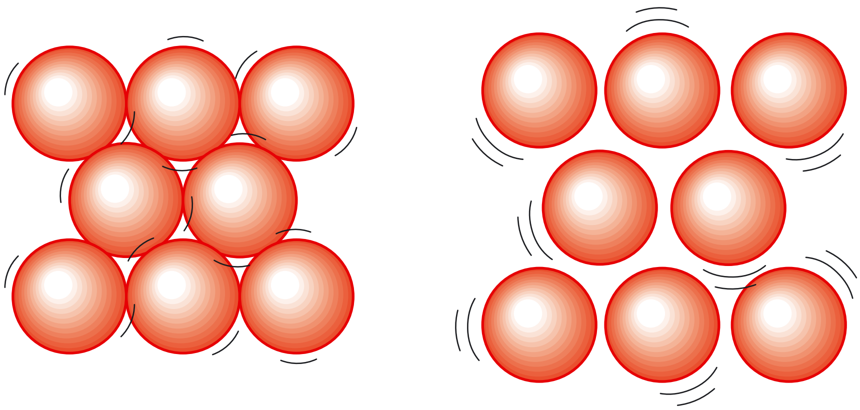


Figure 5 When particles are heated they gain additional **kinetic energy**. This leads firstly to **expansion** and then to a change of state

Gases and liquids also expand when they are heated, because their particles gain more energy and move around more.

Expansion can be a problem – for example, railway lines can expand and buckle in hot weather.

Expansion can be useful too – thermometers work because the liquid inside expands when it is heated and contracts when it is cooled.

Questions

1 Describe the differences in how particles move in each of the three states of matter.
2 What is the difference between having a fixed shape and having a fixed volume?
3 When engineers design metal bridges they do not make them in one piece. The joints they include often include overlaps of metal, which allow some movement. Explain why they are designed this way.
4 Explain why gases can easily be compressed but solids and liquids are very difficult to compress.
5 Explain, using diagrams, why an air-filled balloon goes dow n over the course of a week, even if the neck is securely tied.

Show you can...

Complete this task to show that you understand the differences between the three states of matter.

Consider these everyday examples, which can be difficult to categorise as solids, liquids or gases.

- ice cream
- foam
- toothpaste
- sand

For each one describe whether they have a fixed shape and whether they can flow. Then choose which state of matter matches them best and explain your choice.

1.2 Changing state

Understanding changes of state is important when working with materials. Glass blowing, casting metal and cooking are all activities in which changes of state are used to create a finished product.

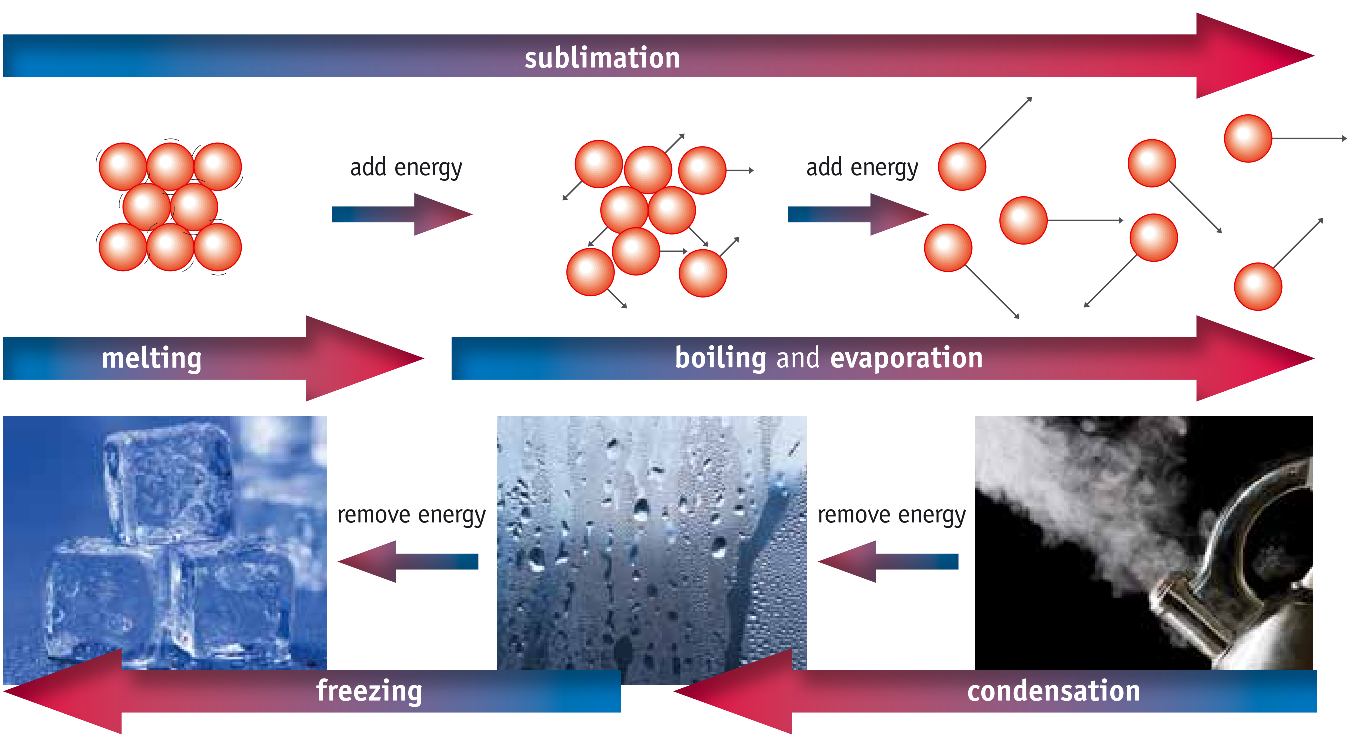
● **Figure 1** Mercury is the only metal that is a liquid at room temperature. Why do you think it is a good choice to use in a thermometer?

