Elements, compounds and mixtures

7

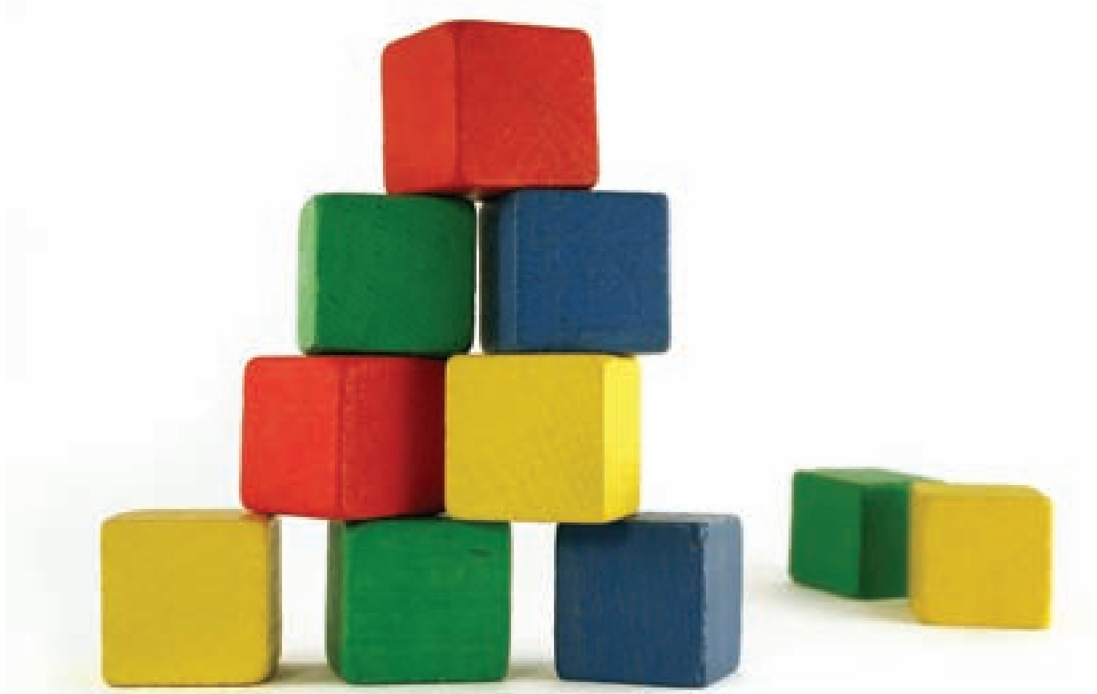
HAVE YOU EVER WONDERED…

- why you can feel a breeze even though it's invisible?
- why diamond is the hardest natural substance on Earth?
- why water can be written as H_2O?

After completing this chapter students should be able to:

- describe differences between elements, compounds and mixtures in terms of the particle model
- describe the arrangement of particles in elements and compounds
- use symbols and formulas for elements and simple compounds
- identify and locate elements on the periodic table
- investigate how the idea of elements has developed over time
- investigate how scientists have created new materials.

7.1 Elements



Elements are the most basic materials for building the world around you—chairs, desks, windows, your skin, the trees, the ocean, the Sun and the stars. By understanding elements, scientists can use them to create new materials for building bridges, powering cars, making clothes and curing disease.

Atomic Lego®

Every substance in the universe is made up of building blocks known as **atoms**. There are only about 100 types of atoms but they can be arranged in different combinations to create countless types of different substances. In this way, atoms are like tiny pieces of Lego. Imagine you just have red, blue and green blocks of Lego. It would still be possible to create many different Lego combinations with just these three types. Figure 7.1.1 shows just a few. In a similar way, the 100 or so different types of atoms can be used to create the millions of substances you see in the world around you.

Unlike blocks of Lego, atoms are round like tiny balls. They are so small that they cannot be seen with even the most powerful optical microscope. Instead, scientists must use a **scanning tunnelling microscope (STM)** to obtain images of atoms such as the copper atoms shown in Figure 7.1.2.

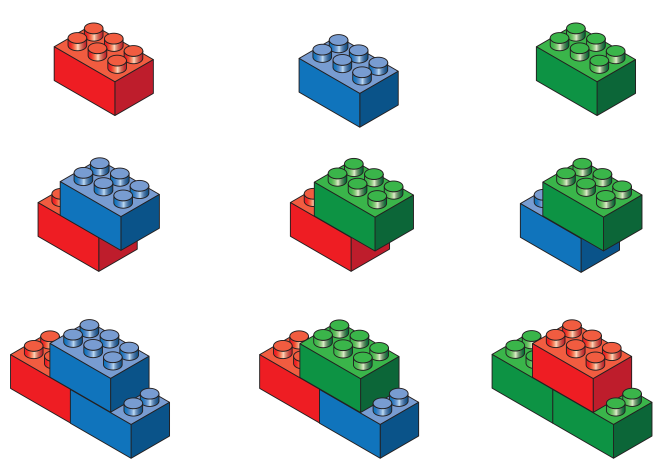


Figure 7.1.1 With just a few types of Lego, you can create many different combinations. Similarly, it takes just 100 or so different types of atoms to make up every substance in the universe.

Elements

Elements are substances that are made up of just one type of atom. Figure 7.1.2 shows an STM image of copper atoms. The air you breathe is mostly made up of two elements—the gases oxygen and nitrogen. Billions of invisible oxygen and nitrogen atoms surround you and they are what you feel hitting your skin when a breeze blows. Apart from these two elements, there are many other elements useful in everyday life. Each element has a unique set of characteristics that scientists refer to as its **properties**.

