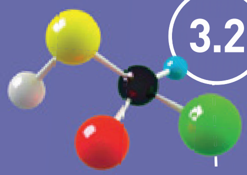
THE PERIODIC TABLE 3

3.1 Scientists refine theories and models over time



3.2 The structure of an atom determines its properties

3.3 Groups in the periodic table have properties in common

3.4 Non-metals have properties in common

3.5 Metal cations and non-metal anions combine to form ionic compounds

3.6 Non-metals combine to form covalent compounds

3.7 Metals form unique bonds

3.8 Nanotechnology involves the specific arrangement of atoms

What if?

What you need:

glass of pure water (distilled or de-ionised), multimeter or speaker, 3 wires, 9 V battery, fine NaCl crystals

What to do:

1 Use the wires to connect an open circuit that includes the battery and the multimeter.

2 Place the open ends of the circuit in the glass of water so that they do not touch.

3 Does the electricity pass through the pure water?

What if?

» What if two teaspoons of salt were mixed through the water?

» What if the electricity was passed through the salt crystals with no water?

//SCIENCE AS A HUMAN ENDEAVOUR//

3.1 Scientists refine models and theories over time

* The development of the periodic table involves scientists building on the work of previous generations. The discovery of new elements, the ability to recognise patterns and predict the existence of previously unknown elements all result from scientists analysing and refining models. The creation of the periodic table is often credited to Dimitri Mendeleev, who constructed a table with gaps for yet to be discovered elements. However, the ideas he used were first suggested decades before, and refined centuries after his work began.

2000 years ago

The ancient Greeks thought that everything was made of four 'elements' mixed together in different ratios (Figure 3.1).

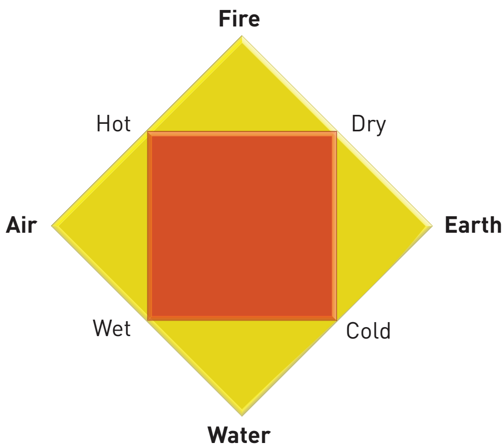


Figure 3.1 The four Greek 'elements'

1661

Irish-born chemist Robert Boyle (Figure 3.2) suggested that an **element** was a substance that cannot be broken down into a simpler substance in a chemical reaction.

Figure 3.2 Robert Boyle

1789

Antoine Lavoisier, a French nobleman (Figure 3.3), made a detailed list of the substances that he believed to be elements. Assisted by his wife, his list contained 33 elements grouped into **metals** and **non-metals**. Lavoisier's list also included some substances that we now know to be compounds.

1820s

Jakob Berzelius was a Swedish chemist who replaced the geometric patterns used as chemical symbols with letters that were an abbreviation of the element's name. Berzelius used English names for most elements, with just a few retaining their non-English (usually Latin) names. In addition, Berzelius used the weight of hydrogen to develop an organised system of atomic weights. Because hydrogen was the lightest element, it was given a value of 1, with all remaining elements believed to have a whole number above 1.

Figure 3.3 Antoine Lavoisier and his wife Marie-Anne

Figure 3.4 Jakob Berzelius gave the elements their symbols.

1829

As more elements were identified, more chemists studied them and their properties. In Germany, Johann Dobereiner was aware of 40 elements. He noted that some groups of three elements had similar properties and named these groups 'triads'. These groupings were important in identifying patterns of behaviour, which helped with more accurate predictions about atomic structures.

1864

English chemist John Newlands arranged the elements according to their atomic weights. He noticed that every eighth element had similar properties. This pattern was considered a recurring, or '**periodic**', feature among the elements. Newlands made the mistake of comparing the properties of the elements to music, with musical notes being grouped eight per octave. This comparison, called the law of octaves, was not taken seriously by Newlands' peers.

Table 3.1 Predicted properties of ekasilicon compared with the actual properties of germanium

EKASILICON (SYMBOL Es) AS PREDICTED IN 1871	GERMANIUM (SYMBOL Ge) AS DISCOVERED IN 1886
Atomic mass: 72	Atomic mass: 72.6
Density: 5.50 g/mL	Density: 5.36 g/mL
Colour: grey metal	Colour: grey metal
Forms oxide EsO_2: density 4.70 g/mL, slightly basic	Forms oxide GeO_2: density 4.70 g/mL, slightly basic
Forms chloride $EsCl_4$: boiling point 100°C, density 1.90 g/mL	Forms chloride $GeCl_4$: boiling point 86°C, density 1.88 g/mL

Figure 3.5 This sculpture in Saint Petersburg, Russia, honours Dmitri Mendeleev and the periodic table.

1869

Dmitri Mendeleev is hailed as the creator of the modern periodic table. Building on the ideas of his contemporaries, Mendeleev, who lived in Russia, knew of 63 elements (Figure 3.5).

It is said that Mendeleev wrote the names and properties of each element on a small card that he then arranged in order of atomic weight. The cards were then rearranged, maintaining their order, into groups with similar properties.

With this organisation complete, Mendeleev proposed the periodic law:

> 'Elements have properties that recur or repeat according to their atomic weight.'

More importantly, Mendeleev's organisation of cards identified 'holes' that he attributed to elements that had yet to be discovered. Mendeleev predicted the properties of 21 unknown or undiscovered elements. His predictions started scientists searching for the missing elements. When these elements were discovered, their properties were found to be very close to the properties that had been predicted by Mendeleev. This convinced many chemists of the accuracy and value of Mendeleev's periodic table. Table 3.1 compares the properties of germanium with an element Mendeleev predicted called ekasilicon.

Mendeleev is given sole credit for the development of the periodic table. This is because of the evidence he provided to support his table and because he assumed that there were missing elements and he accurately predicted the properties of these elements.

1894

William Ramsay, a Scottish chemist, used the then new technology of refrigeration to liquefy and separate the components of air. He successfully removed water, carbon dioxide, oxygen and nitrogen, but found he had some unknown gas left behind. This was argon, the first in its group to be discovered. Further experimentation identified helium, neon, krypton and xenon. All these gases form the group of noble gases at the far right of the periodic table.

1911

Marie Curie (Figure 3.6) was one of the many female scientists who identified and purified elements of the periodic table. Marie Curie won two Nobel Prizes for her work on radiation.

Figure 3.6 Marie Curie developed the theory of radioactivity. She won the Nobel Prize in Chemistry in 1911 for her discovery of radium and polonium.

1913

By the early 1900s, X-rays could be used to determine the atomic number of each element. Using this technology, Henry Moseley (Figure 3.7), a young English physicist, refined the order of some of the elements in Mendeleev's periodic table and proposed a minor change to the periodic law:

> 'Elements have properties that recur or repeat according to their atomic number.'

Figure 3.7 Henry Moseley's name is linked to significant advances in X-ray-related chemistry and physics, with many believing him worthy of a Nobel Prize. His work was cut short when he died at just 27 years of age in the Battle of Gallipoli during World War I.

1940

With the development of nuclear processes, elements heavier than uranium could be created. The US scientist Glen Seaborg, winner of the 1951 Nobel Prize in Chemistry, led a team of scientists who used a cyclotron to bombard uranium atoms with neutrons. This produced the very first atoms of neptunium and plutonium.

Figure 3.8 Atoms heavier than uranium are called the 'transuranium' or 'transuranic' elements. None of them occurs naturally. The image shows a sample of neptunium.

Today

Since the 1940s, similar nuclear processes have been used to synthesise the elements up to and including element 118. These elements are given names based on their atomic number: 118 is called 'ununoctium' (1-1-8-ium).

Extend your understanding 3.1

1. Who proposed the modern idea of an element and when?
2. What was a triad? Why were triads important?
3. Who was the first chemist to lead a team that produced elements that did not occur naturally?
4. When Mendeleev proposed the periodic table, he went one step further. What else did he do and why is this significant?
5. Originally, geometric symbols were used to represent each element. What would be some of the problems associated with using geometric symbols for the elements today?
6. Why were the gases that Ramsay discovered not able to be discovered any earlier?
7. Moseley changed the periodic law proposed by Mendeleev by changing one word. What word was changed, and how did this improve the periodic table?

