2 Properties of substances

HAVE YOU EVER WONDERED ...

- why icebergs float?
- why clothes dry even when it's not hot?
- why you breathe out fog on a cold morning?
- how cold it can get?

After completing this chapter students should be able to:

- identify properties as physical or chemical
- explain how properties affect how a substance is used or not used
- compare properties of different substances
- assess the biodegradability of different substances
- explain the properties of solids, liquids and gases
- explain changes of state, particularly of water.

2.1 Physical and chemical properties

There are millions of different substances in the world. Each can be identified by its properties. Properties describe a substance and how it acts. They include its appearance, what it does when heated or cooled, and how it reacts with other substances.

Physical properties

You can probably tell which objects and substances around you are solid, liquid or gas by the way they look and act. What you see are **physical properties**. Testing a substance for its physical properties doesn't destroy the substance, or change it into anything new.

Some of the most useful physical properties of a substance are:

- whether it's a solid, liquid or gas at room temperature (normally taken as 25°C)
- the temperatures at which the substance freezes or boils (known as its freezing point and boiling point)
- its appearance (such as its colour and texture, the shape of any crystals within it or whether it is shiny or dull)
- its density (how heavy it is compared to other substances of the same size)
- how hard or brittle the substance is (whether it is easily scratched or whether it crumbles)
- whether the substance dissolves in different liquids (such as water or turpentine)
- its ability to let heat or electricity pass through it (known as its thermal and electrical conductivity).

Solids, liquids and gases

Substances exist in either solid, liquid or gaseous form. These forms are known as the **states** (or phases) of **matter**.

Solids, liquids and gases have very different physical properties. Think of the van in Figure 2.1.1. Cars and vans only change shape when they are in an accident or when they are broken up to be recycled. Also solids cannot be **compressed** (squashed to make them smaller). Try to compress a sugar cube and it might crumble, but the amount of sugar is exactly the same as it was before. The fact that solids do not change shape or size allows them to be used to build structures.

Liquids are similar to solids in that they don't change their size and are **incompressible** (unable to be compressed or squashed). They differ from solids in that they can flow and change shape. Think of orange juice: it splashes about and can be poured from one container into another, taking on a new shape as shown in Figure 2.1.2. The ability of liquids to squeeze along pipes and hoses without changing volume allows them to be used in hydraulic (powered by liquid) systems such as car brakes.

Solids:

- have a fixed shape
- have fixed size and volume
- cannot be compressed (pushed in to make it smaller)
- will usually sink when placed in liquids of the same material.

Figure 2.1.1 Cars and vans are solid. They don't change shape or size unless they are in an accident or they are crushed to be recycled.

Liquids:

- have fixed size and volume
- are able to flow
- take the shape of the bottom of the container they are in
- are incompressible (not able to be compressed).

Figure 2.1.2 Liquids always flow to take up the shape of their container.

Gases are often invisible and many have no **odour** (smell). Water vapour is a gas that is invisible because it is colourless and its particles are spread too far apart for the gas to be seen. However, you can feel water vapour since it gives air its humidity. There is a lot of water vapour in the air on a humid day, making you feel sweaty and sticky. Figure 2.1.3 on page 42 shows a mixture of gases that does have a smell.

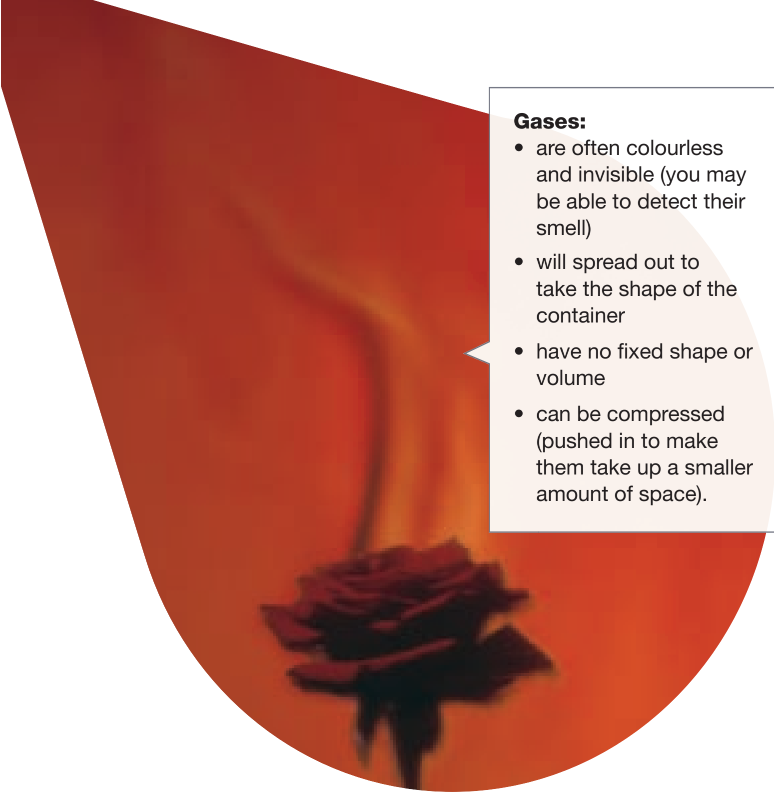
Gases differ from solids and liquids in that they can be compressed. This property allows gases to be squeezed into small volumes such as barbecue gas cylinders. It also makes them useful in the gas struts or shock absorbers found in the suspension of bikes and cars. A bump compresses the gas in the struts, softening the impact of the bump. The gas then expands once more, pushing the strut back to its original shape.

SciFile

No teardrops!

The shapes of raindrops change as they change size. None of them looks like the teardrops shown in the weather report!

Diameter (mm)	Less than 1	1 to 2	2 to 4.5	Bigger than 4.5
Shape				



Gases:
- are often colourless and invisible (you may be able to detect their smell)
- will spread out to take the shape of the container
- have no fixed shape or volume
- can be compressed (pushed in to make them take up a smaller amount of space).

Figure 2.1.3 Perfume, smells, vapours and fumes are all gases. This image shows the gaseous perfume rising from a rose.

Figure 2.1.4 There is a fourth state of matter but it is very rare on Earth. **Plasma** is a gas-like state that only exists at temperatures above 6000°C, making it common on stars but not here. On Earth, plasma is found wherever high-voltage sparks are generated, such as lightning bolts or in this plasma sphere.

Chemical properties

Chemical properties describe how a substance reacts with other substances. A new substance is formed in the process, often with very different properties. For example, iron rusts because it combines with oxygen and water. Iron is grey, hard and often shiny, while the rust it forms is red-orange, flaky and brittle. Likewise, paper burns and dynamite explodes, leaving behind ash and smoke.

Chemical properties that are worthwhile knowing about are whether a substance:

- burns or explodes in oxygen (this is known as combustion)
- rusts or corrodes (known as corrosion) or is corrosion-resistant
- is an acid like vinegar or a base like bicarbonate of soda or neither (this is measured by its pH)
- reacts quickly or slowly with other chemicals (this is known as the rate of reaction). Explosions like the one in Figure 2.1.5 have a fast rate of reaction.

Figure 2.1.5 The chemical properties of LPG and petrol cause them to explode when there is plenty of oxygen and a flame or spark.

2.3

Choosing the right substance

The different properties of substances affect how they are used. For example, the frame of a skyscraper needs to be solid and strong and so is commonly made out of steel. Shopping bags are made of plastic, paper or fabric because they need to be cheap, light, strong and flexible. Likewise, takeaway food containers are often made of polystyrene because it's light and keeps the heat in.

Sometimes liquids or gases will be a better choice than solids. For example, car brakes only work because liquid is pumped through tubes to activate them, while a gas (air) is used to keep a jumping castle in shape. Imagine if the jumping castle shown in Figure 2.1.6 was filled with lead!

Figure 2.1.6 The walls and floor of a jumping castle need to be solid and strong but also smooth and flexible. Inside is a gas (air) that can compress when you jump on it but which will expand as soon as you jump to another spot.

INQUIRY science 4 fun

Property competition

Who is best at identifying physical properties?

Yes

Collect this …

- any object from your pencil case
- 2 sheets of lined paper
- 2 pens or pencils

Do this …

1. Team up with another person.
2. Each person needs to number the first ten lines 1, 2, 3 and so on to 10.
3. Choose any object from your pencil case.
4. On the word 'Go' each person starts writing as many physical properties about the object as they can. Put a new property on each new line.
5. The first person to list ten properties is the winner.
6. Compare the two lists then choose another object and start again.