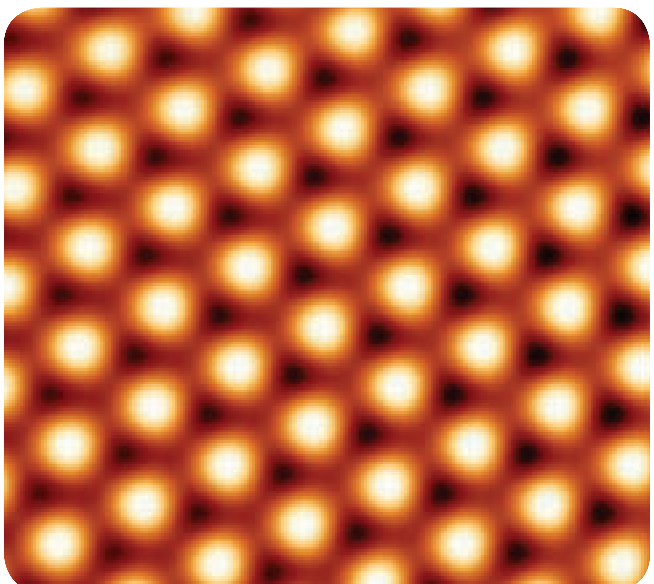


Figure 7.1.2 An STM is the only type of microscope powerful enough to get an image of these copper atoms.

Metallic and non-metallic elements

Elements can be broadly classified into metallic and non-metallic elements. Aluminium, iron, mercury, gold and silver are all examples of metallic elements that are used every day in construction, electronics and jewellery. Metallic elements (such as the ones shown in Figure 7.1.3) all share some properties. **Metals**:

- tend to be shiny (or can be polished to make them shiny)
- are solid at room temperature (except mercury which is a liquid)
- are good conductors of heat and electricity, allowing heat and electricity to flow easily through them
- can be bent and hammered into sheets (when metals act this way, they are referred to as being **malleable**)
- can be stretched into wires (metals are referred to as being **ductile**).

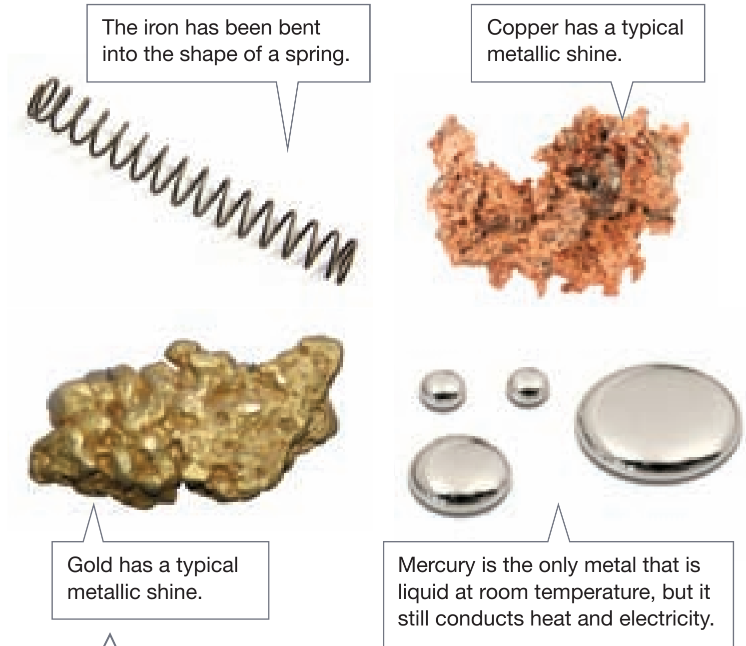


Figure 7.1.3 Common metallic elements

INQUIRY **science 4 fun**

Metals for breakfast

Is the element iron in your breakfast cereal?

Collect this …

- iron-rich cereal such as Special K®
- mixing bowl
- magnet
- sticky tape
- potato masher
- long pencil
- water

Do this …

1. Place 2–3 cups of iron-rich cereal in the mixing bowl.
2. Crush the cereal to pinhead-sized pieces using the potato masher.
3. Add enough water to just cover the cereal and continue to mix with the potato masher for 10 minutes until it looks like soup.
4. Use the sticky tape to attach the magnet to the end of the pencil and use it to stir the cereal soup for 5 minutes.
5. Check the end of the magnet for iron particles.

Record this …

Describe what you saw.

Explain why you think this happened.