3.2 The structure of an atom determines its properties

*

The atomic number and name of an atom is determined by the number of protons it contains in its nucleus. The **relative atomic mass** is the sum of the number of positive protons and number of neutral neutrons. Negatively charged electrons have negligible mass and move about the nucleus in electron shells. The outermost electron shell is called the **valence shell** of the atom. The number of electrons in the valence shell determines many of the properties of the element and therefore its position in the periodic table.

The periodic table

The periodic table shows the types of atoms, or elements, in rows and columns (Figure 3.9). The rows are called **periods**. The atomic number increases by one for each element as you go across a period. The vertical lists of elements are called **groups**, with the elements in each group having similar properties. These groups are similar to the triads described by Dobereiner.

The columns and rows in the periodic table have been given names and numbers. This makes communication easier, because these elements have similar properties and trends.

Atoms and their electrons

The protons and neutrons of an atom are located within the nucleus. These subatomic particles are responsible for most of the mass of the atom and therefore have a strong influence on the properties of the atom. The number of protons is called the **atomic number** and is used to order the elements in the periodic table.

In contrast, electrons have almost negligible mass. However, because they orbit around the nucleus, these subatomic particles interact with other atoms.

Electron configurations

The **Bohr model** of the atom can be used to consider how electrons are arranged in an atom. In this model, the electrons are arranged in areas of space around the nucleus. These areas are called shells. The electron shells are numbered from the nucleus outward. These are shown in Table 3.2, along with the maximum number of electrons in each shell.

Table 3.2 The Bohr model of the atom

SHELL NUMBER (FROM THE NUCLEUS OUTWARDS) (n)	MAXIMUM NUMBER OF ELECTRONS IN THE SHELL ($2n^2$)
1	2
2	8
3	18*
4	32

*The formula $2n^2$ works for most atoms until we get to atomic number 19 (potassium). Once the third electron shell has eight electons, remaining electrons start moving into the fourth shell.

Table 3.2 shows that the further the electron shell is from the nucleus, the more electrons it can contain. The maximum number of electrons a shell can hold is related to its shell number by the simple formula $2n^2$, where n is the number of the shell from the nucleus.

Bohr also stated that the electrons of an atom are normally located as close to the nucleus as possible. This is because the negatively charged electrons are attracted to the positive charges of the protons. This is a lower energy state for the atom and is therefore more stable.

Non-metals · Transition metals · Metals

Key: 6 (Atomic number) / C (Chemical symbol) / 12.01 (Atomic mass) / Carbon (Name of element)

Period	1 Group	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** 1.01 Hydrogen																	2 **He** 4.00 Helium
2	3 **Li** 6.94 Lithium	4 **Be** 9.01 Beryllium											5 **B** 10.81 Boron	6 **C** 12.01 Carbon	7 **N** 14.01 Nitrogen	8 **O** 16.00 Oxygen	9 **F** 19.00 Fluorine	10 **Ne** 20.18 Neon
3	11 **Na** 22.99 Sodium	12 **Mg** 24.31 Magnesium											13 **Al** 26.98 Aluminium	14 **Si** 28.09 Silicon	15 **P** 30.97 Phosphorus	16 **S** 32.07 Sulfur	17 **Cl** 35.45 Chlorine	18 **Ar** 39.95 Argon
4	19 **K** 39.10 Potassium	20 **Ca** 40.08 Calcium	21 **Sc** 44.96 Scandium	22 **Ti** 47.87 Titanium	23 **V** 50.94 Vanadium	24 **Cr** 52.00 Chromium	25 **Mn** 54.94 Manganese	26 **Fe** 55.85 Iron	27 **Co** 58.93 Cobalt	28 **Ni** 58.69 Nickel	29 **Cu** 63.55 Copper	30 **Zn** 65.39 Zinc	31 **Ga** 69.72 Gallium	32 **Ge** 72.63 Germanium	33 **As** 74.92 Arsenic	34 **Se** 78.96 Selenium	35 **Br** 79.90 Bromine	36 **Kr** 83.80 Krypton
5	37 **Rb** 85.47 Rubidium	38 **Sr** 87.62 Strontium	39 **Y** 88.91 Yttrium	40 **Zr** 91.22 Zirconium	41 **Nb** 92.91 Niobium	42 **Mo** 95.94 Molybdenum	43 **Tc** (98) Technetium	44 **Ru** 101.07 Ruthenium	45 **Rh** 102.91 Rhodium	46 **Pd** 106.4 Palladium	47 **Ag** 107.87 Silver	48 **Cd** 112.41 Cadmium	49 **In** 114.82 Indium	50 **Sn** 118.71 Tin	51 **Sb** 121.76 Antimony	52 **Te** 127.60 Tellurium	53 **I** 126.90 Iodine	54 **Xe** 131.29 Xenon
6	55 **Cs** 132.91 Caesium	56 **Ba** 137.33 Barium	57 to 71	72 **Hf** 178.49 Hafnium	73 **Ta** 180.95 Tantalum	74 **W** 183.84 Tungsten	75 **Re** 186.21 Rhenium	76 **Os** 190.23 Osmium	77 **Ir** 192.22 Iridium	78 **Pt** 195.08 Platinum	79 **Au** 196.97 Gold	80 **Hg** 200.59 Mercury	81 **Ti** 204.38 Thallium	82 **Pb** 207.2 Lead	83 **Bi** 208.98 Bismuth	84 **Po** (209) Polonium	85 **At** (210) Astatine	86 **Rn** (222) Radon
7	87 **Fr** (223) Francium	88 **Ra** 226.03 Radium	89 to 103	104 **Rf** (261) Rutherfordium	105 **Db** (262) Dubnium	106 **Sg** (271) Seaborgium	107 **Bh** (272) Bohrium	108 **Hs** (277) Hassium	109 **Mt** (276) Meitnerium	110 **Ds** (281) Darmstadtium	111 **Rg** (280) Roentgenium	112 **Cn** (285) Copernicium	113 **Uut** (284) Ununtrium	114 **FL** (289) Flerovium	115 **Uup** (288) Ununpentium	116 **Lv** (298) Livermorium	117 **Uus** (294) Ununseptium	118 **Uuo** (294) Ununoctium

Atomic masses in parentheses are from the most stable of common isotopes.

Rare earth elements Lanthanoid series	57 **La** 138.91 Lanthanum	58 **Ce** 140.12 Cerium	59 **Pr** 140.91 Praseodymium	60 **Nd** 144.24 Neodymium	61 **Pm** (145) Promethium	62 **Sm** 150.4 Samarium	63 **Eu** 151.97 Europium	64 **Gd** 157.25 Gadolinium	65 **Tb** 158.93 Terbium	66 **Dy** 162.50 Dysprosium	67 **Ho** 164.93 Holmium	68 **Er** 167.26 Erbium	69 **Tm** 168.93 Thulium	70 **Yb** 173.04 Ytterbium	71 **Lu** 174.97 Lutetium
Actinoid series	89 **Ac** 227.03 Actinium	90 **Th** 232.04 Thorium	91 **Pa** 231.04 Protactinium	92 **U** 238.03 Uranium	93 **Np** 237.05 Neptunium	94 **Pu** (244) Plutonium	95 **Am** (243) Americium	96 **Cm** (247) Curium	97 **Bk** (247) Berkelium	98 **Cf** (251) Californium	99 **Es** (252) Einsteinium	100 **Fm** (257) Fermium	101 **Md** (258) Mendelevium	102 **No** (259) Nobelium	103 **Lr** (260) Lawrencium

Figure 3.9 The periodic table of elements.

The arrangement of electrons in an atom is termed its **electronic configuration**.

Electron configurations are often represented by simple **shell diagrams** that show the electron shells as circles. The electrons are presented in pairs. This makes it easier to draw the diagrams and is scientifically correct because, in atoms, electrons exist in pairs within the shells. The outermost occupied shell of atoms is known as the valence shell.

ELECTRONIC CONFIGURATION OF OXYGEN

The atomic number of oxygen is 8, so an uncharged atom contains eight electrons.

- Oxygen is in period 2, so it has two electron shells.
- The first shell can only hold two electrons.
- The second shell holds the other six electrons.
- The electronic configuration of oxygen is written as 2,6.

ELECTRONIC CONFIGURATION OF CALCIUM

The atomic number of calcium is 20, so an uncharged atom contains 20 electrons.

- Calcium is in period 4, so it has four electron shells.
- The first shell can only hold two electrons.
- There are 18 electrons left to place in shells. The second shell can only hold eight electrons. The third shell is stable with eight electrons (even though it holds a maximum of 18).
- The fourth shell holds the last two electrons.
- The electronic configuration of calcium is written as 2,8,8,2.