A material changes its state because energy is either added or taken away from its **thermal store**.

Adding energy to a solid makes its particles move further and faster until the bonds between particles weaken enough for the particles to move past each other – the solid has now melted into a liquid.

Adding energy to a liquid makes its particles move around further and faster until they have enough energy to break their bonds and become free to move anywhere. When this happens the liquid has become a gas.

A substance can become a gas in three ways: **evaporation**, **boiling** and **sublimation**.



● **Figure 2** A summary of state changes

➜ Evaporation

- Only the particles at the surface of the liquid are involved – they are the only particles with enough energy to break free.
- The liquid doesn't bubble.
- Evaporation happens at all temperatures.

➜ Boiling

- All the particles in the liquid are involved – they all have enough energy to break free.
- The liquid bubbles.
- Boiling happens at a fixed temperature.

➜ Sublimation

Some substances have melting and boiling points so close together that when they are heated they won't melt but turn straight into a gas. This is called sublimation, and iodine is an example of such a substance.

Boiling and **melting** happen at fixed temperatures for a given liquid. These temperatures are different for different liquids.

Liquid	Melting point	Boiling point
Pure water	0 °C	100 °C
Mercury	–39 °C	360 °C

Change of state is a physical change – it can be reversed.

Cooling a gas takes energy from its particles so they slow down and move closer together. The gas **condenses** into a liquid.

Cooling a liquid takes energy from its particles so they can't move around and can only vibrate. The liquid **freezes** into a solid.

When they change state, particles do not change size or mass – they just arrange themselves differently.

If you melt 1 kg of solid iron you will get 1 kg of liquid iron!

Questions

1 Explain the difference between the arrows on the liquid particles and those on the gas particles in Figure 2.
2 Which arrangement has the most energy: solid or gas?
3 Why is mercury a good choice of liquid to use in a thermometer? What problems could there be if water was used instead?
4 Compare the effect of heating a liquid and heating a gas.
5 Puddles are an example of water evaporating. Describe this process and explain how it differs from boiling. Explain why we don't see it happening.

Show you can...

Complete this task to show that you understand changes of state.

In warm weather washed clothes can be hung outside to dry. For wet washing to dry, the liquid water particles need to be changed to gas particles and be moved away from the washing. Explain, using diagrams, why the washing dries quicker on a warm and windy day

1.3 Diffusion and gas pressure

When substances are in the gas arrangement they have some unique properties. Scientists and engineers capitalise on these properties to make gases useful. Hydraulic machines use the compressibility of gases to allow heavy loads to be moved with minimal effort.

Figure 1 How can understanding how gases act under pressure influence modern sports equipment?

Diffusion

Moving particles will spread out if they have space to move into. This is called **diffusion**. Diffusion happens even if there is no breeze or current.

