9 Elements and atoms

- The discovery of the elements
- The link between elements and atoms
- The properties of elements
- Chemical symbols
- The first twenty elements of the periodic table

One of the main activities in chemistry is breaking down substances to discover what they are made of. During the course of this work chemists have discovered that some substances cannot be broken down into simpler substances by physical changes or chemical reactions. These substances are called **elements**.

The discovery of the elements

Before 1669 the following elements had already been discovered: carbon, sulfur, iron, copper, arsenic, silver, tin, antimony, gold, mercury and lead. Some had been known for thousands of years, although they had not been recognised as elements. The order in which the other elements were discovered is shown in Table 9.1 on page 109. This table uses mainly European historical data but it is known that the Chinese and people in Muslim countries also studied chemistry, so some of the elements could have been discovered by them at an earlier date.

Use Table 9.1 on pages 109–111 to answer these questions.

1 How many elements were discovered in:
   a) the 17th century or earlier
   b) the 18th century
   c) the 19th century?
2 Which three scientists discovered the most elements?
3 How many Swedish scientists discovered new elements?
4 Which UK scientist discovered the most elements?

Table 9.1 The discovery of the elements

Date	Element	Discoverer	Brief description
1669	Phosphorus	H. Brand (Germany)	white, red or black solid
1737	Cobalt	G. Brandt (Sweden)	reddish metal
1746	Zinc	A. S. Marggraf (Germany)	blue-white metal
1748	Platinum	A. de Ulloa (Spain)	blue-white metal
1751	Nickel	A. F. Cronstedt (Sweden)	silver-white metal
1753	Bismuth	C. F. Geoffroy (France)	silver-red metal
1766	Hydrogen	H. Cavendish (UK)	colourless gas
1771–1774	Oxygen	C. W. Scheele (Sweden) J. Priestley (UK)	colourless gas
1772	Nitrogen	D. Rutherford (UK)	colourless gas
1774	Chlorine	C. W. Scheele (Sweden)	green-yellow gas
1774	Manganese	J. G. Gahn (Sweden)	red-white metal
1781	Molybdenum	P. J. Hjelm (Sweden)	silver-grey metal
1783	Tellurium	F. J. Muller (Austria)	silver-grey solid
1783	Tungsten	J. J. de Elhuya, F. de Elhuya (Spain)	grey metal
1789	Zirconium	M. H. Klaproth (Germany)	shiny, white metal
1789	Uranium	M. H. Klaproth (Germany)	blue-white metal
1794	Yttrium	J. Gadolin (Finland)	shiny, grey metal
1795	Titanium	M. H. Klaproth (Germany)	silvery metal
1798	Beryllium	N-L Vauquelin (France)	brown powder
1798	Chromium	N-L Vauquelin (France)	silvery metal
1801	Niobium	C. Hatchett (UK)	grey metal
1802	Tantalum	A. G. Ekeberg (Sweden)	silvery metal
1803	Cerium	J. J. Berzelius, W. Hisinger (Sweden) M. H. Klaproth (Germany)	grey metal
1803	Palladium	W. H. Wollaston (UK)	silver-white metal
1804	Rhodium	W. H. Wollaston (UK)	grey-blue metal
1804	Osmium	S. Tennant (UK)	blue-grey metal
1804	Iridium	S. Tennant (UK)	silver-white metal
1807	Potassium	H. Davy (UK)	silver-white metal
1807	Sodium	H. Davy (UK)	silver-white metal
			(continued)