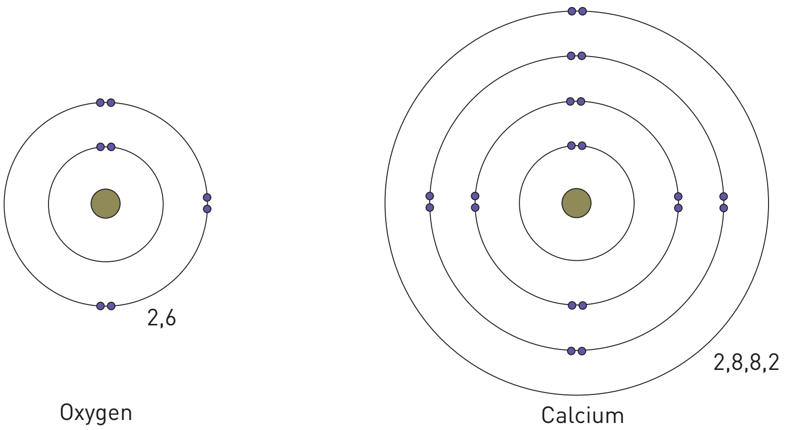


Figure 3.10 The electronic configurations for oxygen and calcium are shown as simple shell diagrams.

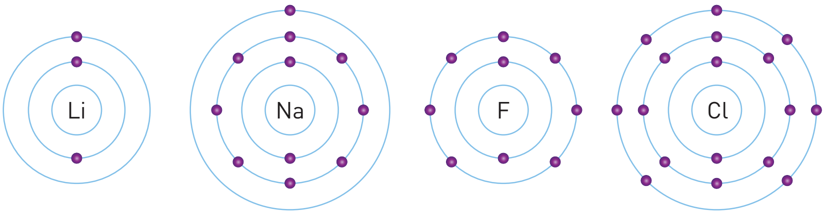


Figure 3.11 In group 1, the electronic configuration of lithium is 2,1, whereas that of sodium is 2,8,1 and that of potassium is 2,8,8,1. The atoms of all other group 1 elements also have one electron in their outer valence shell of electrons.

Electrons and properties of elements

The electronic configurations of the elements can explain the properties of the elements. Being able to confidently navigate the periodic table enables you to identify trends in electrons, the properties of elements and the uses of compounds formed from them.

Groups and valence electrons

The groups of the periodic table are numbered 1–18. Elements in the same group have similar chemical properties that we now know are due to the arrangement of their electrons.

Elements in the same group have the same number of electrons in their outermost or valence shell. The valence shell electrons often interact with other atoms.

Emission spectra and electron shells

When atoms are heated in a flame, the electrons gain heat energy from the flame and become 'excited', jumping from their normal shell to one further out from the nucleus. When the electrons move back to their usual shell, this 'extra' energy is given back out in the form of light. Because the energy gaps between electron shells vary from one atom to the next, the energy released by the different atoms also varies. This variation is seen as different levels of light energy, which have different frequencies; different frequencies of light have different colours. Hence, the emission spectrum of each atom will be a 'fingerprint' of different colour patterns. These spectra cause different-coloured flames when different elements are burned, as you have seen in an experiment in Year 9.

Check your learning 3.2

Remember and understand

1 What is the valence shell of an atom?
2 What determines the atomic number of an atom?
3 For the Bohr model of the atom, what is the maximum number of electrons that the fourth electron shell can contain?

Apply and analyse

4 A potassium atom contains 19 protons.
   a How many electrons will be present in a potassium atom? Justify your answer.
   b What is the electronic configuration of a potassium atom according to the Bohr model?
   c From the electronic configuration of potassium, it is clear that electrons do not normally occupy the fifth shell. What could be done to potassium atoms for electrons to jump into this shell?
5 Copy and complete the following table.

ELEMENT	ATOMIC NUMBER	ELECTRON CONFIGURATION
Beryllium		
	9	
Magnesium		
Neon		
		2,8,3
	11	
		2,8,7
Sulfur		

3.3 Groups in the periodic table have properties in common

The two main types of elements are metals and non-metals, with metals constituting nearly three-quarters of all elements. Metals are defined by their lustrous appearance and their ability to conduct heat and electricity. The **alkali metals** in group 1 of the periodic table have a single electron in their outer shell and as a result are highly reactive when mixed with water. The alkali metals have low melting points and are relatively flexible. Transition metals have properties that are unique to groups 3–12.

Metals

Metals have many properties in common. Pure metals are:

> lustrous (shiny)
> able to conduct heat and electricity
> malleable (can be beaten into a new shape)
> ductile (can be drawn into a wire).

Group 1 metals

The alkali metals, such as sodium and potassium, are found in group 1 – the far left column. Their position tells you that their uncharged atoms have just one electron in their outer shell. The alkali metals have quite low melting points and are soft and highly reactive. In their pure state, they often resemble plasticine that, when cut, is very briefly shiny silver before reacting with the air to become white again (Figure 3.12). Alkali metals react very strongly – some violently – with water, producing hydrogen gas and an alkaline solution. (An alkali is a soluble base.) As you go down the group, this reaction becomes more violent (Figure 3.13).

Figure 3.12 Freshly cut sodium, a group 1 metal.

Group 2 metals

The **alkaline earth metals**, such as magnesium and calcium, are found in group 2. Their position tells you that their atoms have two electrons in their outer shell. The alkaline earth metals have quite low melting points and are relatively soft and very reactive, although in general they are not quite as reactive as group 1 alkali metals. Like the alkali metals, alkaline earth metals react with water, some strongly, producing hydrogen gas and an alkaline solution. As you go down the group, the metals become more reactive (Figure 3.14).

Transition metals

The **transition metals** are found in a large block of the periodic table that consists of the ten groups across the centre (groups 3–12). Many transition metals have special properties that are not shown by group 1 or 2 metals.

EXPERIMENT 3.3: REACTIVITY OF METALS
GO TO PAGE 195

Figure 3.13 Potassium reacts spectacularly with water.

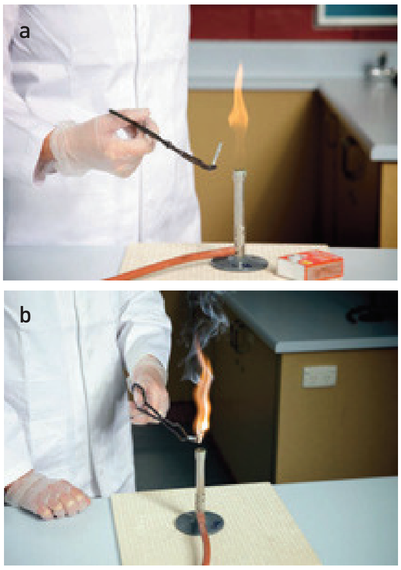


Figure 3.14 Magnesium, an alkaline earth metal (a) before burning and (b) during burning.

Figure 3.15 Calcium is a soft grey metal; calcium carbonate is a white powder or stone.

- A small number are magnetic.
- Gold and copper are the only metals that are not silvery in colour.
- Many form coloured compounds (Figure 3.16).
- Many form more than one compound with a non-metal such as chlorine. For example, iron forms $FeCl_2$ and $FeCl_3$.

Figure 3.16 Gemstones contain atoms of different metals, which results in different colours.

Check your learning 3.3

Remember and understand

1 What is the difference between a period and a group in the periodic table?

2 Examine the periodic table in Figure 3.9.
   a Identify the period and group for each of the following elements: fluorine, bromine, tin, radium, potassium, platinum, arsenic.
   b Are any of the elements in part a in the same group? What would this tell you about them?
   c Are any of the elements listed in part a in the same period?

3 What proportion of the periodic table is composed of metals?

4 What properties are shared by all metallic elements?

5 Which metal will react most strongly with cold water: copper, iron, magnesium, sodium or zinc? Explain your answer.

6 Why is copper found as a native element on Earth, but calcium metal is never found as the native element?

Apply and analyse

7 Name two properties shown by some transition metals that are not shown by group 1 or group 2 metals.

Evaluate and create

8 Design a way to represent the different groups of metals clearly and informatively, identifying the distinguishing properties of each group.

3.4 Non-metals have properties in common

Non-metals are elements found in groups 14–18 of the periodic table. They do not conduct electricity or heat very well and are very brittle. They do not reflect light and as a result have a dull appearance. **Metalloids** are found between metals and non-metals in the periodic table. Their properties are a combination of those of metals and non-metals.