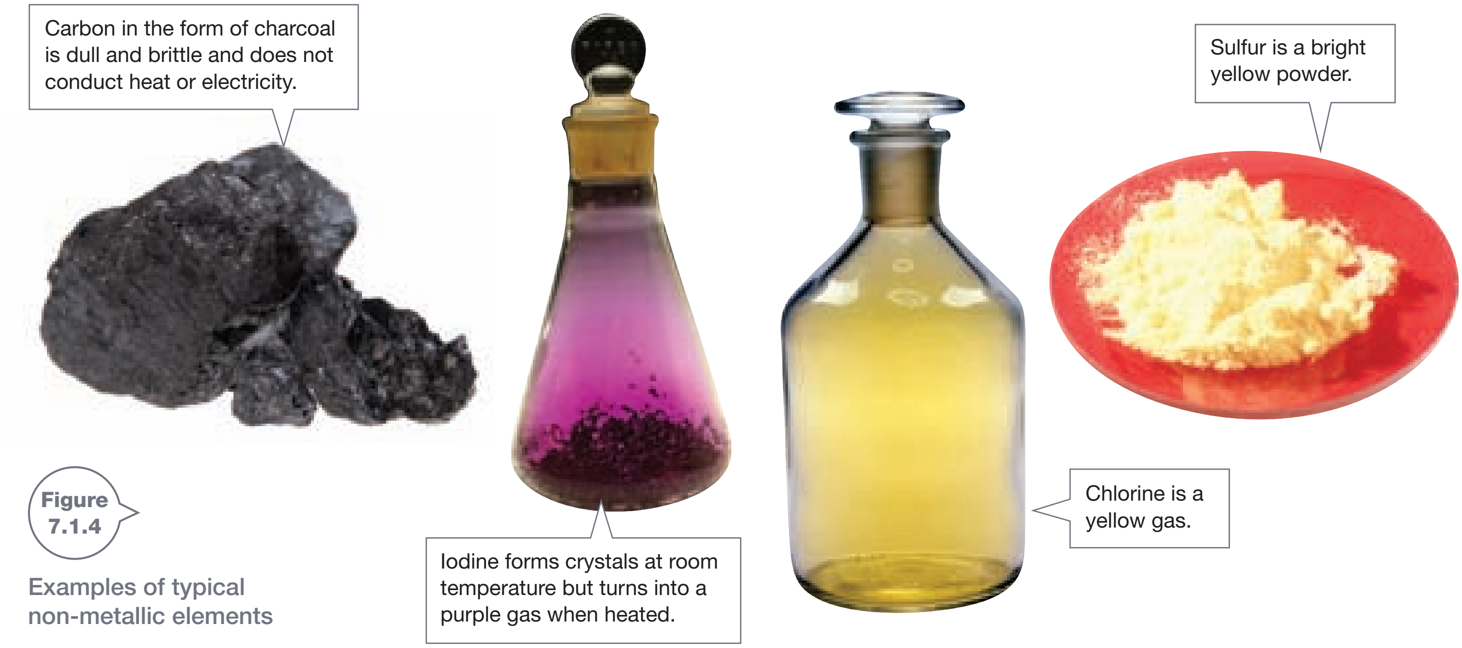


Figure 7.1.4 Examples of typical non-metallic elements

Non-metallic elements tend to be solids or gases at room temperature. Bromine is the only non-metal that is liquid at room temperature. Some non-metallic elements are shown in Figure 7.1.4. **Non-metals**:

- tend to be dull (not shiny)
- do not conduct heat or electricity
- break or crumble when you bend them (non-metals are referred to as being **brittle**).

The black ash or charcoal formed when you burn a piece of paper or wood is made of the element carbon, and is typical of non-metallic solids. The element helium is a non-metallic gas that is light and non-toxic and can be used safely in party balloons.

Naming elements

There are 117 known elements but only 92 of these occur naturally—the rest are synthetic and must be made in a laboratory. Each element has a name and a chemical symbol.

Scientists display all the known elements and their symbols in a table called the **periodic table**, shown in Figure 7.1.6. The periodic table lists the elements from lightest to heaviest and helps scientists to understand some of their physical properties.

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The elements of war

As Figure 7.1.5 shows, the non-metallic element chlorine was used in World War I as one of the first 'weapons of mass destruction'. Chlorine is extremely toxic when breathed in, causing a burning feeling in the chest and painful suffocation. It is much heavier than air so it filled the trenches where the soldiers fought. The first use of chlorine received worldwide criticism but started a trend in chemical warfare. For this reason, World War I is sometimes referred to as 'the chemists' war'.

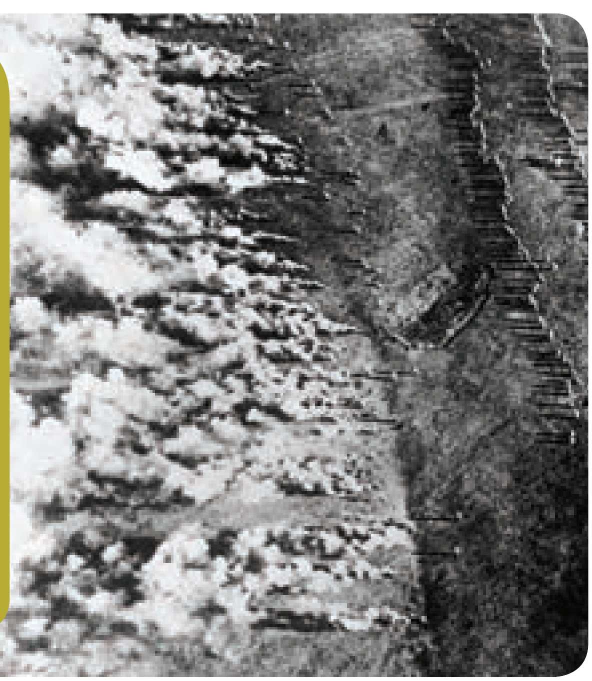

Figure 7.1.5 Chlorine gas floating over the trenches during World War I.