Record this …

Describe what type of physical properties each person listed.

Explain why you could only list physical properties.

SCIENCE AS A

HUMAN ENDEAVOUR

Nature and development of science

Biodegradability

Figure 2.1.7 Rotting and mould are signs that a substance is biodegradable.

ENDEAVOUR

Leave a sandwich in your schoolbag and a few days later you'll be left with a mess of rotting, smelly goo.

This happens because microscopic bacteria cause chemical reactions that break down substances in the sandwich into simpler substances like sugar, water and carbon dioxide. However, the cling wrap or plastic container that the sandwich was in is unlikely to have changed. The chemical properties of the bread, lettuce and tomato caused them to rot, while the chemical properties of the cling wrap or plastic gave them rot-resistance.

Biodegradable

Substances are classified as being **biodegradable** if bacteria or fungi break them down. Fruit, vegetables, flowers, wood, twigs and leaves are biodegradable since they all break down quickly. This is why they are put into composts: they break down, forming simple substances that can then be used to fertilise other plants. The mould on the strawberry in Figure 2.1.7 shows that it is biodegradable. Animals are biodegradable because bacteria quickly break them down into simpler substances once they die.

Anything made of natural, living substances (or from substances that once lived) is usually biodegradable too. Some examples shown in Figure 2.1.8 are:

- paper and cardboard (made from wood)
- cotton, hessian, linen fabrics (made from plants)
- woollen fabrics (the 'hair' of animals like sheep and goats)
- soaps (made from natural fats and oils).

Non-biodegradable

Non-biodegradable substances eventually break down but often take hundreds of years to do so. Non-biodegradable substances have structures that bacteria and fungi cannot pull apart. Even though most plastics are made from a long-dead natural substance (crude oil), their structures are too different from the structures of living substances for them to be biodegradable. Other non-biodegradable substances are:

- cling wrap (used to wrap sandwiches)
- most plastic shopping bags
- wrappers (used for lollies, chocolate bars and ice-creams)
- polystyrene (used for takeaway food)
- house paints
- glass (used for soft drink and sauce bottles)
- metal cans (used for soft drinks and canned spaghetti).

Anything made from these substances therefore remains in the environment as rubbish and pollution for many, many years. They might crush, break or rip into smaller pieces, but their chemicals are still there polluting the environment.

Figure 2.1.8 Biodegradable sustances like soap, wool, cardboard and vegetable scraps all break down quickly.

Figure 2.1.9 Most plastic bags are not biodegradable and so they don't rot away. If they get washed into rivers and the ocean, wildlife like this bird can get caught up in them and can die.

What can we do?

Most non-biodegradable substances can be burnt but they release toxic (poisonous) fumes and smoke unless the fire happens in special incinerators at extremely high temperatures. Some (like glass bottles and plastics like PET) are able to be recycled. However, most non-biodegradable substances are simply thrown out. To minimise the impact of non-biodegradable substances on the environment, we all need to:

- use biodegradable packaging whenever possible, buying food with no packaging or wrapped in paper or cardboard
- dispose of non-biodegradable packaging in bins, so that it will not end up on the street, rivers and oceans where it may catch and tangle fish, dolphins and birds like the one in Figure 2.1.9
- recycle glass and PET bottles and other plastics wherever possible
- re-use plastic shopping bags or use paper or re-useable cloth bags instead.

Scientists have developed biodegradable plastics from plant-based substances but these plastics are more expensive than similar oil-based plastics. They can't be recycled and cannot be used for long-term packaging. For these reasons, their use is not yet widespread.

2.4
2 p48

2.1 Unit review

Remembering

1 **List** the three states of matter commonly found on Earth.

2 **State** whether the following are solids, liquids or gases.
- **a** a sugar cube
- **b** ink
- **c** air

3 **List** the different states in which different substances exist in the following mixtures.
- **a** soft drink
- **b** chicken curry
- **c** mud

4 **List** two physical properties and one chemical property of a sheet of paper.

5 **List** four biodegradable and four non-biodegradable substances.

Understanding

6 **a** **Explain** why plasma is usually found in stars but rarely on Earth.
- **b** **Describe** the conditions on Earth that allow plasma to form.

7 **Define** the terms:
- **a** compress
- **b** incompressible
- **c** biodegradable.

8 **Explain** how the compressibility of gases makes them ideal for using in shock absorbers in the suspension of cars and bikes.

9 **a** **State** what causes humidity.
- **b** **Describe** what a humid day feels like.

10 **Describe** evidence that tells you that the following are biodegradable.
- **a** a banana
- **b** a sausage

Applying

11 **Identify** an appropriate substance from which to make the walls of a compost bin.

12 A log in the forest grows mushroom-like fungi on it.
- **a** **Use** this information to **state** whether the log is biodegradable or not.
- **b** **Describe** what will be left of the log after 10 years.

Analysing

13 Each of the following substances displays properties of both liquids and solids. **Analyse** the properties of each and use them to **classify** each as solid or liquid.
- **a** sand
- **b** toothpaste
- **c** hair gel

14 **Classify** faeces as biodegradable or non-biodegradable.

Inquiring

1 People are becoming more aware of the effect that plastics like PVC and polystyrene have on the environment. Research how their use has changed because of this awareness.

2 Investigate the guidelines of your local council regarding what can be recycled and what cannot.

3 Design a way of comparing two different substances that can be used for the same purpose (such as the strength and biodegradability of paper and plastic bags, the frothing and cleaning abilities of soap and detergent, or the strength, flammability and biodegradability of natural and synthetic fabrics). Show your plan to your teacher. Once you have approval, test your substances.

4 Oobleck is an easy-to-make slimy goo with such strange properties that it is classified as a 'non-Newtonian' liquid. Basically this means that it is a liquid that doesn't act normally. Search the internet to find recipes or videos showing how to make oobleck. Then make some!

2.1 Practical activities

1 Slime

Purpose
To make slime and observe its properties.

Materials
Note: PVA tends to change consistency depending on the brand chosen and its age. The quantities of PVA and borax shown below may need to be altered slightly depending on the brand of PVA used.

- 4–6% borax solution
- PVA glue
- food dye
- eye dropper/Pasteur pipette
- disposable medicine measuring cup
- 10 mL measuring cylinder
- 2 disposable plastic cups
- icy-pole stick

SAFETY

Wear safety glasses at all times.

Borax can stain, so wash your hands thoroughly after the practical activity.

Procedure
1. Use the measuring cylinder to measure out 10 mL of borax solution.
2. Use the disposable medicine measuring cup to measure out 25 mL of PVA glue.
3. Pour the PVA into a disposable plastic cup, using the icy-pole stick to scrape the last bits out.
4. Add a few drops of food dye to the PVA.
5. Pour the borax solution, all at once, into the cup containing the PVA and food dye.
6. Empty out the slime and rinse it gently under a slow-running tap.

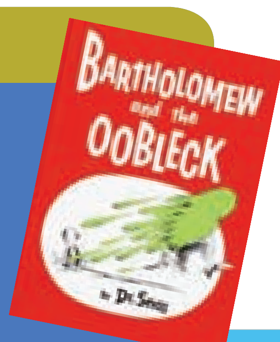
Results
Investigate the properties of slime and record your results in a table like that shown below.

Discussion
1. **List** the physical properties of your slime.
2. **Use** the physical properties of solids and liquids to **classify** your slime as solid or liquid.
3. **Justify** your choice.

Investigation	Observation	Is this property more like that of a solid or a liquid?
Can slime be rolled into a ball?		
What happens when slime is stretched?		
Does slime flow to take the shape of its container?		
What happens when a ball of slime is dropped?		

SciFile

The Oobleck of Dr Seuss
In the book *Bartholomew and the Oobleck* by Dr Seuss, a king is so bored with ordinary weather that he instructs his wizard to create something new. A green goo called oobleck soon falls from the sky, gumming up the whole kingdom!



2.1 Practical activities

2 What's biodegradable and what's not?

Purpose

To assess how biodegradable different substances are.

Materials

- 4 samples each of different substances or packaging materials such as polystyrene takeaway containers, plastic bags, paper bags, reuseable cotton bags (or any cotton sample), newspaper, PET plastic drink bottles, waxed cardboard juice containers, plastic netting (used for oranges)
- wooden pegs or camp pegs
- access to different environments in which samples can be left undisturbed for at least 3 months. Suggestions are:
  - open, exposed area in sunlight
  - compost bin or pile of grass clippings and leaves
  - sandpit or similar
  - garden bed
- rubber gloves

SAFETY

Wear rubber gloves at all times when handling sand, dirt, compost and samples.