During diffusion, particles move from areas where they are strongly concentrated to areas where there are fewer of them. This means that the particles are spread out more evenly after diffusion than before.

Gases diffuse easily because their particles can move freely.

Liquids can also diffuse. Diffusion in a liquid usually happens slowly.

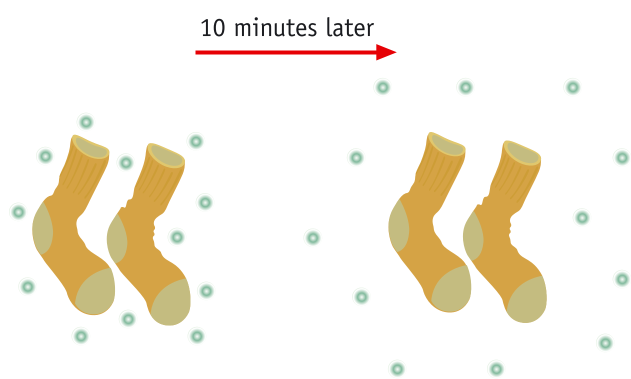


Figure 2 Particles that cause smell travel by diffusion

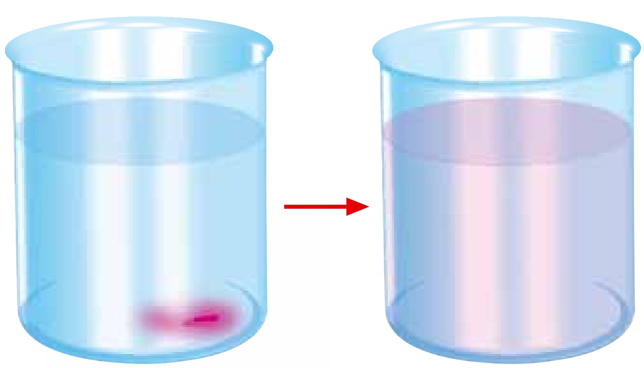


Figure 3 Using a coloured dye can allow us to observe diffusion in liquids

How quickly particles diffuse depends on a number of factors. For example:

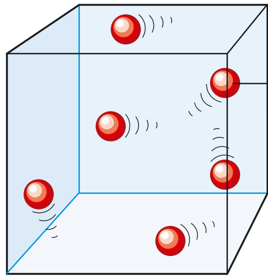
- the size of the particles – the smaller and lighter the particles are, the faster they diffuse
- the temperature – the higher the temperature of the gas or liquid, the more energy the particles will have and the faster they will diffuse
- the difference in concentration between where the particles were when they started and where they are moving into – the greater the difference, the faster they will diffuse
- any other particles that are in the way – they could bump into other particles, which would slow the diffusing particles down.

→ Gas pressure

As gas particles move around they hit objects. This causes **gas pressure**.

The faster the gas particles move, the more force they exert so the greater the pressure is.

The hotter the gas, the more energy its particles have and the harder they hit the container.



● **Figure 4** As the gas particles hit into the side of the container they cause gas pressure

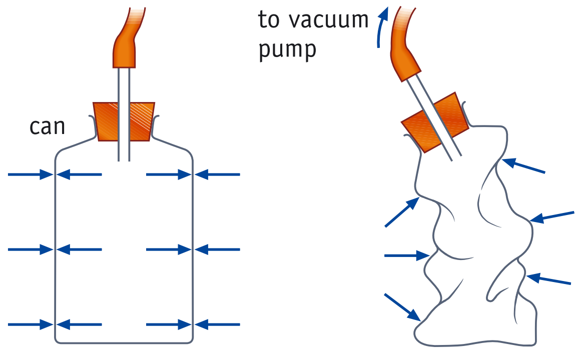
→ Air pressure

Air particles moving around cause air pressure (**atmospheric pressure**). Air pressure acts in all directions.

If air pressure is greater on one side of a surface, the unbalanced forces can make the object collapse. If you remove the air from inside the can shown here the can will collaps.

Aerosols, steam turbines, drinking straws and pneumatic drills all use air or gas pressure to work.

Two thousand years ago, the Egyptian scientist, Hero of Alexandria, designed machines that used air pressure to move objects.