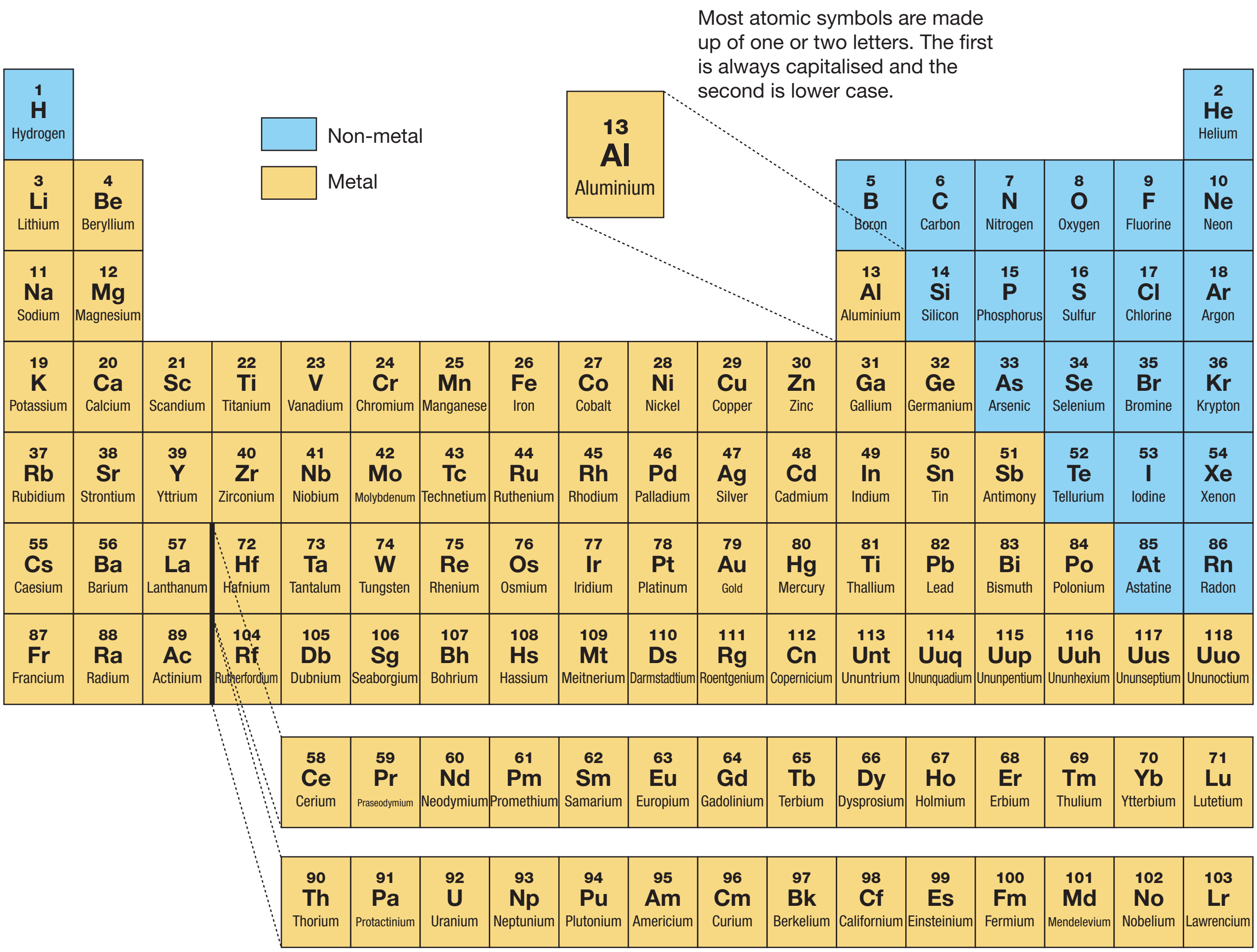

Figure 7.1.6 The periodic table is a list of the known elements from the lightest to the heaviest.

Often the chemical symbol of an element comes directly from its name. For example, the element calcium is given the symbol Ca, carbon has the symbol C and magnesium has the symbol Mg. However, sometimes the symbol of an element does not appear to relate to the name at all. For example, potassium has the symbol K and sodium has the symbol Na. This is because their symbols come from the Latin names for the elements, names which may be different from those used in English. In Latin, the name for potassium is *kalium*, while sodium is *natrium*—knowing this, their symbols K and Na actually make sense.

From the periodic table you can see that the chemical symbol is always made up of one, two or three letters. The first letter is always in upper case and the others are always lower case. So the chemical symbol for chlorine is always written as Cl and never CL or cl.

7.2
7.3

Atoms in elements

Elements are made up of just one type of atom. However, the atoms in elements can be arranged in different ways. The atoms can exist:

- as single atoms (this is referred to as being monatomic)
- in clusters of atoms called molecules
- in large grid-like structures called lattices (like the one in Figure 7.1.7 on page 250).

The way the atoms are arranged in an element determines many of the physical properties of the element. Physical properties include whether the element is solid, liquid or gas, its melting and boiling points, how well it conducts heat or electricity and if it can bend or whether it breaks when a force is applied.

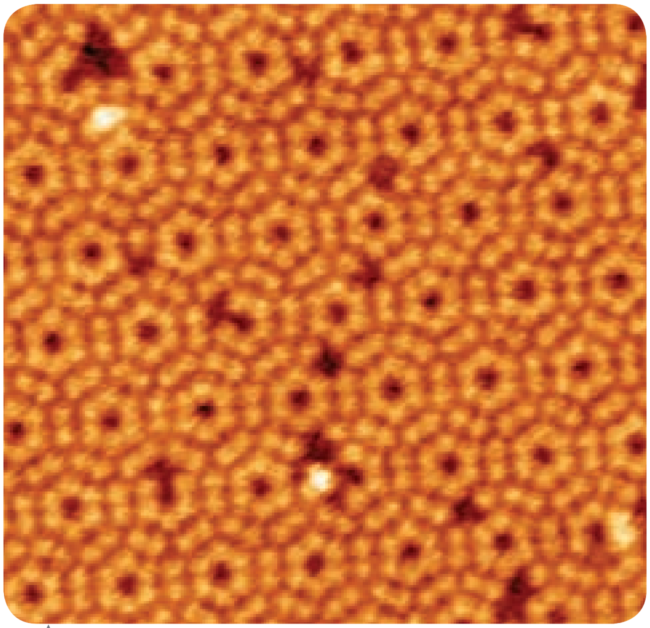

Figure 7.1.7 An image of a lattice of silicone atoms taken with a powerful microscope known as a scanning tunnelling microscope (STM).