Procedure

1. Use the wooden stakes or camp pegs to spread and peg out one sample of each substance in the sunlight.
2. Bury one sample of each substance in the compost bin, another in a sandpit and another in a garden bed.
3. Wet each sample thoroughly in each different environment.
4. Leave for a month and record what the samples left in the sunlight look like. Look for signs of breakage, mould and discolouration.
5. Carefully dig out the other samples and again record your observations. Re-bury the samples.
6. Observe again after another month and then at the end of a third month.
7. At the end of three months, throw any samples that have not decomposed into the bin or recycle bin. (Check whether they have a triangle with a number in it. If they do, then they are usually recyclable.)

Results

In your workbook, construct a table like that below. Use it to record your observations over the 3 months.

Discussion

1. **Classify** each of the substances as biodegradable or non-biodegradable.
2. **Assess** whether 3 months is really long enough to test whether a material is biodegradable or not.
3. Discolouration is a sign that the sample is beginning to rot. **Propose** what might be causing the change of colour.

Substance	Observation Month 1	Observation Month 2	Observation Month 3
Polystyrene			
Plastic bag			
Paper bag			
Newspaper			
PET plastic bottle			
Waxed cardboard			
Plastic netting			

2.2 Solids, liquids and gases

Each of the states of matter has its own characteristic properties that can be explained using a simple model called the particle model.

INQUIRY science 4 fun

The weight of a gas

Does gas have weight?

Yes

Collect this ...

- 2 balloons
- 3 lengths of string (each about 30 cm long)
- 1 m ruler
- needle (sharp enough to burst a balloon)

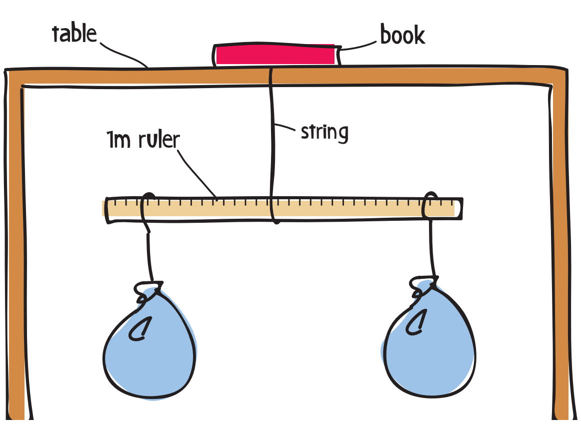
Do this ...

1 Inflate both balloons until they are roughly the same size.

2 Tie their ends and tie a piece of string to the top of each balloon.

3 Tie one balloon to one end of the ruler and the other balloon to the other end as shown in the diagram. Use the ruler markings to make sure that the strings are the same distance from the ends of the ruler.

4 Tie the third string to the middle of the ruler and hang the ruler from the edge of a table.



5 Balance the ruler so that it hangs parallel to the floor. Do this by sliding the middle string along the ruler until you find the balance point.

6 Puncture *one* of the balloons with the needle and observe what happens.

Record this ...

Describe what happened.

Explain why you think this happened.

Particles and atoms

Scientists have long wondered what makes up substances. The ancient Greeks thought that all substances were built up from incredibly tiny building blocks known as particles. They even gave these particles a name: *atomos*. We now call these particles **atoms**. Atoms are the particles all matter is made from. Atoms are far too small to be seen with your eyes or even with a normal microscope, but they can sometimes be seen with a powerful type of microscope called a scanning tunnelling microscope (STM). An example is in Figure 2.2.1. STMs are incredibly powerful and expensive and so only a few universities and research laboratories in Australia and around the world have them.

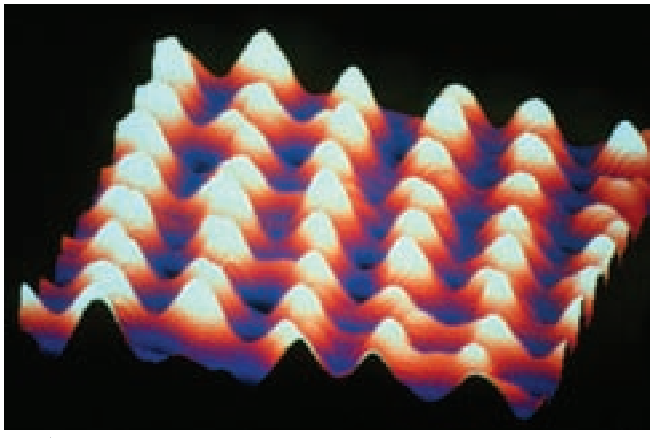


Figure 2.2.1 Each bump in this STM image represents an atom.

Models in science

The physical properties of solids, liquids and gases can be described by the way the particles or atoms that make them up are arranged. Atoms are invisible to all but an STM, however, and this makes an explanation of the properties of solids, liquids and gases extremely difficult. To get over this difficulty, scientists have developed a model called the **particle model** to explain what is happening. Models are often used in science to test or explain something that is difficult to understand. One type of scientific model is shown in Figure 2.2.2.

Figure 2.2.2 Models allow scientists to test ideas and explain what is happening in the world around them. This is a model of a robotic explorer to be used on Mars.

The particle model

In the particle model, atoms are thought of as incredibly small, hard, spherical balls. Each ball has energy and moves according to how much energy it has. If a particle has lots of energy, then it will move about a lot. If the particle has very little energy, then it will be sluggish and move about slowly. You add energy to **matter** whenever you heat it. This causes the particles to move about more, and faster. If you cool a substance, then the reverse happens: the particles move about less and move more slowly.

The particle model assumes the following:

- All substances are made up of tiny, hard particles that are too small to see.
- The particles always have energy and are moving.
- The particles move about more and move faster as temperature is increased.
- Particles are attracted (drawn) to each other. The closer the particles are to one another, the stronger the attraction between them.

Explaining solids

In solids the particles are closely packed in fixed positions. Forces between neighbouring particles form **bonds** that hold all the particles in the solid closely together. The particles in a solid have energy and jiggle about as shown in Figure 2.2.3. The particles don't break out of position but just **vibrate** about on the spot. If you increase the temperature, the particles have more and more energy and so they vibrate about more and more.

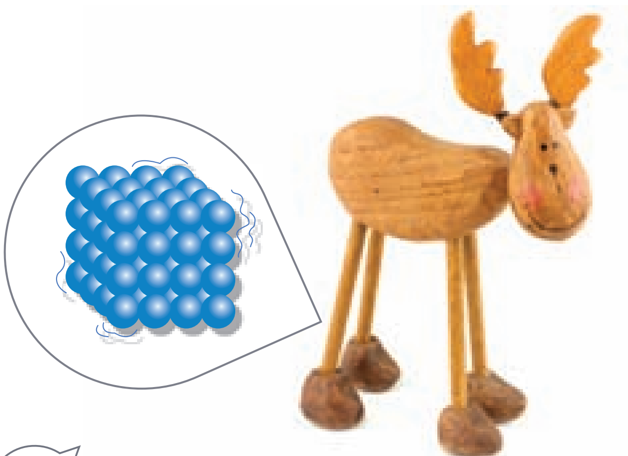


Figure 2.2.3 The particles in a solid are closely packed together and just jiggle about on the spot.

Table 2.2.1 How the particle model explains the physical properties of solids

Property of solids	How the particle model explains it
Solids have a defined shape (they do not flow).	The particles in solids are strongly bonded to their neighbours, fixing their positions.
Solids are incompressible.	The particles in a solid cannot be pushed closer to each other because they are so closely packed that there is almost no space between them.
Solids expand when heated and contract when cooled.	Heating causes the particles in a solid to vibrate faster, making them spread further apart and causing the solid to expand. Cooling slows down vibrations and the opposite happens.

Explaining liquids

In a liquid, the particles are still packed closely together but they are far more loosely bonded (joined) to their neighbours than the particles are in a solid. This is shown in Figure 2.2.4. The loose bonding allows the particles to move about and over each other, allowing the liquid to flow, drip and fill the bottom of whatever container it is in. As the liquid is heated, this movement gets faster.

Figure 2.2.4 The particles in a liquid are packed closely together but are able to move about and over one another. This gives the particles the ability to flow.