Figure 3.17 Silicon and germanium are widely used in electronic devices because of their semiconductor properties – they conduct electricity in a very controlled way.

Metalloids

Metalloids are the small set of elements along the 'staircase' diagonal boundary between the metals and non-metals (Figure 3.18). As might be expected from this location, metalloids exhibit properties between those of metals and non-metals. Most of their properties would be considered un-metallic; however, metalloids conduct electricity like the metals. Three of the metalloids are semiconductors (Figure 3.17), which means that they only conduct electricity in a certain way under certain conditions.

Non-metals

Non-metals, as the name suggests, are elements that do not have the set of properties common to all metals. Non-metals are not lustrous (shiny), or ductile (easily manipulated); a small number of non-metals are coloured; some are brittle. In addition, non-metals have a much larger range of melting points and boiling points than the metals do. At room temperature, several non-metals are gases and one (bromine) is a liquid, whereas all the metals except for one (mercury) are solids at room temperature. Only 18 elements in the periodic table are considered non-metals, compared with more than 80 metals. Despite this, non-metals make up most of the crust and atmosphere of the Earth, as well as the bulk of living organisms' tissues.

Only two groups (vertical columns) in the periodic table are made up entirely of non-metals: groups 17 and 18.

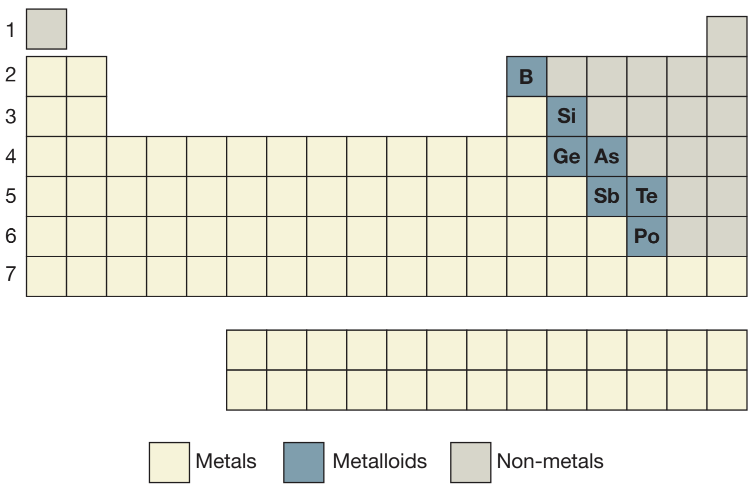


Figure 3.18 Regions of the periodic table

Figure 3.19 Boron and silicon are combined to form borosilicate glassware, such as the common Pyrex brand. This glassware is tough and has excellent heat conduction properties that make it suitable for cooking.

CHALLENGE 3.4: IDENTIFYING PATTERNS IN THE PERIODIC TABLE
GO TO PAGE 196

Group 17: the halogens

The **halogens**, such as fluorine and chlorine, are found in group 17. The atoms of all the halogens have seven electrons in their outer shell. The halogens are mostly known for their capacity to react with metals to form salts. The word 'halogen' means 'salt-forming' and the term was coined for this group by Jakob Berzelius. Some halogens have bleaching properties as well (Figure 3.20).

Figure 3.20 Bleaches often contain halogens.

As you go down the group, the melting points and boiling points of the halogens increase. At room temperature, fluorine and chlorine are gases, bromine is a liquid and iodine and astatine are solids. This is the only group in which the elements range from gas to liquid to solid at room temperature. Astatine is radioactive and very unstable.

Unlike the metals in groups 1 and 2, the further down you go in this group of non-metals, the less reactive the element. Fluorine is the most reactive non-metal of all and is extremely dangerous to handle (Figure 3.21). Halogens are very effective cleaning and sterilising substances because of the lethal effects they can have on bacteria and fungi.

Group 18: the noble gases

The **noble gases**, such as neon and argon, are found in group 18. The uncharged atoms of the noble gases have eight electrons in their outer shell, except for helium, which has two. The noble gases are so called because they are all gases at room temperature and are unchanged if mixed with other elements; that is, they are very unreactive, or inert. The first three in the group (helium, neon and argon) do not react with any other element and form no compounds. It was first thought that the same was true of xenon and krypton, but recently chemists have discovered that these two elements will react with fluorine under certain conditions and form a very small number of compounds. The last member of the group, radon, is very dangerous – not because of any chemical reactivity, but because it is a radioactive gas (Figure 3.22).

Figure 3.22 Radon is responsible for most background radiation experienced in public spaces. It occurs naturally as the decay product of uranium and can be found in natural springs.

Check your learning 3.4

Remember and understand

1 Why are non-metals named according to what they are 'not' rather than what they have in common?

2 The two main groupings of non-metals are in groups 17 and 18.
   a What does the group number tell you about the elements it contains?
   b What properties do members of each of these groups share?

3 What is a semiconductor?

4 What is the dominant state of matter within the groups of non-metals?

Evaluate and create

5 Why could the term 'metal-like' be used to describe metalloid elements? Suggest a better name for this group of elements. Explain your answer.

Figure 3.21 Fluorine, the most reactive non-metal, is used to etch glass. It is extremely dangerous to handle.

Figure 3.23 Halogen lamps have been commonly used in car headlights and outdoor lighting for decades. The halogen reversibly reacts with a tungsten filament to provide a bright light that also keeps the bulb clean.

3.5 Metal cations and non-metal anions combine to form ionic compounds

Metals form **cations** when they lose electrons to achieve a full, stable valency shell. Non-metals form **anions** when they gain electrons to achieve a full, stable valency shell. Polyatomic ions form when two or more atoms combine to form a charged ion. Positive cations are attracted to negative anions and form **ionic compounds**. The properties of ionic compounds reflect the ionic bonds that hold the ions together.

Forming ions

Electron shells are most stable when they are full – containing eight valence electrons. The behaviour of valence electrons can be explained by the atom seeking a stable state. The atom may gain or lose electrons in an attempt to gain a full outer electron shell. In certain cases, electrons are shared between atoms to achieve this balance.

The easiest way to achieve stability for atoms with only a few (1–3) valence electrons is to lose these electrons. For example, it is easier for an atom with two electrons in its outer shell to lose two electrons than to gain six electrons. In contrast, if the valence shell is almost full (seven electrons), it is more likely that atom will gain an electron to fill the gap in the shell. The number of positive protons does not change, even when the electrons move. Therefore, if an atom gains a negative electron, the overall charge of the atom becomes negative (more negative electrons than positive protons). If an atom loses electrons, then it becomes positively charged (more positive protons than negative electrons). In both these cases, the atom is then referred to as an **ion** – a charged atom.

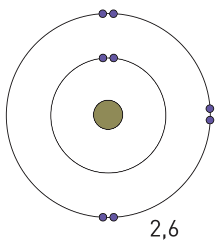


Figure 3.24 Oxygen tends to gain two electrons to fill its valence shell. Overall, there will be two more negative charges than positive charges (from the protons in the nucleus), so the ion is written as O^{2-}.

Metals are usually found on the left-hand side of the periodic table. This means they have fewer than four electrons in their valency shell. Therefore, metals tend to lose electrons and become positively charged. Positively charged metals are called cations.

In contrast, most non-metals have almost full valency shells. This means they need to gain electrons to achieve a full valency shell of electrons. As a result, non-metals will become negatively charged. Negatively charged ions are called anions.

Positively charged cations are attracted to negatively charged anions. A cation with a 2+ charge is likely to combine (bond) with an anion of 2– charge or with two anions each with a charge of 1–. The positive charge is balanced by an equal negative charge. The bonds that are formed when ions interact are referred to as **ionic bonds**.

Properties of ionic compounds

Compounds that are held together by ionic bonds are called ionic compounds. As an ionic compound forms, the like-charged ions repel each other and the oppositely charged ions attract each other. After all the pushing and pulling, the ions settle into alternating positions, as shown in Figure 3.27, because this is the most stable arrangement. The particles are held together by strong electrostatic forces of attraction between the positively charged ions and the negatively charged ions. Because these forces bind the ions together, this is known as ionic bonding.

A lot of energy is required to move the ions out of their positions. This means that ionic compounds are hard to melt. At room

EXPERIMENT 3.5: CONDUCTIVITY OF IONIC COMPOUNDS
GO TO PAGE 197

SKILLS LAB 3.5: IONIC COMPOUNDS
GO TO PAGE 198

temperature, they are in the form of hard, brittle crystals. The most commonly known example of an ionic compound is sodium chloride (table salt). Its melting point is 801°C. If you use a salt grinder at home, you will be aware of how hard and brittle salt crystals are.