Monatomic elements

An element that consists of just single atoms is known as monatomic. **Monatomic** elements are rare, with only six of the 92 naturally occurring elements being monatomic. These are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn). These elements are all non-metallic gases. Three of them are shown in Figure 7.1.8.

The monatomic element helium (He) is used in party balloons because it is lighter than air and so the balloons float. Neon (Ne) is used in neon lights for creating signs of different colours. Old-fashioned light globes contained the monatomic element argon (Ar) to stop the filament from burning.

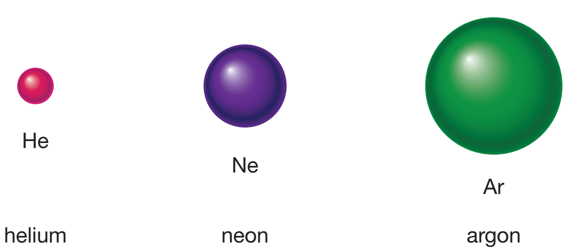

Figure 7.1.8 Helium, neon and argon are monatomic and do not combine with other elements.

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An element by a different name

The symbols for elements sometimes make more sense in other languages. For example, the symbol for silver, Ag (which comes from the Latin *argentum*), makes perfect sense in French (*argent*) and Italian (*argento*). Similarly, the word for sodium in German, Swedish and Norwegian is *natrium*. In these languages, the symbol for sodium, Na, is logical.

Molecular elements

Most non-metallic elements are made up of molecules. **Molecules** are clusters of two or more atoms bonded (joined) together. In a molecular element, all the molecules are identical with the same size, shape, number and type of atoms. Molecules of some common elements are shown in Figure 7.1.9.

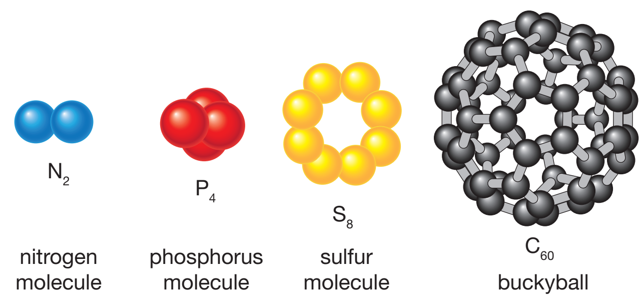


Figure 7.1.9 Non-metallic elements tend to form molecules like these where every molecule contains just one type of atom.

The oxygen you're breathing in right now is made up of billions of oxygen molecules. Each oxygen molecule contains two oxygen atoms. For this reason scientists represent oxygen gas by the molecular formula O_2. Each type of molecule has its own different molecular formula. The molecular formulas show what atoms are in a molecule and how many there are of each. The molecular formula O_2 shows that each oxygen molecule has two oxygen atoms. Other non-metallic elements that are made up of molecules with just two atoms are nitrogen (N_2), hydrogen (H_2) and chlorine (Cl_2).

Some non-metallic elements are made up of molecules with more than two atoms. For example, phosphorus commonly has four atoms, giving it the molecular formula P_4. Sulfur forms ring-shaped molecules of different sizes. One ring has just six sulfur atoms (with a molecular formula S_6) while other rings contain eight sulfur atoms (S_8) and 20 sulfur atoms (S_{20}).

Carbon is unique among the non-metallic elements in that it can form very large molecules of almost any size. The most famous is called the buckyball. This is a molecule that has 60 carbon atoms arranged in the shape of a soccer ball and has the molecular formula C_{60}.

2 p256

Elements in lattices

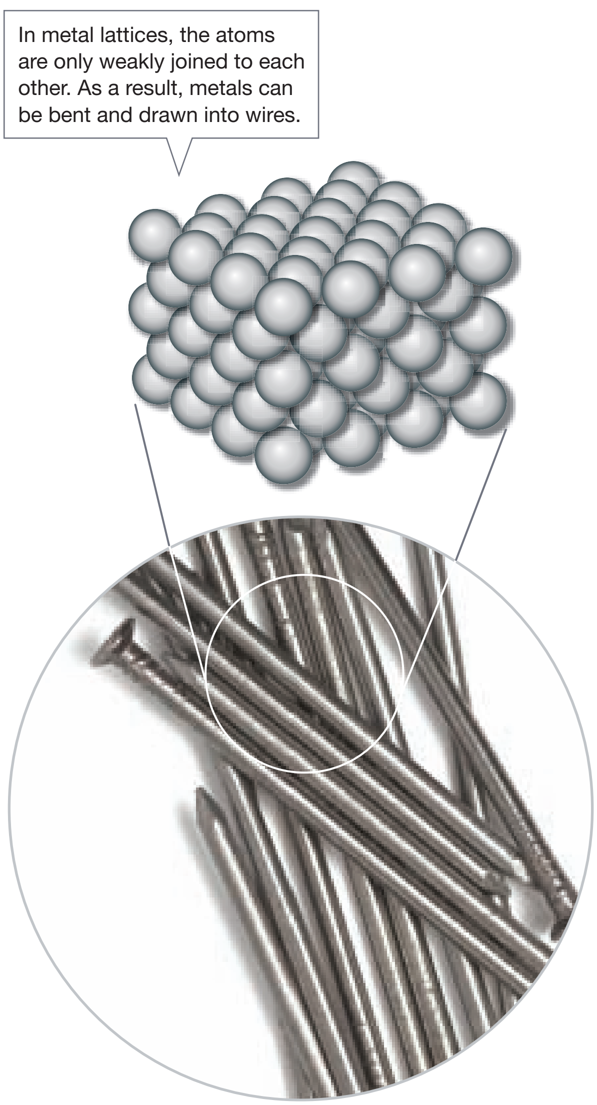
Metallic lattices

Eighty per cent of the known elements are metals. The atoms in metals do not form molecules but instead form large grid-like structures known as crystal **lattices**. An example is shown in Figure 7.1.10. This structure makes metals strong and solid at room temperature (with the exception of mercury, which is a liquid). Unlike non-metallic solids, the atoms in metallic lattices can slide and move over each other without breaking the lattice. This is why metals can be bent, hammered into thin sheets or drawn out into thin wires.