Table 2.2.2 How the particle model explains the physical properties of liquids

Property of liquids	How the particle model explains it
Liquids flow to take the shape of the bottom of their container.	Bonds are strong but loose enough to allow the particles in liquids to slip over one another.
Liquids are incompressible.	The particles in a liquid cannot be pushed closer to each other because they are so closely packed that there is almost no space between them.
Liquids expand when heated and contract when cooled.	Heating causes the particles in a liquid to move over each other faster, making them spread further apart and causing the liquid to expand. Cooling slows down this movement and the opposite happens.

Explaining gases

Gases have nothing holding their particles together. This lack of bonds allows the gas particles to travel randomly in straight lines until they hit something, either other gas particles or the walls of the container they are in. This is shown in Figure 2.2.5.

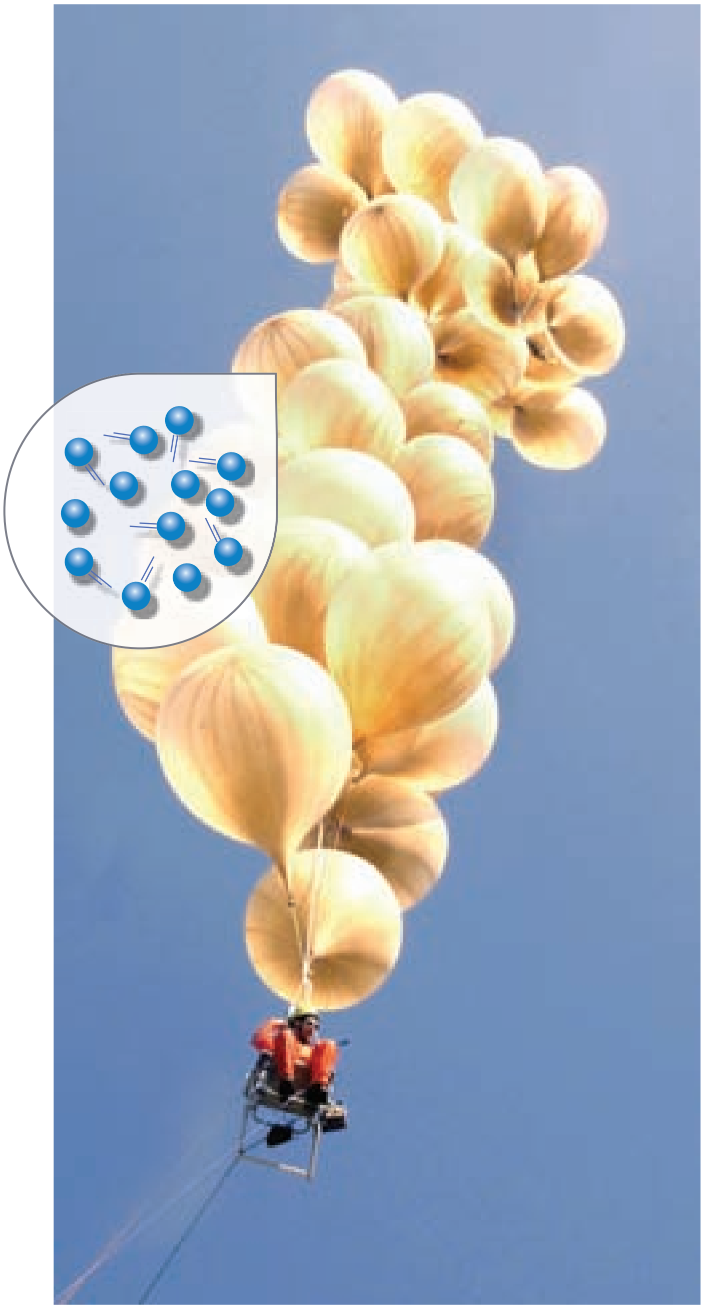


Figure 2.2.5 The particles in a gas are a long way apart and move fast and in straight lines. They only change direction when they hit the walls of their container or each other.

Table 2.2.3 How the particle model explains the physical properties of gases

Property of gases	How the particle model explains it
Gases are often invisible.	Particles in a gas are spread so far apart that you cannot see the gas.
Gases can be compressed.	Particles in a gas are spread so far that there is plenty of vacant space between them. This space allows them to be pushed closer together.
Gases spread to fill their container.	There are no bonds between gas particles and so they are able to move unrestricted by other particles. They travel until they hit the walls of the container.
Gases expand when heated and contract when cooled.	Heating causes the particles in a gas to move faster, making them spread further apart and causing the gas to expand. Cooling slows down this movement and the opposite happens.

SciFile

Colder than cold

As a solid is cooled, energy is removed from its particles, making them vibrate less and less. Eventually they have no energy at all and all vibrations stop. This happens at a temperature of **absolute zero** (–273°C). The particles can't move any slower and so absolute zero is the lowest temperature that is possible.

SCIENCE AS A

HUMAN ENDEAVOUR

Nature and development of science

Robert Brown

Figure 2.2.6 Pollen grains are incredibly light and can be jostled about by water particles. This jostling became known as Brownian motion.

Scientists had an extremely good idea about the particles that made up matter well before the invention of the scanning tunnelling microscope (STM).

This is because you don't always need to see something to know that it exists. Observations indicated that, although they are 'invisible', atoms do exist. These types of observations are known as indirect evidence. You use indirect evidence every day: you know what you are having for dinner from smells coming from the kitchen, and you can often guess what's in a package by its weight and shape and the sounds it makes.

Some of the most convincing indirect evidence for particles came from the work of the Scottish botanist Robert Brown. In 1827, Brown was using his microscope to study tiny pollen grains like those on the bee in Figure 2.2.6 that were floating on some water. He expected the pollen grains to be still but they were moving about, as if being jostled about by something invisible in the water. His sketches of their motion are shown in Figure 2.2.7. Brown could not explain what was happening and it was 1905 before Albert Einstein explained it: 'invisible' particles in the water were constantly moving about, colliding with the pollen grains and pushing them around as they did so.

Brown was not the first to notice this type of motion. In 1785, Jan Ingenhousz had observed similar movement in coal dust suspended in alcohol, and the ancient Roman Lucretius wrote in around 60 BCE of dust particles jiggling about in a beam of sunlight. You may have already noticed something similar. This jiggling eventually became known as **Brownian motion**.

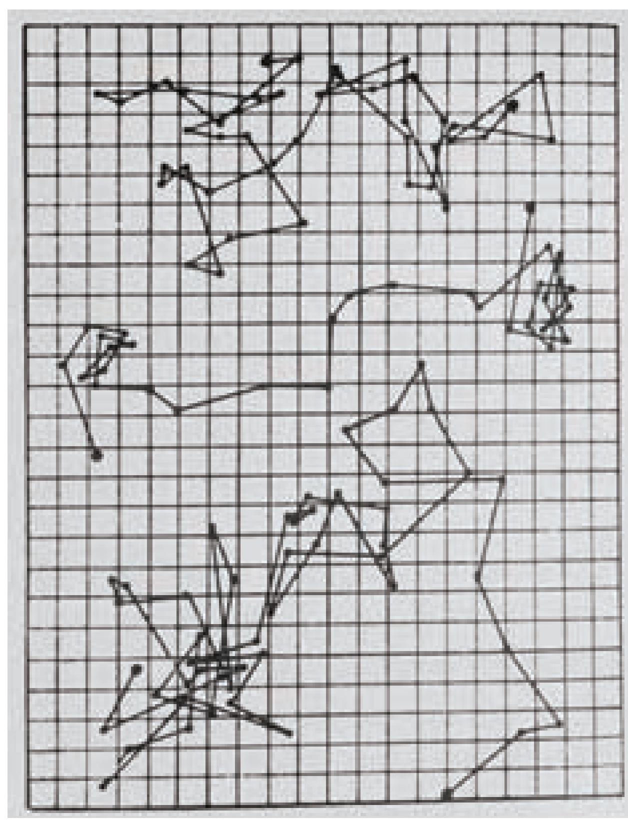


Figure 2.2.7 Robert Brown's original notes marking the positions of pollen grains every 30 seconds.

2 p55

2.2 Unit review

Remembering

1 **State** what causes atoms to move constantly.

2 **State** what temperature is absolute zero.

Understanding

3 Match the state of matter with the movement its particles that **describes** it best.

Solid	Particles move very fast in straight lines.
Liquid	Particles vibrate on the spot.
Gas	Particles vibrate but can also move over one another.

4 **Explain** what happens to the particles in a substance when it is:
- a heated
- b cooled.

5 **Describe** the arrangement of the particles in a:
- a solid
- b liquid
- c gas.