Polyatomic ions

A number of ions are made up of more than one atom. These are termed **polyatomic ions**. Figure 3.28 shows some examples of polyatomic ions.

These clusters of atoms have a charge because the total number of protons does not equal the total number of electrons present. For example, in the hydroxide ion, which is made up of two atoms (one each of oxygen and hydrogen), there are nine protons and ten electrons. This means the two atoms that form the ion have an overall charge of 1–.

Calcium carbonate, the main constituent of marble, is an example of an ionic compound that contains a polyatomic ion. Calcium carbonate contains calcium ions (Ca^{2+}) and carbonate ions (CO_3^{2-}). These ions must be present in the ratio 1 : 1 so that the total positive charge equals the total negative charge. The formula of calcium carbonate is $CaCO_3$.

Ammonium carbonate is used in smelling salts. It contains ammonium ions (NH_4^+) and carbonate ions (CO_3^{2-}). In this case, the ions need to be present in the ratio 2 : 1. The formula of ammonium carbonate is $(NH_4)_2CO_3$.

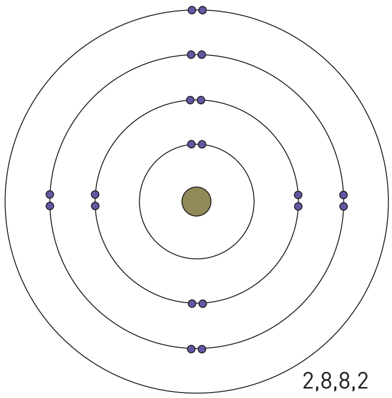


Figure 3.25 Calcium has two electrons in its valence shell, so it tends to lose them to achieve stability. The calcium ion formed is then written as Ca^{2+} to show that there are two extra protons compared with the number of electrons.

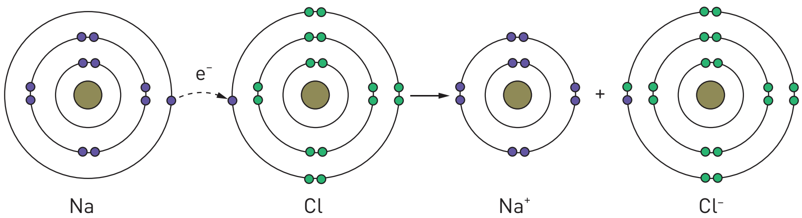


Figure 3.26 Sodium chloride is formed when sodium donates an electron to chlorine.

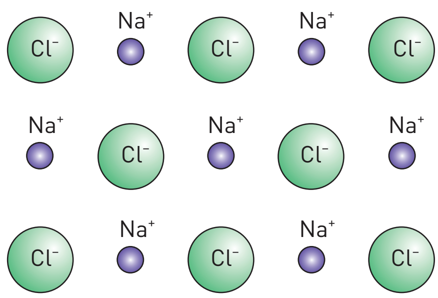


Figure 3.27 In an ionic compound, such as sodium chloride, the ions are arranged in alternating positions.

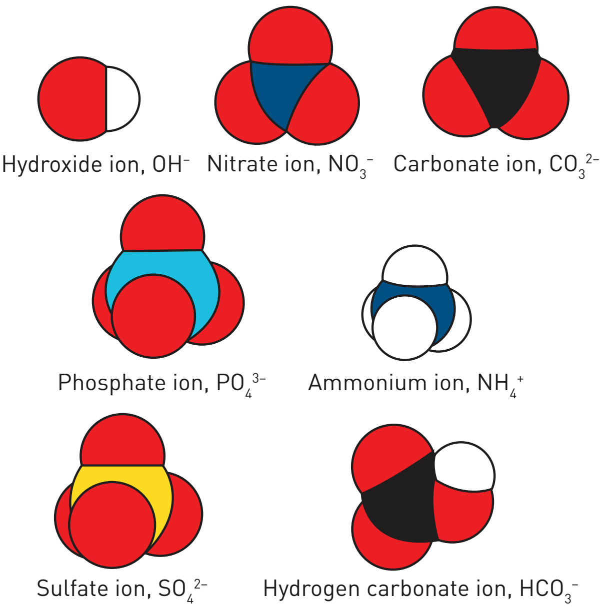


Figure 3.28 Some common polyatomic ions.

Check your learning 3.5

Remember and understand

1 Carefully examine the periodic table.
   a Which elements are likely to form positively charged ions?
   b Which elements are likely to form negatively charged ions?
   c What does this tell you about which elements will combine to form ionic compounds?
2 What kinds of particles are present in ionic compounds?

Apply and analyse

3 How does the group in which an element is found in the periodic table quickly identify one or more of its properties?
4 What is the maximum number of electrons that can be gained or lost by an atom? Why?
5 Use your knowledge of atomic structure and valence electrons to explain why many ionic compounds are made up of a metal and a non-metal.

3.6 Non-metals combine to form covalent compounds

Two non-metals need a full outer shell of electrons to remain stable. As a result, they merge their valency shells to share two electrons (one from each atom). This sharing of pairs of electrons between atoms is called a **covalent bond**. Covalent compounds form when two or more elements share pairs of electrons so that each has a full valency shell. The bonds between these atoms help explain the compound's properties.

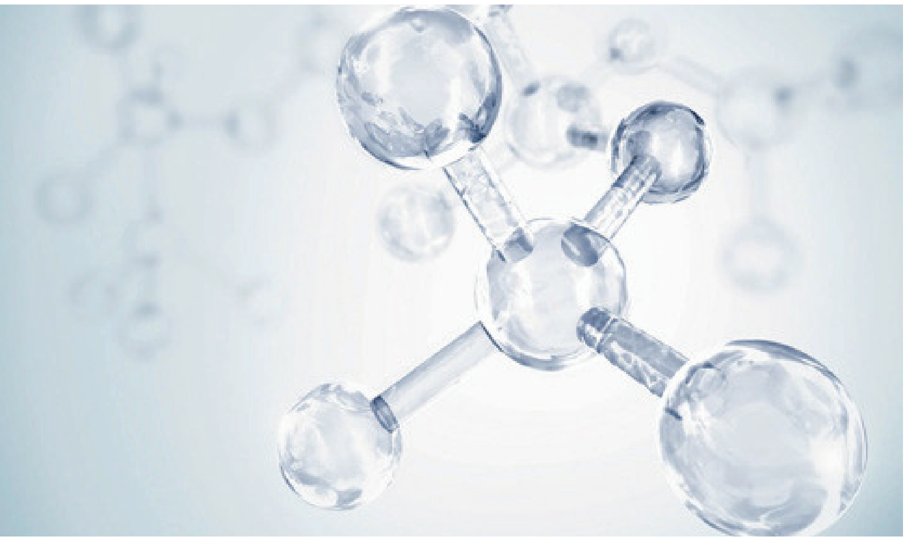
Electrons and molecules

You have seen that when electrons are transferred from one atom to another, positive and negative ions are produced and ionic compounds are formed. However, two non-metals that complete their outer shells of electrons by gaining electrons can also bond together.

We can see this with the smallest, lightest atom: hydrogen.

Hydrogen molecules

An uncharged atom of hydrogen has just one electron in the first shell. If it could gain one more electron, this shell would contain its maximum number of electrons – two. If hydrogen was in contact with a reactive metal such as lithium, the hydrogen atom could gain that extra electron from a lithium atom. An ionic compound would form as a result. But what if only other uncharged hydrogen atoms were present? The only way each hydrogen atom can gain an extra electron is by sharing its electron with another.



As two uncharged hydrogen atoms come close together, the electrons are drawn into the region between the two nuclei. The atoms partially merge into one another, with the nuclei of both atoms now sharing the two electrons. The electrons travel in the spaces surrounding the nuclei of each atom. In effect, each atom now has a stable electron configuration because its outer shell is full.

The particle produced has two hydrogen atoms bonded strongly together and is called a molecule. A molecule is a particle produced when two or more atoms combine so that the atoms share electrons. A molecule has no overall charge because the total number of electrons and the total number of protons is the same.

The hydrogen molecule is given the formula H_2 because there are two hydrogen atoms present in the cluster.

The hydrogen molecule is an example of a molecule of an element. It is called a **diatomic molecule** because it is made up of two atoms. Other examples of diatomic molecules of non-metals are fluorine (F_2), chlorine (Cl_2), oxygen (O_2) and nitrogen (N_2).