Non-metallic lattices

Only a few non-metallic elements form lattices. A notable example is carbon, which forms crystal lattices to make graphite and diamond (Figure 7.1.10). In these lattices, the atoms are bound tightly to each other and are fixed in position. In graphite, the atoms bond together in sheets that can slide over one another. This makes graphite a good lubricant. In diamond, the carbon atoms are bonded strongly to each other in four directions. This is the reason why diamond is the hardest natural substance on Earth.

7.4



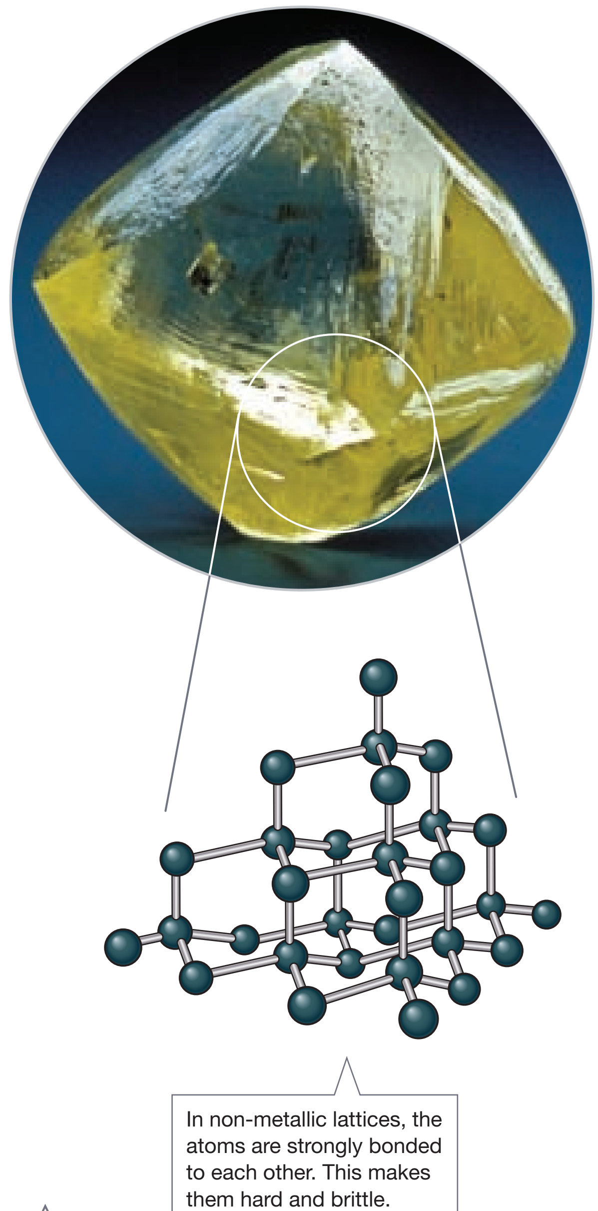


Figure 7.1.10 Metals and non-metals can both form crystal lattices.

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SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

The many faces of carbon

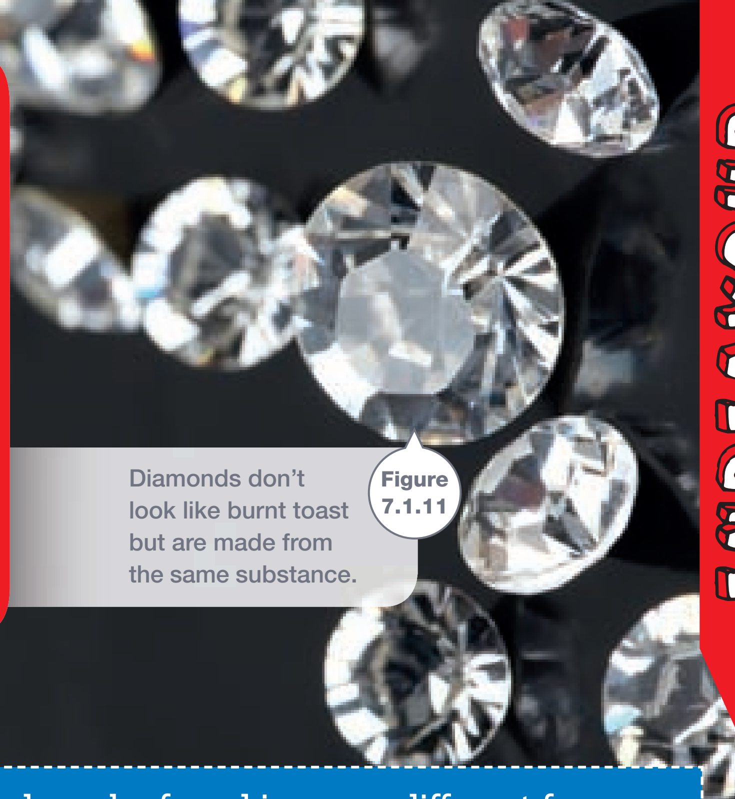

Figure 7.1.11 Diamonds don't look like burnt toast but are made from the same substance.