6 **Define** the following terms.
- a vibrate
- b bonds

Applying

7 **Use** the particle model to **explain** why:
- a solids keep their shape
- b a gas can be compressed
- c liquids take the shape of the container they are poured into
- d a solid cannot be compressed.

8 The idea of Brownian motion came from scientific observation. **Identify** the observations Robert Brown made.

Evaluating

9 Barbecue gas cylinders are usually weighed as they are being filled. **Propose** a reason why.

10 Inspect the apparatus shown in the science4fun activity on page 49. Two balloons full of air are balancing on a metre ruler.
- a **Predict** what will happen when one of the balloons is burst.
- b **Justify** your prediction.

Creating

11 **Construct** a Venn diagram showing which properties are shared between solids, liquids and gases and which properties belong to only one state. Follow these instructions.
- a Copy Figure 2.2.8 into your workbook.

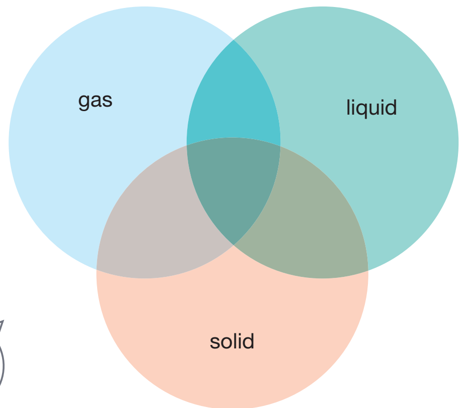


Figure 2.2.8

- b **Identify** which of the following properties is shared by all three states and write it in the overlap of all three circles.

  has energy, fixed shape, changing shape, fixed volume, changing volume, can be compressed, incompressible, closely packed, loosely packed
- c **Identify** the properties shared by two states (for example, solid and gas) and list them in the relevant overlaps.
- d **Identify** the properties displayed by only one state and list these in the appropriate spaces.

Inquiring

1 Search the internet for animations showing how Brownian motion occurs.

2 Construct a biography for Robert Brown in which you outline his achievements.

2.2 Practical activities

1 Compressing liquids and gases

Purpose

To determine whether liquids and gases can be compressed.

Materials

- plastic syringe (without needle)
- 250 mL beaker
- water

SAFETY

Do not use the syringe to squirt water at other people.

Procedure

1 You are about to use a syringe to try to compress water and then try to compress air.

Predict what will happen. Will you be able to compress either of them? If so, which do you think you will able to compress?

2 Fill the beaker with water and use the syringe to suck up water until it is full.

3 Push the nozzle of the syringe against your finger as shown in Figure 2.2.9.

4 Push the plunger down and observe what happens. Can you compress the water?

5 Take the syringe apart, empty it of its water and re-assemble it.

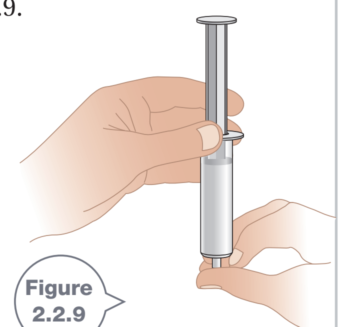


Figure 2.2.9

6 The syringe is now full of air (with a little water that will help seal it). Once again, push the nozzle against your finger and attempt to push the plunger down. Observe what happens. Can you compress the air?

Discussion

1 **Explain** your observations in terms of the spacing of particles in liquids and gases.

2 **Construct** a conclusion about what materials can and cannot be compressed.

2 Indirect evidence

Purpose

To show that you don't always need to see something to know what it is.

Materials

- at least 1 matchbox
- assortment of 'secret' small objects, each one able to fit in the matchbox (for example, an eraser, paperclip, stone, cork, match, pen top)

Procedure

1 Pair up with a classmate. One of you is to place a 'secret' object in the matchbox.

2 The other of the pair is to predict what is in the box without opening it.

3 After a few attempts, swap roles.

Discussion

1 **State** how accurate this method was in determining what is in the matchbox.

2 **Assess** whether you actually need to see something to know that it's there and what it is.

2.3 Changing state

Liquid water freezes to form frost on cold mornings. When it's really cold water can form ice and snow. As the temperature increases during the day, the frost, ice and snow begin to melt to form pools of liquid water. Water can be changed from one state into another by adding energy to it or by removing energy from it. This is done by heating it up or cooling it down.

Adding heat

A solid, liquid or gas might just increase its temperature when heated. If you add enough heat, however, then the substance will change its state. Given enough heat, solids will change into liquids and liquids will change into a gas, as shown in Figure 2.3.1.

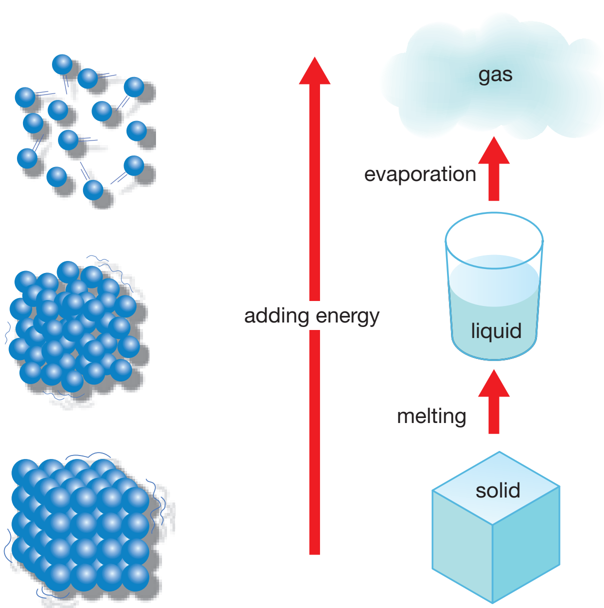


Figure 2.3.1 Adding heat to a solid or liquid causes its particles to move about more, and faster. If enough heat is added, particles break free from each other and the substance changes state: it may melt, evaporate or sublime.

Melting

Melting is the process in which heat causes a solid to change into a liquid. Although the physical properties of the substance change, the substance itself is exactly the same as it was before. Ice (solid water) is exactly the same substance as the liquid water it melts into when it is heated. Likewise, the solid wax that makes up a candle is exactly the same substance as the clear, molten drips of wax that slide down its side.

Heat adds energy to the particles in a solid, making them vibrate faster. If you add enough heat, then the particles at the edges of the solid will be vibrating so violently that they will break free, allowing them to melt away from the others in the solid. You can see this in the melting butter in Figure 2.3.2.

Melting point

The temperature at which a solid melts is known as its **melting point**. A substance is solid below its melting point and is molten (a melted liquid) above it. Water, for example, has a melting point of 0°C.

Different substances have different melting points, as shown in Table 2.3.1.

Figure 2.3.2 Melting starts at the edges of the solid becasue these particles are the first to receive heat from outside. This is why butter and ice cubes melt from the outside towards the centre.

Table 2.3.1 The boiling, melting and freezing points of various substances

Substance	Boiling point (°C)	Melting point (°C)	Freezing point (°C)
Ethanol (alcohol)	78	114	114
Water	100	0	0
Mercury	357	39	39
Silver	2193	961	961

Evaporation

Evaporation is the process in which heat causes a liquid to change into a gas. Evaporation is sometimes also known as **vaporisation**. Heat, for example, causes liquid water to evaporate (or vaporise), turning it into the gas known as water vapour. Wet clothes eventually dry out because the liquid water in them has evaporated to become water vapour. This water vapour then escapes from the clothes and joins the other gases of the air. Figure 2.3.3 shows this process being used.

The bonds between the particles in a liquid are just strong enough to hold them all together to form a fixed volume of liquid. These bonds are too weak to stop the particles from moving about within the liquid, slipping and sliding over one another. Adding energy to a liquid causes its particles to move faster and loosens their bonds even more. If sufficient energy is added, then the particles at the liquid surface move so fast that they can break away completely from the rest of the particles in the liquid. They are now particles of gas, and escape into the atmosphere.

Figure 2.3.3 Evaporation always occurs at all temperatures because there will always be some particles moving fast enough to break free from the liquid. This explains why clothes on the line will eventually dry, even on cold days.

Boiling

Boiling is a special case of evaporation. Evaporation occurs at any temperature, but boiling only happens at a temperature known as the **boiling point**. Boiling is obvious because bubbles appear throughout the liquid. These bubbles are formed by the evaporation of pockets of liquid deep inside the liquid. These pockets change into gas, which expands to form a bubble. The bubble then rises and escapes into the atmosphere when it reaches the surface of the liquid.