In a molecule such as the hydrogen molecule, there is strong electrostatic attraction between each positively charged nucleus and the negatively charged electrons that they share.

CHALLENGE 3.6: MODELLING COVALENT MOLECULES
GO TO PAGE 199

The electrons spend a considerable part of their time between the two nuclei. This electrostatic attraction is termed covalent bonding. The two shared electrons create a strong bond between the two atoms.

Molecular compounds

Like elements, compounds also form molecules. Water is an example of a **molecular compound**. Its formula is H_2O. You are now in a position to understand why it has this formula. To gain a more stable electron configuration, an:

> uncharged hydrogen atom, which has one valence electron, requires one more electron

> uncharged oxygen atom, which has six valence electrons, requires two more electrons.

A single hydrogen atom cannot supply the two electrons the oxygen atom needs, but two hydrogen atoms can. This is why there are two hydrogen atoms and just one oxygen atom in a water molecule. An oxygen atom now effectively has eight electrons in its valence shell and each hydrogen atom has two electrons. This is shown in Figure 3.30. Notice that each atom now has a full outer shell of electrons.

There are other ways of representing the structure of molecules, including with three-dimensional models. However, remember that in any representation, a single chemical bond holding the molecule together is actually a pair of negative electrons, shared between two atoms, attracted to the positive nuclei of both of these atoms.

Properties of molecular substances

Almost all molecular substances do not conduct electricity, even in the liquid state, because the molecules do not have free charged particles and so they cannot carry a current. There are no strong forces of attraction between molecules, so most molecular substances are liquids or gases at room temperature. It does not take much energy to separate the individual molecules and get them to move around.

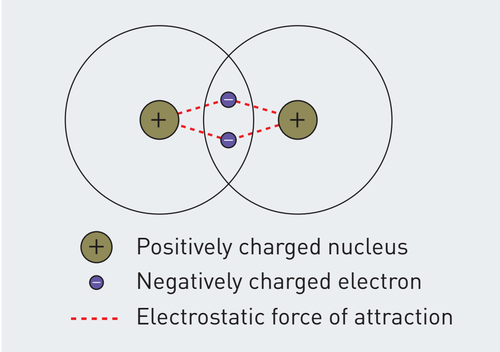


Figure 3.29 Covalent bonding within a hydrogen molecule.

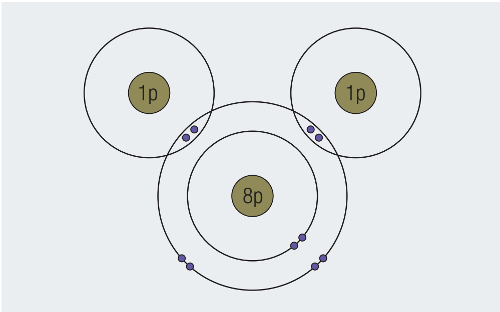


Figure 3.30 A shell diagram of a water molecule

Check your learning 3.6

Remember and understand

1 What is a diatomic molecule?

2 What types of atoms form covalent bonds?

Apply and analyse

3 Explain why molecular substances cannot conduct electricity.

4 In terms of the structure of the substance, why is it easier to turn liquid water into a gas than to break the bonds between the hydrogen and oxygen atoms?

5 a When chlorine atoms combine to form molecules, how many electrons need to be shared between the two chlorine atoms?

b Would this be the same for two oxygen atoms combining to form a molecule? Explain your reasoning.

3.7 Metals form unique bonds

Metals form the largest collection of elements in the periodic table. They have many properties in common. All metals arrange their atoms into layers that can easily slide over each other. Some valence electrons are **delocalised**, and are able to freely move from one atom to another. This enables most metals to be good conductors. Metal alloys are mixtures of two or more metals that are stronger than pure metals. Smart alloys are metal mixtures that are able to retain a memory of their original shape.

Metallic structure

Many metals are malleable (can be bent into any shape). This property of metals is a result of the arrangement of atoms. Metal atoms arrange themselves into layers. When the metal is bent or hammered into shape, the atoms slide over one another (Figure 3.31).

Metals and conductivity

Remember that metals are found on the left-hand side of the periodic table. Metals do not have many electrons in their outer shells, and it does not take much energy for these outer electrons to move from one atom to another. This is the clue as to why metals are so good at conducting electricity.

A substance will conduct electricity if it contains charged particles that are free to move around the structure. In metals, these charged particles are electrons. Scientists refer to the outer-shell electrons as delocalised **electrons** because they are not 'stuck' in one locality. (Most electrons in metal atoms are not delocalised because they move about the nucleus of each metal atom in the inner electron shells.) Metals are good electrical conductors because the outer-shell electrons are free to move from nucleus to nucleus along the metal.

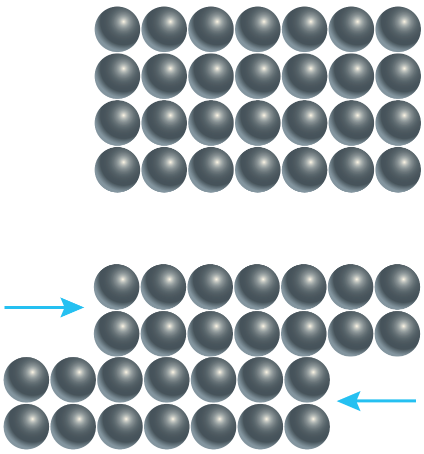


Figure 3.31 The arrangement of atoms in metals allows them to slide over each other when bent or hammered into shape.

Table 3.3 gives the electrical conductivity of a number of elements at 25 °C.

All metals conduct electricity in the solid state, some better than others. They continue to conduct electricity when molten, but more weakly. The higher the temperature, the lower their electrical conductivity.

Only some metals are used for their electrical conductivity. For example, power lines have a core of steel and an outside layer of aluminium. Household wiring is usually copper, which is coated with a special kind of plastic. Metals like silver and gold are used in more specialised applications, such as in electronic devices.

Table 3.3 Electrical conductivities of some common elements at 25°C

ELEMENT	ELECTRICAL CONDUCTIVITY ($\times 10^6$ ohm^{-1} cm^{-1})
Aluminium	0.37
Silver	0.63
Carbon (graphite)	0.100
Copper	0.596
Gold	0.452
Iron	0.093
Lead	0.048
Magnesium	0.226
Sodium	0.210

CHALLENGE 3.7: MODELLING ALLOYS
GO TO PAGE 199

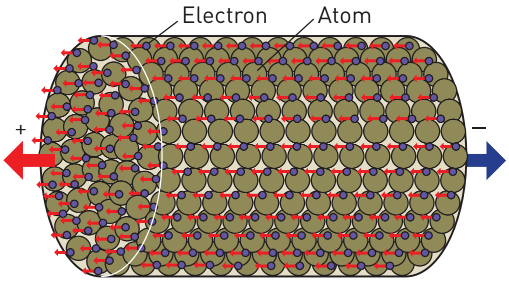


Figure 3.32 Delocalised electrons move about randomly in a metal, but move towards the positive terminal of the power source when connected into a circuit.

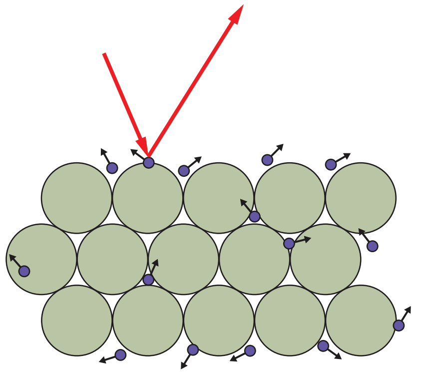


Figure 3.33 The delocalised electrons in the surface of a metal reflect light and cause it to be lustrous.

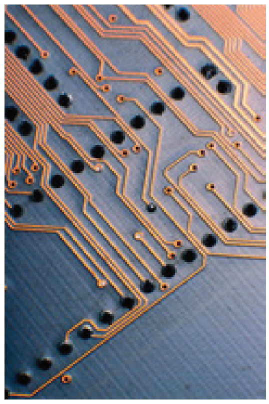


Figure 3.34 Gold bonding wire is used in integrated circuits.

Delocalised electrons are responsible for a pure metal being so lustrous (shiny). The delocalised electrons in its surface reflect light exceptionally well (Figure 3.33).

Metal alloys

An alloy is a mixture of two or more metals. Because the metal atoms are different sizes, the atoms are not arranged in the usual arrangement. This means there are no layers of atoms to slide over one another. As a result, alloys are harder than pure metals.