Carbon is an incredibly versatile element and can be found in many different forms. Different forms of the same element are called **allotropes** and almost every allotrope of carbon is useful to humans.

Charcoal

7.5

When most people think of carbon, they think of the black powdery ash or charcoal left over after paper or wood have been burnt. Charcoal is used by artists for sketching (Figure 7.1.12) but it is also used in industry for processes such as the smelting of iron. Charcoal can also adsorb certain gases so is used as tablets to help with digestive problems, as odour-eaters in shoes and as poisonous gas filters in gas masks.

Figure 7.1.12 Carbon in the form of charcoal is used for drawing because it is black and soft and crumbles easily.

Graphite

In graphite, the carbon atoms form sheets that are stacked on top of each other as shown in Figure 7.1.13. The sheets do not break easily but can slide across each other. This makes graphite a good lubricant for industrial machinery. The lead in grey-lead pencils is also made of graphite mixed with clay. As you write, the thin layers of graphite are slowly rubbed off onto the page. Graphite can also withstand very high temperatures and conducts electricity so can be used to replace electrical wiring in very hot situations such as industrial kilns for firing clay tiles.

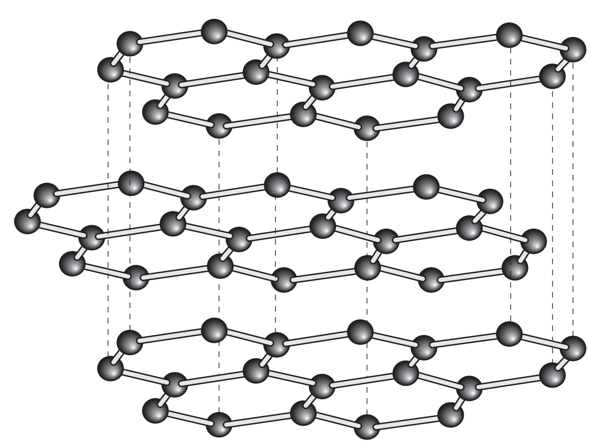

Figure 7.1.13 The carbon atoms in graphite form layers. The layers are difficult to break but can slide over each other easily. This makes graphite an excellent lubricant.

Diamond

Diamond is another form of carbon. Unlike graphite, all of the carbon atoms in diamond are tightly bonded to each other in a rigid crystal lattice. As a result, diamond is extremely hard and does not conduct electricity. Most people will know diamonds as the sparkling and very expensive jewels such as the one shown in Figure 7.1.14. However, only 20% of diamonds mined are used in jewellery. The rest are used by industry to make long-lasting tools for cutting and drilling.

Figure 7.1.14

Carbon in the form of diamond is the hardest natural substance on Earth because the bonds between the carbon atoms are extremely strong.

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Wear the ones you love

It is now possible to keep your loved ones wrapped around your little finger—quite literally. A company called Life Gem in the USA creates synthetic diamonds from the carbon ashes of your dead loved ones. The diamonds can then be made into jewellery such as rings, bracelets and necklaces.

Carbon fibre

Carbon fibres are very thin strands of compressed crystals of carbon. These fibres can be woven together to form new types of material that are very strong but also very lightweight. As a result, carbon fibre materials are ideal for things such as tennis racquets, bike frames (like the one in Figure 7.1.15) and aircraft, which require maximum strength yet minimum weight.

Figure 7.1.15

Carbon fibre is very light, very strong and flexible and so is often used in sporting equipment such as this mountain bike.

Buckyballs and nanotubes

In 1985, Americans Robert Curl and Richard Smalley and Briton Harold Kroto discovered yet another allotrope of carbon that they called buckyballs. These are balls of 60 carbon atoms that have the same geometric shape as a soccer ball. This discovery led to a whole new area of chemistry and the development of another allotrope of carbon called nanotubes. Nanotubes are sheets of carbon rolled into hollow tubes like the one shown in Figure 7.1.16.

Like graphite, carbon nanotubes conduct electricity. This means they can be used to construct nanowires for miniature electrical circuits. Nanotubes are also very strong. For this reason, the CSIRO is currently studying ways to mass–produce carbon nanotubes. This would allow creation of a new generation of materials which are strong, lightweight and heat–resistant.

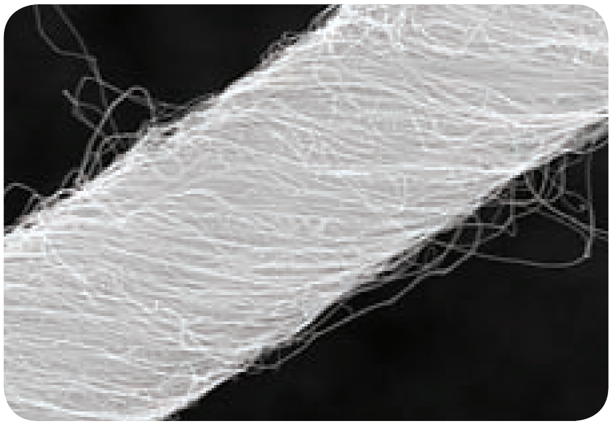

Figure 7.1.16

A carbon nanotube can be thought of as a sheet of carbon rolled into a tube. These tubes are very tough so scientists at CSIRO are researching how to spin them into yarn to create new-age materials.

7.1 Unit review

Remembering

1 **Name** the invisible particles that make up all matter.

2 **List** four properties of metallic elements.

3 **Name** three monatomic elements and give their element symbols.