Date	Element	Discoverer	Brief description
1808	Magnesium	H. Davy (UK)	silver-white metal
1808	Calcium	H. Davy (UK)	silver-white metal
1808	Strontium	H. Davy (UK)	silver-white metal
1808	Barium	H. Davy (UK)	silver-white metal
1808	Boron	J. Gay-Lussac, L. Thernard (France)	dark brown powder
1811	Iodine	B. Courtois (France)	grey-black solid
1817	Lithium	J. A. Arfwedson (Sweden)	silver-white metal
1817	Cadmium	F. Stromeyer (Germany)	blue-white metal
1818	Selenium	J. J. Berzelius (Sweden)	grey solid
1824	Silicon	J. J. Berzelius (Sweden)	grey solid
1825–1827	Aluminium	H. C. Oersted (Denmark) F. Wohler (Germany)	silver-white metal
1826	Bromine	A. J. Balard (France)	red-brown liquid
1829	Thorium	J. J. Berzelius (Sweden)	grey metal
1830	Vanadium	N. G. Sefstrom (Sweden)	silver-grey metal
1839	Lanthanum	C. G. Mosander (Sweden)	metallic solid
1843	Terbium	C. G. Mosander (Sweden)	silvery metal
1843	Erbium	C. G. Mosander (Sweden)	silver-grey metal
1844	Ruthenium	K. K. Klaus (Estonia)	blue-white metal
1860	Caesium	R. W. Bunsen, G. R. Kirchhoff (Germany)	silver-white metal
1861	Rubidium	R. W. Bunsen, G. R. Kirchhoff (Germany)	silver-white metal
1861	Thallium	W. Crookes (UK)	blue-grey metal
1863	Indium	F. Reich, H. T. Richter (Germany)	blue-silver metal
1868	Helium	J. N. Lockyer (UK)	colourless gas
1875	Gallium	L. de Boisbaudran (France)	grey metal
1878	Ytterbium	J-C-G de Marignac (Switzerland)	silvery metal
1878–1879	Holmium	J. L. Soret (France) P. T. Cleve (Sweden)	silvery metal
1879	Scandium	L. F. Nilson (Sweden)	metallic solid
1879	Samarium	L. de Boisbaudran (France)	light grey metal
1879	Thulium	P. T. Cleve (Sweden)	metallic solid

Date	Element	Discoverer	Brief description
1880	Gadolinium	J-C-G de Marignac (Switzerland)	silver-white metal
1885	Neodymium	C. Auer von Welsbach (Austria)	yellow-white metal
1885	Praseodymium	C. Auer von Welsbach (Austria)	silver-white metal
1886	Dysprosium	L. de Boisbaudran (France)	metallic solid
1886	Fluorine	H. Moissan (France)	green-yellow gas
1886	Germanium	C. A. Winkler (Germany)	grey-white metal
1894	Argon	W. Ramsay, Lord Rayleigh (UK)	colourless gas
1898	Krypton	W. Ramsay, M. W. Travers (UK)	colourless gas
1898	Neon	W. Ramsay, M. W. Travers (UK)	colourless gas
1898	Polonium	Mme M. S. Curie (Poland/France)	metallic solid
1898	Xenon	W. Ramsay, M. W. Travers (UK)	colourless gas
1898	Radium	P. Curie (France), Mme M. S. Curie (Poland/France), M. G. Bermont (France)	silvery metal
1899	Actinium	A. Debierne (France)	metallic solid
1900	Radon	F. E. Dorn (Germany)	colourless gas
1901	Europium	E. A. Demarçay (France)	grey metal
1907	Lutetium	G. Urbain (France)	metallic solid
1917	Protactinium	O. Hahn (Germany), Fr L. Meitner (Austria), F. Soddy, J. A. Cranston (UK)	silvery metal
1923	Hafnium	D. Coster (Netherlands) G. C. de Hevesy (Hungary/Sweden)	grey metal
1925	Rhenium	W. Noddack, Fr I. Tacke, O. Berg (Germany)	white-grey metal
1937	Technetium	C. Perrier (France), E. Segre (Italy/USA)	silver-grey metal
1939	Francium	Mlle M. Percy (France)	metallic solid
1940	Astatine	D. R. Corson, K. R. Mackenzie (USA), E. Segre (Italy/USA)	metallic solid
1945	Promethium	J. Marinsky, L. E. Glendenin, C. O. Corgell (USA)	metallic solid

The link between elements and atoms

So far we have seen that an element is a substance that cannot be broken down by physical changes or chemical reactions into a simpler form of matter. In the previous chapter we learnt that particles are made of molecules and atoms and that atoms are the particles from which all forms of matter are made. You also learnt that the word 'atom' means indivisible. This leads us to look for a link between an element, a substance which cannot be broken down into simpler substances, and an atom, a particle from which all things are made.

The link is that each element is made of one particular type of atom which has its own particular properties. The properties of the atom of the element also give the element its own particular properties.

5 Why do elements have different properties?

The properties of elements

Figure 9.1 Mercury and bromine are liquid at room temperature.