● **Figure 5** As the gas particles are pumped out of the can the sides collapse

Questions

1. Why is diffusion usually slower in a liquid than in a gas?
2. When smell particles diffuse across a room, what are the other particles that could get in the way?
3. Draw a series of three particle diagrams to show the stages of diffusion that relate to Figure 3.
4. Explain what would happen to an inflated balloon if you put it into the freezer.
5. Explain how the air in a bicycle tyre causes pressure and describe in detail what will happen to the gas pressure on a very warm day.

Show you can...

Complete this task to show that you understand diffusion.

You are going to investigate the effect of temperature on the rate of diffusion.

a) Describe the equipment you will need for this investigation and why.

b) Explain the factors that you will have to keep the same in each part of the investigation.

1.4 Introducing density

Not all solids are the same. In some solids the particles are packed so tightly together that you get a lot of mass in a small volume. These very dense materials are useful if you want strength and hardness, such as in the iron used in the head of a sledgehammer.

● **Figure 1** *RMS Titanic*. How can a ship made of steel, and with a mass of over 40 000 tonnes, float?

Density measures how concentrated the mass of an object is.

- If an object has its mass spread over a large volume, its density will be low.
- If all the mass is concentrated in a small space, its density will be high.

➜ Properties of solids

1. Solids have a fixed volume and a fixed shape.
2. However, they can be **elastic**. This means they return exactly to their original shape after bending or stretching.
3. Solids can be hard. This means they will not easily change shape when a force is applied.
4. Solids can also be strong, meaning a large force is needed to break them. This is because their particles are close together and held in place by strong bonds. It can take a lot of force to break these bonds.
5. Solids can be dense. This is because their particles are packed closely together. This means that there can be a large mass in a small volume of material.
6. Some solids can have lower density. A good example is aluminium, which is used to make aircraft. The advantage of this metal is that it has the hardness and strength of a solid but a lower mass, which reduces the force needed to lift off.

● **Figure 2** Can you think of any other tools or toys that use elastic energy to work?

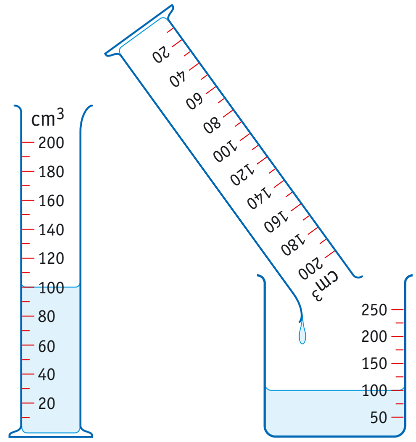
● **Figure 3** Other than helping the aircraft lift off, what other advantages are there to keeping its mass to a minimum?

➜ Properties of liquids and gases

Liquids have a fixed volume but no fixed shape.

Gases have no fixed volume and no fixed shape.

Gases expand to fill the space available. They can also be compressed into a very small space.



● **Figure 4** Liquids take the shape of their container

● **Figure 5** What could happen if the exit for the steam was blocked?

➜ Density and buoyancy

An object will float if its density is less than the density of the liquid it is in. Some types of wood are less dense than water, so they will float on water. Most metals are denser than water, so they won't float on water.

Materials that float easily are described as 'buoyant'.

As a general rule, solids are denser than liquids and liquids are denser than gases.

- **Solids** – highest density, because their particles are closest together
- **Liquids**
- **Gases** – lowest density, because their particles are furthest apart

However, there are some exceptions.

Liquids with a low density can float on liquids with higher density – oil floats on water! Gases with a low density will float on high-density gases too – warm air will rise and float on colder air.

Water is an example of a substance in which the solid arrangement is less dense than the liquid. This is why ice will float on water.

● **Figure 6** What could the advantage be to the living organisms in aquatic environments once there is a layer of ice floating on the surface of the water?

Questions

1. Why are solids harder than liquids?
2. What would it mean if a solid was described as strong, hard and dense?
3. Why is it an advantage to run cars on liquid fuels, such as petrol, rather than solid fuels, such as coal or wood?
4. Explain why the density of a metal object decreases when the object expands.
5. An object, such as a rubber ring, can be made to float on water by filling it with air. Explain, using particle diagrams, why this occurs.

Show you can...

Complete this task to show that you understand density.

Choose two items from your school bag or pencil case. How could you determine which one has the greater density? Think about what equipment you might need and what results you might expect.