Boiling point

The boiling point of a substance is the temperature at which it changes from a liquid into a gas. Water has a boiling point of 100°C. This represents the highest temperature that liquid water can be, and the lowest temperature at which water vapour can be.

Sublimation

Most substances change from solid to gas in two stages: first they melt, and then they evaporate. A few substances change from solid into a gas directly, without going through a liquid stage. **Sublimation** is the process in which heat causes a solid to change directly into a gas.

Two substances that sublime are iodine and solid carbon dioxide (dry ice). Figure 2.3.4 on page 58 shows iodine crystals subliming.

Figure 2.3.4 Iodine doesn't melt. Instead, the black crystals sublime to produce a purple vapour (gas).

SKILL BUILDER

Identifying boiling

Although boiling is accompanied by the release of bubbles from deep within a liquid, it is not the only time bubbles are released when a liquid is heated. Most liquids contain some dissolved gases, such as the oxygen that fish use to breathe. These gases form small bubbles soon after heating begins and can trick you into believing that boiling is happening. However, the bubbles appear at temperatures well below the boiling point and are generally much smaller than big bubbles seen at boiling, shown in Figure 2.3.5. After a short time, these small bubbles stop being released and no more bubbles appear until the liquid itself is boiling.

Figure 2.3.5 Continuous bubbling is a sign of boiling.

Removing heat

The temperature of a substance drops when heat is removed from it. A substance might change state if sufficient heat is removed from it, as seen in Figure 2.3.6.

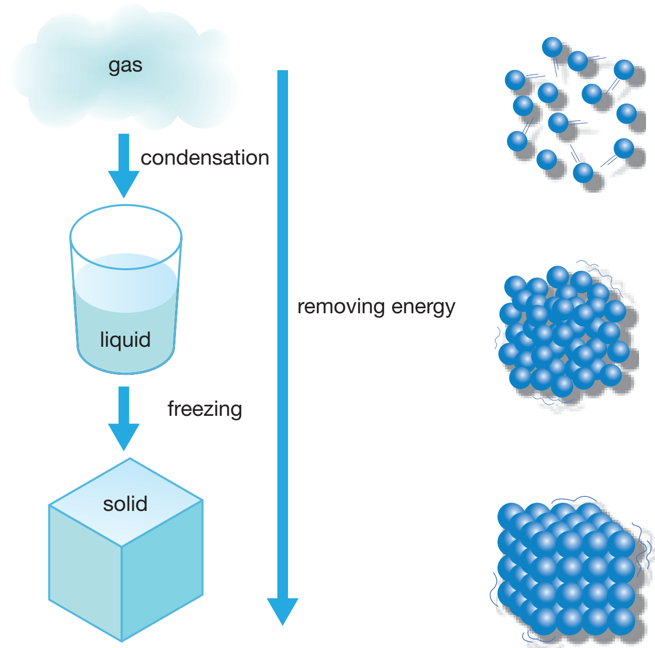


Figure 2.3.6 Substances will condense, freeze or deposit if enough heat is removed from them.

Freezing

Freezing (also known as **solidification**) occurs when heat is lost and a liquid changes into a solid. An example of freezing is shown in Figure 2.3.7. These snowflakes show some of the amazing shapes that can form.

Figure 2.3.7 Snow is a form of ice. It is caused by liquid water freezing around a speck of dust high in the atmosphere to form fantastically shaped snowflakes. Likewise, frost is dew (liquid water) that has frozen overnight.

As a liquid cools, energy is lost from its particles and the particles move more slowly than before. If you remove enough energy, the particles will end up just vibrating on the spot. Bonds form between the particles, locking them into their position to form a solid of definite shape and size.

Freezing point

The **freezing point** is the temperature at which a liquid changes into a solid. Freezing is the opposite process to melting, and so freezing and melting occur at exactly the same temperature. For water, the freezing point is the same as its melting point: 0°C.

INQUIRY

science 4 fun

Role play

No

Collect this ...

- masking tape
- a clear space of floor (a carpeted area is ideal)

Do this ...

1. Use the masking tape to mark out a closed rectangle on the floor or on a grassed area.
2. Stand within the marked-out area with all the other students in the class.
3. Imagine you are all particles within a solid and that the masking tape represents solid walls. Move about to model what the particles would be doing when:
   - very cold
   - the solid is being heated
   - the solid is starting to melt
   - the liquid formed is being heated
   - the liquid is starting to evaporate
   - the gas formed is being heated.

Record this ...

Describe what happened.

Explain why you think this happened.

Condensation

Condensation is when a substance loses heat and changes from a gas into a liquid. Your lungs are full of water vapour (gaseous water) that will condense into tiny droplets of liquid water when you breathe out onto something cold, like a window or mirror. Likewise, water vapour in the air will condense on a cold night to form droplets of liquid dew that will make the lawn and spider webs wet. This is shown in Figure 2.3.8.

Figure 2.3.8 The dew on this spider web is caused by water vapour condensing overnight.

As a gas is cooled, its particles slow down. When they have slowed enough, the individual particles begin to attract each other and form bonds that will tie their movement to the other particles in the substance. They now act as a group, forming droplets of liquid.

Steam is water vapour that has condensed to form a cloud of tiny but visible liquid water droplets in the air. Water vapour emerges as a gas from a kettle or from a boiling pot on the stove but quickly cools to form a visible fog of tiny liquid water droplets.

Deposition

Some gases change directly into solids without ever passing through a liquid state. This process is known as **deposition**.

2 p63 2.6 2.7

2.3 Unit review

Remembering

1 **State** the temperature at which liquid water:
a boils b freezes.

2 **Name** two substances that sublime.

3 **State** alternative words for:
a evaporation b freezing.

4 **Recall** the various changes of state by copying and completing Figure 2.3.9.

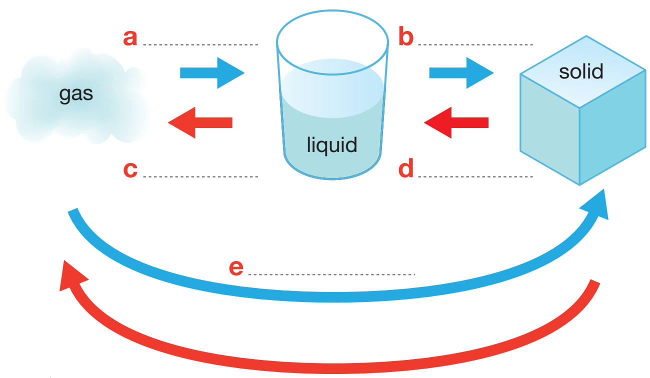


Figure 2.3.9

Understanding

5 **Explain** why the melting point and freezing points of a substance are at exactly the same temperature.

6 **Explain** where all the heat energy is going when a substance is boiling.

7 You peg some wet clothes on a clothes line. **Explain** why the water in the clothes evaporates despite the temperature never getting near the boiling point of water.

8 **Explain** how:
a snow forms
b dew forms
c frost forms.

Applying

9 **Identify** two substances that:
a melt at relatively low temperatures
b evaporate at relatively low temperatures.

10 **Identify** the change of state that happens when:
a ice-cream starts to drip
b jelly sets
c the bathroom mirror gets foggy.

11 **Use** the information from Table 2.3.1 to **predict** what state ethanol, water, mercury and silver would be in at the following temperatures.
a –50°C b –20°C
c 50°C d 200°C
e 500°C f 1000°C

12 Sunglasses often fog up when you walk outside from an air conditioned building on a humid summer day. **Use** the idea of condensation to **explain** why.

13 The addition of impurities such as salt to water does two things to the water: it lowers its freezing point, and it increases its boiling point. **Use** this information to **explain** the following.
a Salt is spread on the roads in northern United States and Canada to help keep the roads clear of ice.
b Additives can stop a car radiator boiling over.
c Ice-cream makers are cooled with a mixture of salt and ice and not just pure ice.

Analysing

14 **Contrast**:
a evaporation and boiling
b melting and sublimation
c steam and water vapour.

Inquiring

1 Find out how additives like antifreeze stop car radiators from freezing.

2 Find out if it is safe to eat snow or drink its melt.

3 Research the differences between techniques for freezing food, such as snap freezing and freeze-drying.

4 Search the internet to download images of the different shapes of snowflakes.

5 Search the internet to find videos of substances that sublime.

2.3 Practical activities

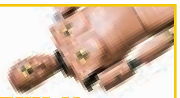
1 Temperature graphs

Purpose

To determine what effect salt has on the melting and boiling points of water.