There are only two elements that are liquid at room temperature and standard pressure. They are mercury and bromine. Eleven elements are gases under normal conditions. All the others are solids.

Each element has its own special properties. For example, sodium is a soft, silvery-white metal with a melting point of 98 °C and a boiling point of 884 °C and chlorine is a yellow-green gas with a melting point of −101 °C and a boiling point of −34 °C.

Most substances are made from two or more elements that are joined together.

These substances are called **compounds**. When elements form compounds they no longer display their own special properties. Instead the compound has its own special properties. For example, when sodium and chlorine form the compound sodium chloride they form a white solid with a melting point of 801 °C and a boiling point of 1420 °C that easily forms crystals. You can learn more about compounds in Chapter 10.

Probably the most spectacular use of the properties of elements is in fireworks. Compounds of some elements are used to make fireworks. When they are heated they produce light of various colours (see Table 9.2).

Figure 9.2 A dazzling firework display

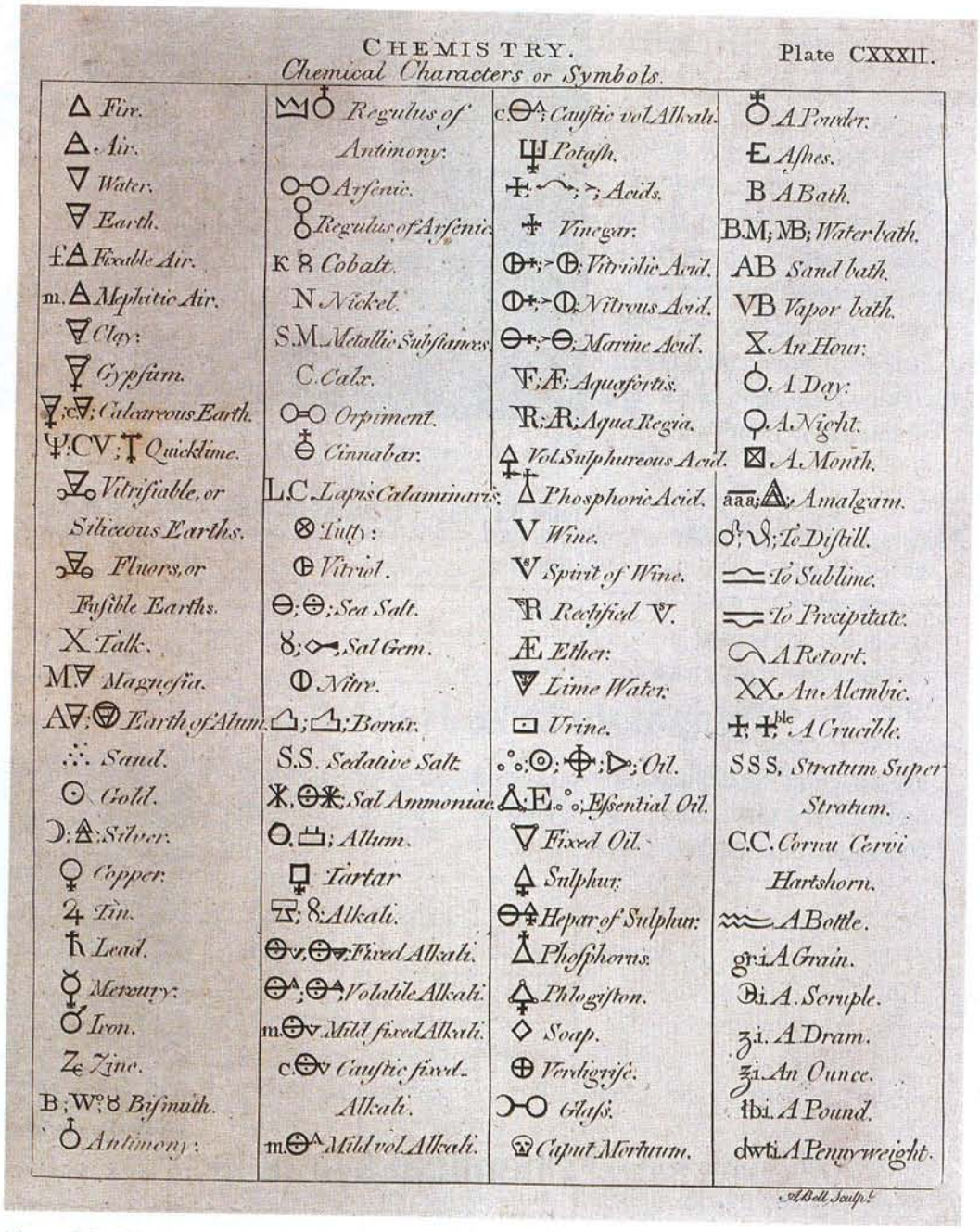
6 Iron and titanium are two elements that are used in compounds to make sparks and zinc is used in compounds to make smoke. Which other elements could you use in compounds to make a firework that produced green and red sparks and finished with blue smoke?