4 **Recall** the atomic symbols of the following elements: hydrogen, helium, carbon, oxygen, nitrogen.

5 **List** three allotropes of carbon and give examples of where they are used.

Understanding

6 **Define** what is meant by the *properties of an element.*

7 **Explain** why metallic elements bend while solid and non-metallic elements break or crumble.

8 **Define** the following terms.
  a ductile
  b malleable
  c brittle

Applying

9 **Use** the periodic table to **identify** an example of an element and a non-element.

10 **Use** the periodic table to **identify** an element named after:
  a a famous scientist
  b a continent
  c an American state.

11 **Identify** the number and type of atoms in the following molecules.
  a nitrogen (N_2)
  b oxygen (O_2)
  c ozone (O_3)
  d phosphorus (P_4)
  e sulfur (S_{20})

Analysing

12 a **Compare** the way carbon atoms are arranged in diamond and graphite.
  b **Use** these arrangements to help **contrast** the properties of diamond and graphite.

13 **Classify** the following elements as either metallic or non-metallic: carbon, iron, copper, chlorine, helium, gold, oxygen, sulfur, nickel.

14 **Classify** the following elements as monatomic, molecular or lattice: helium, oxygen, copper, chlorine, silicon, neon, iron, nitrogen, germanium, argon, gold.

Evaluating

15 The atoms in both diamond and gold form lattices. **Propose** a reason why diamond is much harder than gold.

16 **Propose** reasons why graphite might be used instead of gold or copper wires to conduct electricity in very hot situations such as an industrial kiln.

Creating

17 Use coloured modelling clay to **construct** models of molecular and lattice elements presented in this unit.

18 Use the periodic table to **construct** a table of elements with chemical symbols that do not match their name in English.

Inquiring

1 Oxygen has two allotropes, oxygen gas, O_2 and ozone O_3. Research the properties of these two allotropes and compare the two.

2 Investigate when the first 10 elements in the periodic table were discovered and construct a timeline showing these dates.

3 Investigate how the idea of elements has developed from ‘air, earth, fire and water’ to our current list of over 100 elements.

4 Investigate how natural and synthetic diamonds are formed.

7.1 Practical activities

1 Measuring density, a physical property

Purpose

To measure the density of metals.

Materials

- cubes of metallic elements such as iron, copper and aluminium
- electronic balance
- ruler
- calculator

Procedure

1. Use the electronic balance to measure the mass of each metallic cube and record your measurements in a table like the one below.
2. Use the ruler to measure the length, width and height of the cubes. Once again, record your measurements.

Results

1. In your workbook, construct a table like that below.
2. Enter all the masses and sizes you measured in the table.
3. Calculate the volume of each cube by multiplying length × width × height and enter these values into the table.
4. Calculate the density of each cube by dividing the mass by the volume. Enter these into the table.

Discussion

1. From your table, **identify** which element is most dense and which is least dense.
2. The official densities for these metals are:
   - iron 7.88 g/cm^3
   - aluminium 2.70 g/cm^3
   - copper 8.93 g/cm^3.

   Compare these values with the ones you measured.
3. **Propose** reasons why your values might be a little different from the ones you calculated.
4. **Propose** ways that your experiment could be done more accurately.

Metal	Mass (g)	Length (cm)	Width (cm)	Height (cm)	Volume ($l \times w \times h$) (cm^3)	Density (mass/volume) (g/cm^3)
Iron						
Aluminium						
Copper						

2 Obtaining hydrogen, a non-metallic element

Purpose
To form the element hydrogen

Materials
- magnesium metal strip
- test-tube
- 2 M hydrochloric acid
- scissors
- eyedropper

SAFETY

Hydrochloric acid is very corrosive. Take care to ensure none touches your skin or clothing. Be aware of first aid procedures. Report any spills to your teacher immediately.

Procedure
1. Use scissors to cut the magnesium ribbon into small pieces (2 cm) and place them into the test-tube.
2. Using the eyedropper, add enough hydrochloric acid to cover the pieces of magnesium metal.
3. Watch what happens.

Results
Record your observations.

Discussion
1. The bubbles you see in this experiment are hydrogen. **Discuss** what evidence there is that a new substance is being produced.
2. **State**:
   a. whether hydrogen is a solid, liquid or gas at room temperature
   b. the colour of hydrogen.
3. **Use** the periodic table to find the following information for hydrogen.
   a. Chemical symbol
   b. Atomic number
   c. Whether it is a metal or non-metal
4. a. **State** whether hydrogen would exist in a monatomic form, as a lattice or as molecules.
   b. **Justify** your answer.

3 Obtaining copper, a metallic element

Purpose
To form crystals of metallic copper.

Materials
- beaker
- zinc metal strip
- 0.1 M copper sulfate solution
- filter paper
- magnifying glass or microscope

SAFETY

Copper sulfate is toxic.

Procedure
1. Half-fill the beaker with copper sulfate solution.
2. Place the zinc metal strip so that it is partly immersed in the copper sulfate solution.
3. Observe the copper crystals as they deposit on the zinc strip.
4. Once you have seen a noticeable change, remove the zinc strip and place it on the filter paper.

Results
1. Record your observations as the copper crystals form.
2. Record what happens to the colour of the copper sulfate solution as the experiment proceeds.
3. Once you have removed the zinc strip, observe the copper crystals more closely and record what you see. Use a magnifying glass or microscope if possible.

Discussion
1. **Use** the periodic table to find the following information for copper:
   a. chemical symbol
   b. atomic number
   c. whether it is a metal or non-metal.
2. a. **State** whether copper would exist in a monatomic form, as a lattice or as molecules.
   b. **Justify** your answer.