Soft metals such as copper, gold and aluminium are often mixed with other metals to make them hard enough for everyday use.

Brass (70% copper and 30% zinc) is used in electrical fittings and hinges.

Jewellery is often made of 18-carat gold (75% gold and 25% copper and other metals).

SMART ALLOYS

Some alloys have unique properties. When nitinol (a mixture of nickel and titanium) is cast into a particular shape and heated to 500°C, the atoms arrange themselves into a compact and regular pattern. This allows it to create a memory of this shape. If the alloy is bent out of shape, heat or an electric current can cause it return to its original shape. These metals are often called memory alloys (Figure 3.35).

An example of such memory wires are those used in orthodontic wires. The wires will constantly return to their original shape reducing the need to retighten or adjust the wire.

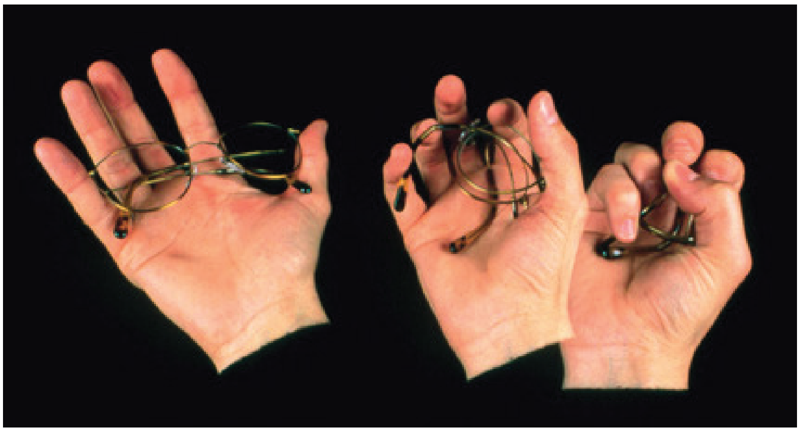


Figure 3.35 Memory wire is useful in eyeglass frames, allowing them to be bent out of shape without breaking.

Check your learning 3.7

Remember and understand

1. Describe the structure of a metal.
2. Identify the arrangement of atoms in a metal that enables each of the following properties.
   a. Malleability
   b. Conductivity
   c. Shiny appearance
3. What is an alloy?

Apply and analyse

4. Compare the properties of an alloy with those of pure metal.
5. Memory alloys have been used to repair broken bones. Suggest why a memory alloy would be beneficial in this situation.

//SCIENCE AS A HUMAN ENDEAVOUR//

3.8 Nanotechnology involves the specific arrangement of atoms

The average atom is 0.3 nanometres (0.000 000 3 mm) in diameter. Understanding the structure and properties of individual atoms allows scientists to control how these atoms are arranged. Scientists are able to manipulate atoms to design nanobots, very small structures no larger than the width of a human hair. These nanobots can be used to boost the immune system, repair parts of the body or clean up the environment.

Nanotechnology operates at the scale of the nanometre, which is approximately one ten-thousandth of the width of a human hair. This is the level of atoms or molecules. Nanotechnology allows artificial manipulation of atoms or molecular processes or objects. For example, computers the size of blood cells with tiny wireless transmitters could report on the health of a person without that person requiring surgery. **Nanomachines** (or nanobots) are tiny structures that are being designed to rearrange the atoms in our bodies, or to detect imbalances in chemical reactions. Scientists hope to develop nanobots as small as viruses or bacteria to perform tasks on a nanometre scale.

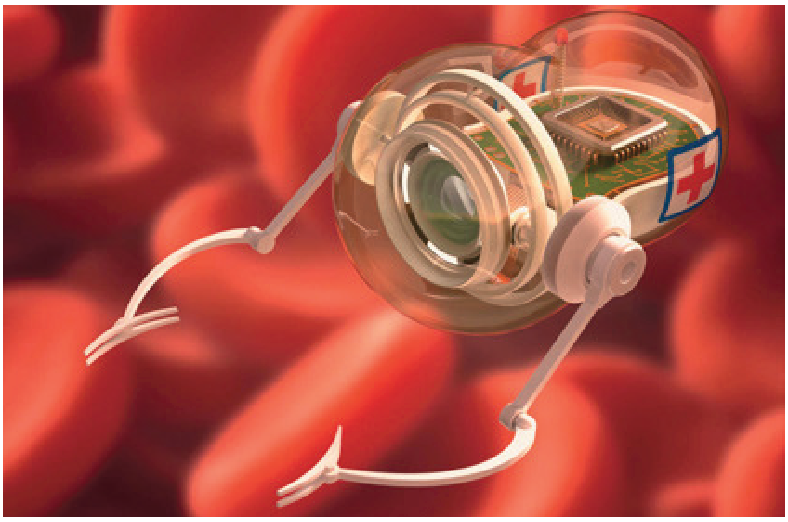


Figure 3.36 Nanobots can be used to treat viruses.

Nanobots in medicine

Many medical scientists are very excited about the use of nanobots in medicine. Imagine tiny structures monitoring a patient's body, constantly looking for viruses or bacteria that can cause disease. If a virus is detected, the nanobot could break it down molecule by molecule.

Other nano-technicians have designed a bot that is capable of carrying 9 billion oxygen and carbon dioxide molecules. This could potentially remove the need for blood transfusions in the future.

Carbon nanotubes

A **carbon nanotube** is an arrangement of carbon atoms that has very different properties from other arrangements of carbon atoms, such as graphite and diamond. Carbon nanotubes are the focus of intensive research for many applications in the future.

Carbon nanotubes are extremely hard, have very high tensile strength and are very efficient conductors of heat and electricity. That is, carbon nanotubes exhibit many properties usually found in metals. However, in contrast with most metals, carbon nanotubes are extremely light and flexible.

Carbon nanotubes might be used:

> in medicine, where their high electrical conductivity may make them suitable to bypass faulty nerve cell wiring in damaged brains

> to create clothing with unique properties, such as protection against bullets and other missiles

> in computing and television, where they are being used to develop flat, folding, futuristic television screens with greater image resolution than the human eye can detect

> for renewable energy devices, such as solar panels, due to their efficient absorption

of heat, and in wind turbines for making blades lighter and stronger
- to break down pollution in waterways or in smog ridden cities.

How carbon nanotubes are made

The emergence of nanotechnology as a key scientific force has resulted from relatively recent and rapid developments in the capacity of scientists to:

- put (nano-sized) quantities of matter where they are wanted
- use controlled amounts of nano-sized materials for a practical purpose
- detect and monitor the location and configuration of nanoscale materials.

There are two manufacturing approaches to making nano-sized materials.

1. The **top-down method** involves using mass materials and breaking them down by physical or other means into nanoscale components.
2. The **bottom-up method**, also referred to as molecular manufacturing, is a more complicated process because it relies on the construction of templates on which nanomolecules will form under the appropriate chemical and physical conditions.

A good example of the top-down method can be found in the sunscreen industry, where materials to block UV light, such as titanium oxide and zinc oxide, can be transformed by a grinding process from their white, opaque mass forms into invisible, nano-sized particles. These are known as nanopowders.

A good example of the bottom-up method is the production of carbon nanotubes. A layer of metal catalyst particles is exposed to high heat and a carbon-containing gas. The nanotubes form at the interface between the gas and the metal catalyst.

Extend your understanding 3.8

1. How many nanometres in a millimetre?
2. How many average-sized atoms would fit in a single nanometre?
3. What is a nanobot?
4. What is a carbon nanotube? Describe its structure.
5. What two main manufacturing processes are used to make nanomaterials?
6. All powders are made up of small particles. How is a nanopowder different from a normal powder?