Table 9.2 The colours produced by elements when heated

Element	Colour
aluminium	silvery-white
barium	apple green
calcium	orange
caesium	blue
copper	green
lithium	red
magnesium	white
sodium	golden yellow
rubidium	violet-red
strontium	red

Chemical symbols

The first chemists were called alchemists. Two of their main activities were investigating materials in an attempt to find a way to make gold or a medicine which would extend the human lifespan. They wrote down details of their investigations using symbols to represent the substances they used or produced. The use of symbols saved them time. Figure 9.3 on page 114 shows a few of the alchemists' symbols. Some of the symbols were deliberately mysterious as the alchemists really wanted to keep their work a secret – just in case they discovered how to make gold or a medicine that would make them live forever!


CHEMISTRY. Plate CXXXII.
Chemical Characters or Symbols.

Fire. Air. Water. Earth. Fixable Air. Mephitic Air. Clay. Gypsum. Calcareous Earth. Quicklime. Vitrifiable, or Siliceous Earths. Fluors, or Fusible Earths. Talk. Magnesia. Earth of Alum. Sand. Gold. Silver. Copper. Tin. Lead. Mercury. Iron. Zinc. Bismuth. Antimony:

Regulus of Antimony. Arsenic. Regulus of Arsenic. Cobalt. Nickel. Metallic Substances. Calx. Orpiment. Cinnabar. Lapis Calaminaris. Tutty: Vitriol. Sea Salt. Sal Gem. Nitre. Borax. Sedative Salt. Sal Ammoniac. Alum. Tartar. Alkali. Fixed Alkali. Volatile Alkali. Mild fixed Alkali. Caustic fixed Alkali. Mild vol. Alkali.

Caustic vol. Alkali. Potash. Acids. Vinegar. Vitriolic Acid. Nitrous Acid. Marine Acid. Aquafortis. Aqua Regia. Vol. Sulphureous Acid. Phosphoric Acid. Wine. Spirit of Wine. Rectified V. Ether. Lime Water. Urine. Oil. Essential Oil. Fixed Oil. Sulphur. Hepar of Sulphur. Phosphorus. Phlogiston. Soap. Verdigrise. Glass. Caput Mortuum.

A Powder. Ashes. B A Bath. B.M; MB; Water bath. AB Sand bath. VB Vapor bath. X An Hour. A Day. A Night. A Month. Amalgam. To Distill. To Sublime. To Precipitate. A Retort. An Alembic. A Crucible. SSS. Stratum Super Stratum. C.C. Cornu Cervi Hartshorn. A Bottle. gri A Grain. Di. A Scruple. zi. A Dram. zi. An Ounce. lbi. A Pound. dwti. A Penny-weight.

A Bell Sculp.

Figure 9.3 Alchemists' symbols

The alchemists also gave many of the substances a number of different names, again to increase secrecy, and this led to confusion when the science of chemistry began properly.

It was decided that each substance used in an investigation or produced from it should be clearly identified by one name only so that reports of investigations could be clearly understood.

In 1787 Lavoisier and three other scientists set out the names of all the substances used in chemical investigations in a 300-page book.

In 1813 Jöns Jakob Berzelius introduced the symbols we still use today to represent the elements. Each element was identified by the first letter of its name. If two or more elements began with the same letter, another letter in the name was also used.

Some of the symbols are made from old names for the elements. Iron, for example, had an old name of ferrum and the symbol Fe is made from it. Silver was known as argentum and its symbol is Ag.