Materials

- 250 mL beaker
- thermometer
- stirring rod
- spatula or spoon
- stopwatch, watch or clock
- Bunsen burner, bench mat, tripod and gauze mat
- retort stand and clamp
- crushed ice or ice cubes
- water
- salt
- graph paper
- ruler
- grey-lead pencil



SAFETY!

Wear safety glasses at all times.

Turn the Bunsen burner flame to yellow when it is not being used.

Allow the Bunsen burner and other equipment to cool before putting it away.

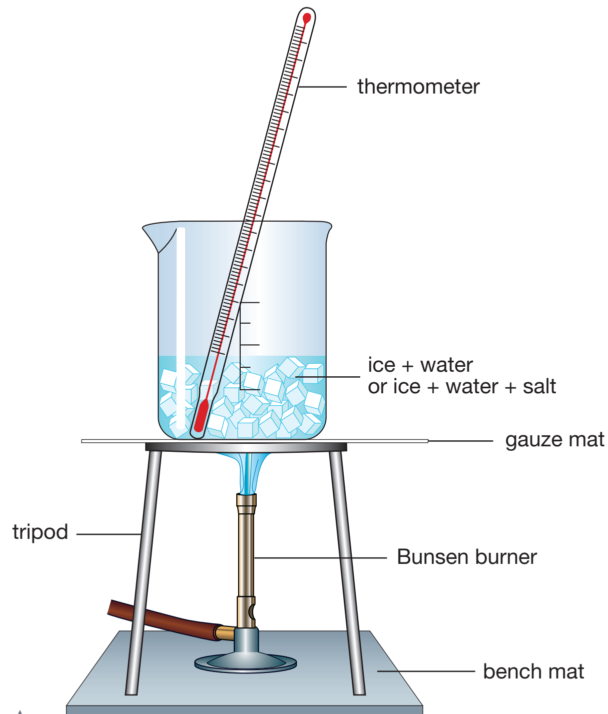


Figure 2.3.10

Procedure

1. Your teacher will tell you which of the following two groups you and your lab partners will be part of:
   - The tap water group: this group will heat a mixture of tap water and ice
   - The salty group: this group will heat a mixture of salt, pure water and ice.
2. Both groups need to add crushed ice or ice cubes to their beaker so that they come up to about the 100 mL mark.
3. Add water to the ice cubes so that it surrounds the ice and also comes up to about the 100 mL mark.
4. The salty group also needs to add salt (a couple of spatula loads or spoonfuls) to their ice/water mixture.
5. Set up the apparatus as shown in Figure 2.3.10.
6. Measure and record the starting temperature of the ice/water or ice/water/salt mixture.
7. Light the Bunsen burner and turn the collar so that the airhole is open and the flame is blue. Start timing immediately.
8. Measure and record the temperature every minute. Use the stirring rod to stir the mixture gently before measuring the temperature.
9. Continue measuring and recording the temperature until the water has been boiling for 2 or 3 minutes. Once it is boiling, you may need to turn the collar on the Bunsen burner to partly close the airhole.

Temperature graphs continued on next page

Temperature graphs continued

10 Copy the graph template shown in Figure 2.3.11 onto graph paper. Ensure that your scale uses equal intervals. Plot your data on the graph and **create** a line graph by joining the points with straight lines.

11 Your graph probably has two parts that are reasonably flat with little or no increase in temperature. Identify those sections of your graph by highlighting them.

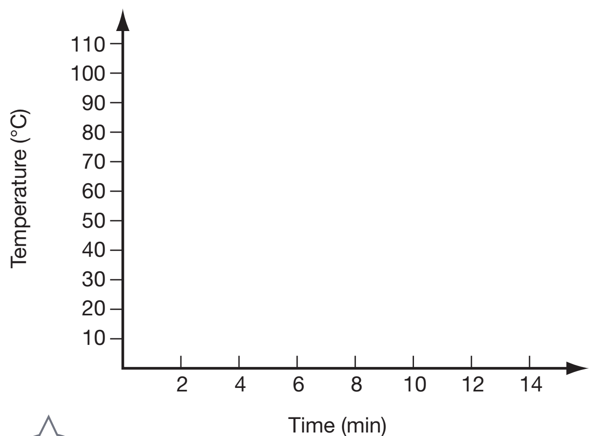


Figure 2.3.11

Discussion

1 **Use** your graph to:

- **a** **identify** the melting point and boiling point
- **b** **state** the water temperature 5 minutes after you started heating
- **c** **state** the time that your sample reached 80°C
- **d** **predict** the temperature of your sample 10 minutes after it started to boil.

2 **Compare** your graph with those of other groups and use the graphs to **compare** the melting and boiling points of salt water with those of tap water.

SKILL BUILDER

Graphing changes of state

A substance changes state because heat causes bonds between its particles to break. Temperature will not change while this is happening, so a graph of temperature versus time will be flat, as shown in Figure 2.3.12.

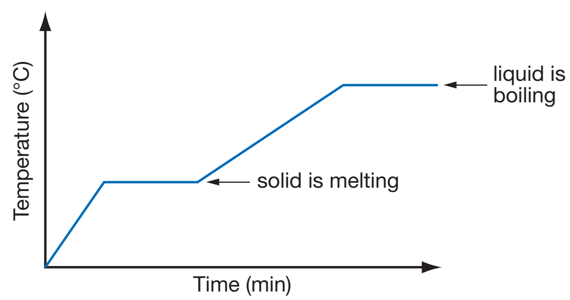


Figure 2.3.12

2 Custard shockwaves

Purpose

To use the increased volume of a gas to create a shockwave.

Materials

- large empty coffee can with lid
- rubber or plastic tubing
- plasticine or Blu Tack
- tea-light candle
- long barbecue matches
- custard powder

SAFETY!

Wear safety glasses at all times.

Make sure everyone stands clear and behind a safety screen.

Can be done as a Teacher Demonstration if preferred.

Procedure

1. Make a hole near the base of the coffee can about the same diameter as that of your tubing.
2. Insert the rubber tubing into the hole and use plasticine or Blu Tack to ensure a good seal.
3. Pour a small amount of custard power into the can so that it covers the end of the rubber tube.
4. Place the tea-light candle opposite the tubing/custard powder as shown in Figure 2.3.13.
5. Use the long barbecue matches to light the candle and immediately secure the lid back on the can.
6. As soon as you can, blow a small puff of air through the tubing.

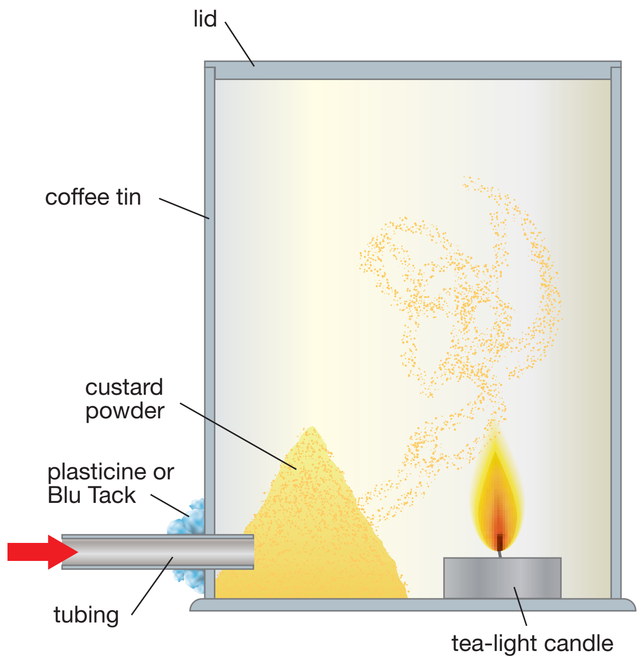


Figure 2.3.13

Results

Describe what happened.

Discussion

1. The flame caused the custard powder to react and burn. **Explain** how you know gases were produced in this experiment.
2. Gases take up far more space than liquids or solids. **Use** this idea to **explain** what happened.
3. A similar sort of explosion happens when gunpowder is ignited in a gun. **Outline** how it could get a bullet moving.

2 Chapter review

Remembering

1 **State** two physical properties each for:
- **a** solids
- **b** liquids
- **c** gases.

2 **State** what happens to particles in the following states when they are heated:
- **a** solid
- **b** liquid
- **c** gas.