Asking questions and making predictions

Applying the particle model

Models help us understand new ideas by relating them to things we already know about. We use the particle model of solids, liquids and gases to explain their behaviour.

We can also use models to make predictions about how similar materials will behave and develop scientific questions about real-life observations.

Hardness and scratch resistance

Solids can be hard because their particles are held together by strong bonds. The stronger the bond between the particles in a material, the harder the material is.

A common way to compare the hardness of materials is to rub two objects against each other and observe which one becomes scratched. The softer of the two objects will show either temporary or permanent changes to its shape.

Try this now – rub your pencil against a piece of paper.

Figure 1 Why would you expect some dust to be created during a scratch test?

1 Which is harder? How do you know?

Now let's make a prediction.

2 What do you think will happen if you rub a metal pen tip against the wood of your pencil? Explain your prediction in terms of the hardness of the materials you are comparing. Then test it out. What did you observe?

Diamond is one of the hardest natural materials. It can be cut using small pieces of other diamonds.

3 How would you break the diamond apart when it is so hard?

Elasticity

Solids can be elastic because the forces (bonds) between their particles resist the stretching force trying to pull the particles apart.

Some solids are more elastic than others – because the forces holding the particles together are different.

James was investigating the elastic properties of a rubber band. You could repeat his investigation if you have a rubber band available and make your own observations.

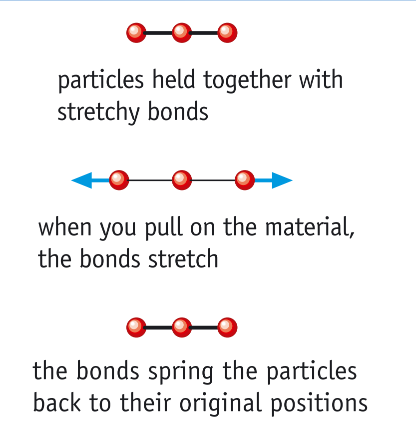


Figure 2 The stretchy bonds between particles in an elastic material allow it to store energy

The first thing James wanted to do was observe what happened when the rubber band stretched. He started by sketching out how the particles are arranged in the unstretched rubber band.

4 Predict what will happen to the thickness of the rubber band as it is pulled tight. Explain your prediction and draw a particle diagram to show the arrangement in the stretched rubber band.

The next thing James was interested in was whether the rubber band would always spring back to its original length however far it was stretched.

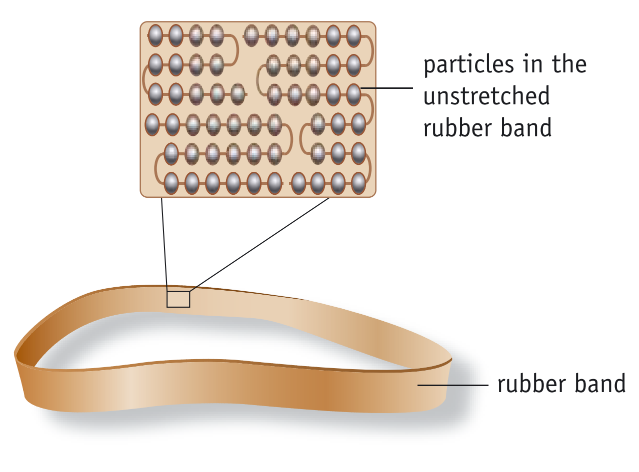


Figure 3 The arrangement of particles in an unstretched rubber band

5 Do you think stretchy bonds have a limit? Give an example of something you have observed to support your idea.

6 What might happen to the stretchy bonds between the particles if the rubber band is stretched very far?

Everyday particles

Mary was going on a school trip. While she was having her packed lunch she made some unusual observations. She wanted to try and explain them using her scientific knowledge and understanding.

Mary was feeling rather thirsty, so she decided to drink one of the cartons of juice that she had bought. She pushed the straw into the carton and drank all of the juice. She noticed that the carton had become squashed. She thought that while the squashed carton was left on the side it would expand again and regain its original shape, but it didn't.

7 Why do you think this happened?

8 How could Mary get the carton to return to its original shape?

Figure 4 A squashed drinks carton

During the school trip it was a hot day, and Mary had filled a plastic bottle with water but had left it on the coach during the day. When she got back to her seat she saw that the lid had popped open and some of the water had spilt.

9 Why do you think this happened?