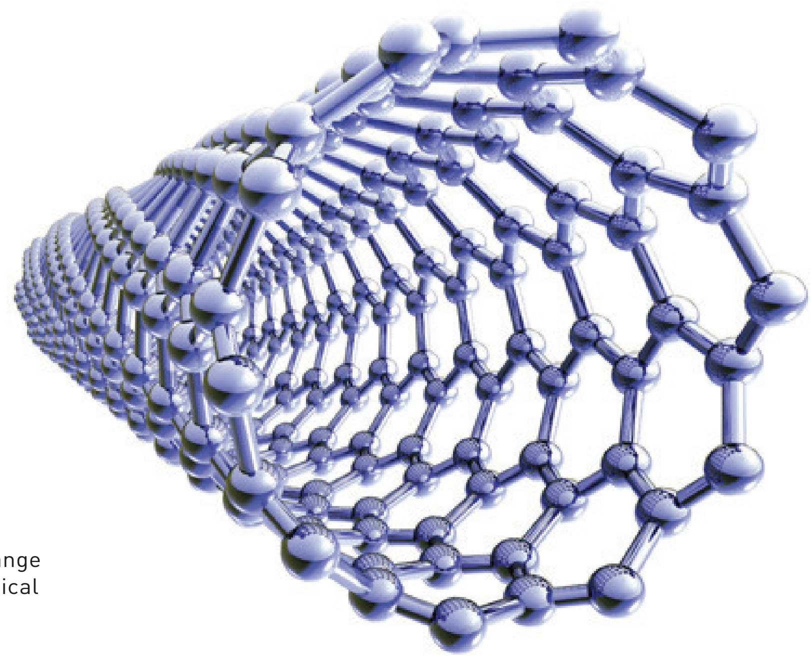


Figure 3.37 Nanotube technology is being investigated for a wide range of technological and medical uses.

* REVIEW

3

Remember and understand

1 What is the atomic number of the element known as ununpentium?

2 What is the overall order of elements in the periodic table based on?

3 What is the difference between an atom and an element?

4 What is the name given to the following features of the periodic table?
- a Horizontal row
- b Vertical column
- c The set of 10 groups from group 3 to group 12

5 State the group number of the:
- a alkaline earth elements
- b halogens
- c noble gases
- d alkali metals.

6 What is a valence shell?

7 State the features that elements in the same group have in common.

8 Suggest why transition metals are much more widely used than the alkali metals.

9 An inert substance is one that will not react with any other substance. Originally, group 18 elements were known as the 'inert gases'. Suggest why the name was changed to 'noble gases'.

10 What special feature of metals allows them to conduct electricity in the solid state?

11 What number of electrons in the valence shell makes an atom particularly stable?

12 When naming an ionic compound, which ion is written first?

13 Give explanations for the following.
- a Argon will not react with any other element.
- b The reaction between sodium and chlorine gives out a lot of heat and light.
- c When you accidentally spill sodium chloride onto a stove while cooking, it does not melt.

Apply and analyse

14 Only two elements are liquids at room temperature – bromine and mercury. Bromine is a non-metal and mercury is a metal. Describe how these two liquids are likely to appear and behave differently from each other.

15 Consider the following pairs of elements:
- i chlorine and oxygen
- ii nitrogen and lithium
- iii fluorine and argon
- iv aluminium and potassium.

- a Which pair(s) will react to form an ionic compound?
- b Which pair(s) will react to form a molecular compound?
- c Which pair(s) will not react to form a compound?

In each case, justify your answer.

Evaluate and create

16 Scientists such as Berzelius and Mendeleev worked on their own to produce new ideas. Others, like Seaborg, worked in a team. Now most scientists work in teams. What are the advantages of working in a team?

17 Scientists have had to deduce what it is like inside an atom from indirect evidence, similar to how astronomers determine the temperature and composition of stars. List three advantages and three disadvantages of using indirect evidence to develop scientific theories.

18 What two elements would you expect to react together in the most violent way? Justify your answer.

19 Before the 1980s, the groups of the periodic table were numbered with Roman numerals. Some scientists prefer this version because the atoms of the elements in group III (now 13) have three electrons in their valence shell, those in group IV (now 14) have four electrons in their valence shell and so on. Examine how the groups of transition metals were numbered in the old way. Which numbering system do you think is the most helpful? How can you deduce the number of electrons in the valence shell from the new group number?

20 A certain particle was found to contain 16 protons and 18 electrons.

a What element must it be? State your reasoning.

b Is the particle neutral, positively charged or negatively charged?

c What is the formula of the particle? Justify your answer.

21 When the uncharged atoms of potassium lose an electron, they then have an electronic configuration of 2,8,8. This is the same as the electronic configuration of argon. Does this mean that the potassium atoms have become argon atoms? Discuss.

Ethical understanding

22 Meyer and Mendeleev each published a periodic table within months of each other. However, Mendeleev is given sole credit for developing the periodic table.

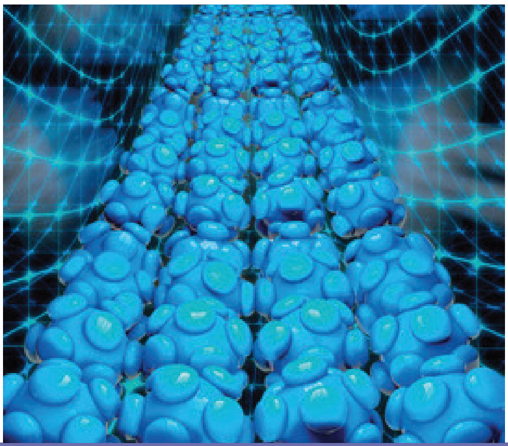
a Is it fair that the person who first discovers, develops or publishes something receives the credit for this discovery?

b What did Mendeleev do to get sole credit for developing the periodic table?

Critical and creative thinking

23 A substance will conduct electricity if it contains charged particles that are free to move across the sample. The charged particles can be electrons or ions. Suggest why ionic compounds cannot conduct electricity when in the solid state, but can conduct electricity when melted.

24 A student claimed that sodium chloride is made of molecules. Is the student correct? Discuss.



Research

25 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

> **The noble gases**
> The story behind the discovery of the noble gases is a fascinating one. The challenge was this: how do you detect the existence of something that only exists as a gas that does not react with anything and, except for argon, is only present in the air in extremely small concentrations? How was the first noble gas found? What role did the periodic table of that time play in helping chemists hunt for other noble gases?

> **Hydrogen**
> Hydrogen is a most unusual non-metal because it can form H^+ ions and H^- ions depending on what it reacts with. Although alkali metals do not react with one another, hydrogen will react with alkali metals and form compounds, such as lithium hydride (LiH). Show why the hydride ion (H^-) is stable. What are the properties of metal hydrides such as lithium hydride? What uses are made of these compounds?

> **Nanotechnology**
> Nanomaterials are now being used to assist in a range of chemical reactions, often to increase the rate of very specific reactions that produce valuable products. Research the products that are produced by using nanoparticles and how the use of these has improved the production method.

KEY WORDS

3

alkali metal
an atom found in group 1 of the periodic table

alkaline earth metal
an atom found in group 2 of the periodic table

anion
a negatively charged ion

atomic number
the number of protons of an atom

Bohr model
a way to represent the electrons of an atom in a series of shells around the atomic nucleus

bottom-up method
this process is also known as molecular manufacturing. It involves constructing templates which nanomolecules will form under suitable chemical and physical conditions

carbon nanotube
a very small tube made by the careful arrangement of carbon atoms

cation
a positively charged ion

covalent bonding
a bond formed when two or more atoms share electrons

delocalised electron
an electron in a molecule that can easily move between atoms

diatomic molecule
a molecule that consists of two atoms

electronic configuration
the arrangement of electrons in each electron shell surrounding an atom

element
pure substance made up of one type of atom, e.g. oxygen, carbon

group
a vertical list of elements found in the periodic table that have characteristics in common

halogen
the group of elements found in group 17 of the periodic table

ion
an atom that has gained or lost electrons, resulting in a negative or positive charge

ionic bond
a bond that forms between a negatively charged anion and a positively charged cation

ionic compound
a molecule that is formed by a negatively charged anion and a positively charged cation

metal
a collection of elements found on the left-hand side of the periodic table that are malleable, lustrous, ductile and highly conducting

metalloid
a small collection of elements that have a mixture of characteristics of metals and non-metals

molecular compound
a molecule that is formed through covalent bonding

nanomachines
these refer to nanometre-sized robots that can perform tasks at a molecular level

nanotechnology
the manipulation of individual atoms to form structures

noble gas
a collection of gaseous elements found in group 18 of the periodic table

non-metal
a collection of elements that are found on the right-hand side of the periodic table

period
a horizontal list of elements found in the periodic table

periodic
the arrangement of elements into a table according to their chemical elements

polyatomic ion
a charged ion that consists of two or more atoms bonded together

relative atomic mass
mass of an atom relative to carbon-12, which is given a relative atomic mass of 12; calculated by taking into account the percentage abundance of each isotope; usually shown for each element in the periodic table.

shell diagram
a diagram that shows the arrangement of electrons and electron shells in an atom

top-down method
this involves breaking down mass materials into nanoscale componenets by physical or other means

transition metal
an element found in groups 3–12 of the periodic table

valence shell
the outermost electron shell in an atom that contains electrons