3 **Name** the opposite processes to:
- **a** melting
- **b** evaporation
- **c** sublimation.

Understanding

4 Density measures how much of a substance is packed into a certain space. Gases are less dense than liquids or solids of the same material. **Explain** why.

5 **Describe** the property that makes gases ideal for filling jumping castles.

6 **Predict** which of the following is most likely to be the melting point of butter:

A –20°C	**B** 0°C
C 30°C	**D** 100°C

Applying

7 When you dive into a swimming pool, the water parts around you as you enter it. **Use** the particle model to **explain**:
- **a** what happens to the water particles as you dive in
- **b** why the swimming pool water gives you a ‘punch’ in the stomach when you do a ‘bellywhacker’ and not a clean dive.

Analysing

8 **Contrast**:
- **a** melting and sublimation
- **b** melting and freezing
- **c** plasma and gas.

Evaluating

9 **Predict** what might happen when you place an empty balloon around the rim of a conical flask with some water in it (shown in Figure 2.4.1) and heat the flask.

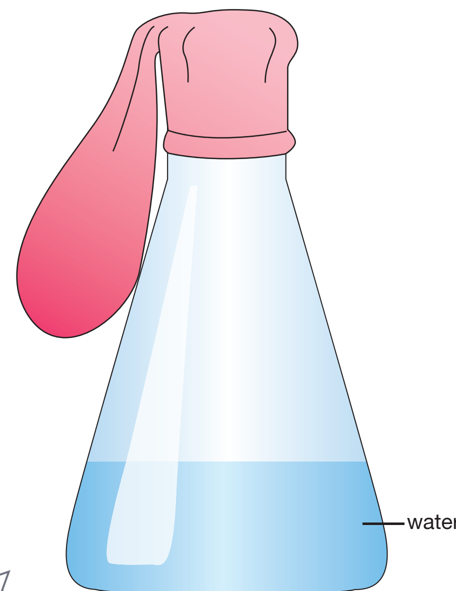


Figure 2.4.1

10 **a** **Propose** what would happen to you if you jumped around in a jumping castle filled with water instead of gas.
- **b** Refer to the particle model to **justify** your prediction.

11 Aerosol cans should never be thrown in a fire. **Propose** reasons why.

Creating

12 **Use** the following ten key words to **construct** a visual summary of the information presented in this chapter.

matter	solid
liquid	gas
melt	freeze
evaporate	condense
sublime	heat

2.8

Thinking scientifically

Q1 The properties of a substance never change. Properties describe what a substance looks like, how heavy, dense, hard and brittle it is and how it acts when heated, cooled or mixed with other chemicals. Below are several statements that describe solid gold. Assess which is *not* a property of solid gold.

A Gold is yellow and shiny.

B Gold melts at a temperature of 1064°C.

C One gram cost $45.40 in May 2010.

D Gold reacts with strong acids to form hydrogen gas.

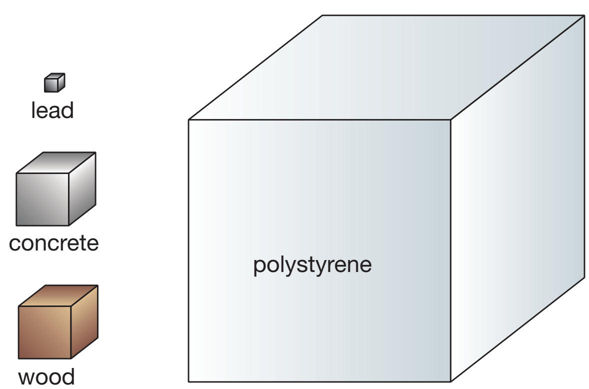
Q2 All the blocks in the diagram below weigh exactly the same. Density measures how much of a substance fits into a volume. Which of the following shows the correct order of densities from highest to lowest density?

A Highest density = concrete, lead, wood, polystyrene = lowest density

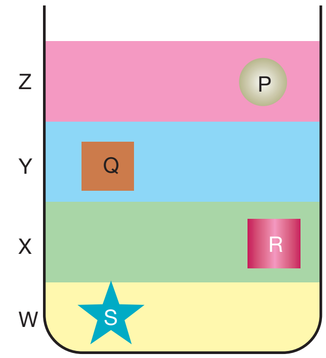
B Highest density = lead, concrete, wood, polystyrene = lowest density

C Highest density = concrete, wood, lead, polystyrene = lowest density

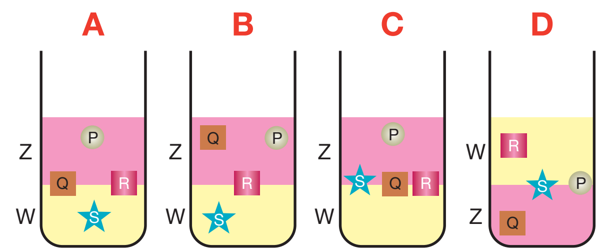
D Highest density = lead, polystyrene, concrete, wood = lowest density



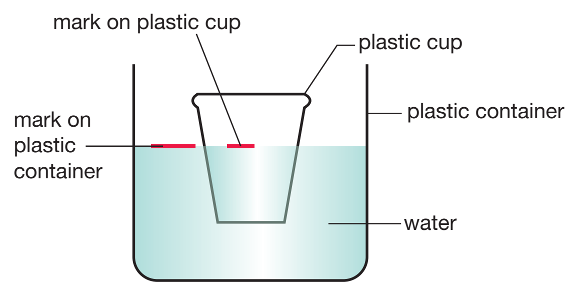
Q3 Liquids do not always mix together. Sometimes one liquid floats on top of another. Alice filled a container with some liquids as shown. P, Q, R and S are different objects floating in the liquids.



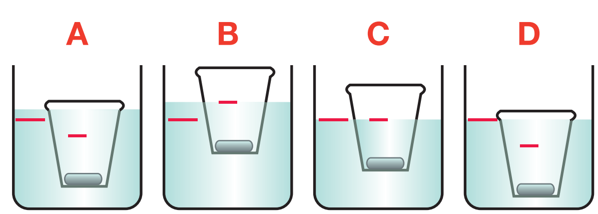
What would happen if liquids X and Y were removed?



Q4 Angus placed a plastic cup in a plastic container filled with water. He marked the level of the water on the cup and the container.



Angus then placed a heavy rock inside the plastic cup. What did he observe?

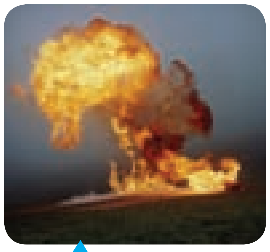


Glossary

Unit 2.1

Biodegradable: bacteria or fungi breaks down the substance into simpler substances

Chemical properties: how substances react with other substances



Chemical properties

Compressed: squashed

Incompressible: not able to be compressed or squashed

Non-biodegradable: doesn't rot or break down

Odour: smell

Physical properties: describe things about the substance like its appearance, melting, freezing and boiling points and its hardness

Plasma: the fourth state of matter; found in sparks, lightning bolts and in stars

States (phases): solid, liquid, gas (also plasma at temperatures over 6000˚C)

Unit 2.2

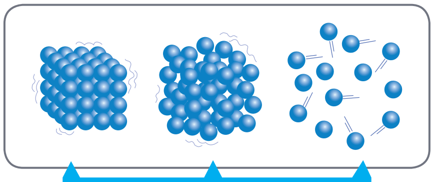
Atoms: the incredibly tiny particles that make up all matter

Bonding: forces of attraction that hold particles together (verb: bonds)

Brownian motion: random motion of particles caused by being bumped and jostled by other particles

Matter: the particles that make up everything

Particle model: the model used to help describe and explain the behaviour of particles in solids, liquids and gases



Particle model

Vibration: jiggling about on the spot (verb: vibrates)

Unit 2.3

Boiling: when vigorous bubbling appears (verb: boils)

Boiling

Boiling point: the temperature at which a liquid boils; 100°C for water

Condensation: removal of heat, changing a gas into a liquid (verb: condenses)

Deposition: a gas changing directly into a solid

Evaporation (vaporisation): heat changing a liquid into a gas (verb: evaporates)

Freezing (solidification): removal of heat, changing a liquid into a solid (verb: freezes)

Freezing point: the temperature at which a liquid freezes; 0°C for water

Melting: heat changing a solid into a liquid (verb: melts)

Melting

Melting point: the temperature at which a solid melts; 0°C for ice

Steam: condensation of water vapour, forming a visible fog of water droplets

Sublimation: a solid changing directly into a gas