Sodium is known as natrium, and potassium is known as kalium in Latin and some other languages and the symbols for sodium and potassium were made from these names. The symbol for sodium is Na and the symbol for potassium is K.

The elements have received their names from a variety of sources. Some elements, such as chlorine (from the Greek word meaning green colour) and bromine (from the Greek word for stench), are named after their properties. Other elements are named after places. The places may be as small as a village – strontium is named after Strontian in Scotland – or as large as a planet – uranium is named after the planet Uranus. A few elements, such as einsteinium, are named after people.

7 Why do some elements have two letters for their chemical symbol and others have only one?
8 Why isn't the symbol for silver S and the symbol for potassium P?
9 How did some of the elements get their names?

The first twenty elements in the periodic table

After a large number of elements had been identified scientists began arranging them into order based on their properties, such as mass, and a table called the periodic table was produced. It is called the periodic table because as you move along the rows elements with certain properties occur periodically. We will look at how this occurs in more detail in *Checkpoint Science 3* but for now we just need to know that such a table exists and is very widely used. For example, there may be a copy of the periodic table on the wall of your laboratory. Figure 9.4 shows part of the periodic table.

You do need to know the first twenty elements in the periodic table now so for easy reference their names and chemical symbols are given in Table 9.3. Note that you read down the left-hand column first, then sodium follows neon and you read down the right-hand column.

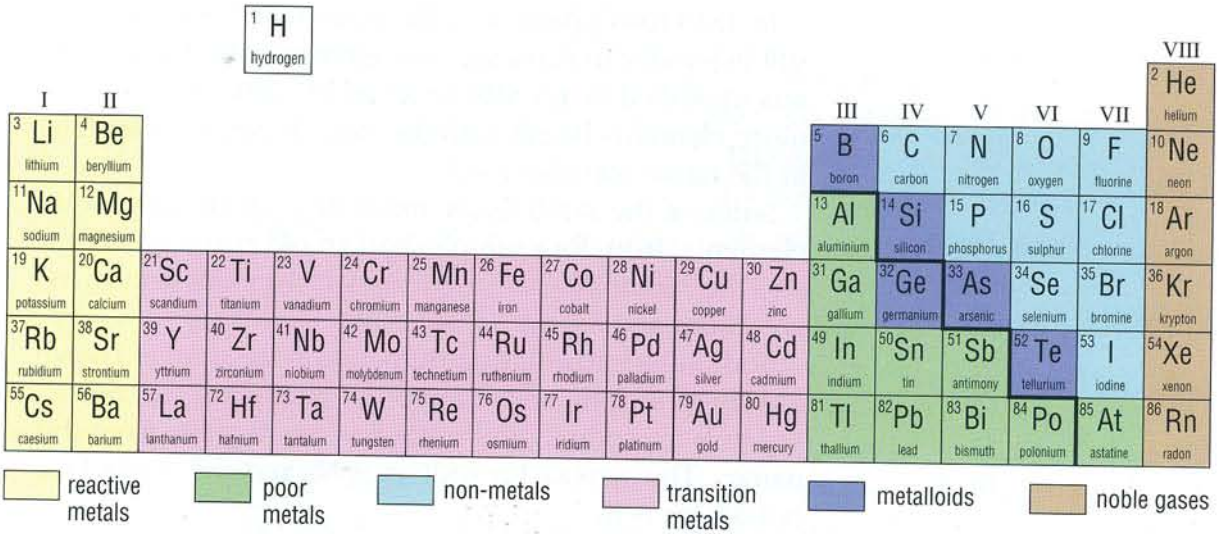


Figure 9.4 Part of the periodic table showing six classification groups of elements

10 Carbon and sulfur were discovered before 1669 but the other elements were discovered afterwards.

a) What was the date of discovery of the other elements in Table 9.3?

b) Arrange the elements in the order in which they were discovered.

Table 9.3 The names and chemical symbols of the first twenty elements of the periodic table (sodium follows on from neon)

	Name	Symbol		Name	Symbol
1	hydrogen	H	11	sodium	Na
2	helium	He	12	magnesium	Mg
3	lithium	Li	13	aluminium	Al
4	beryllium	Be	14	silicon	Si
5	boron	B	15	phosphorus	P
6	carbon	C	16	sulfur	S
7	nitrogen	N	17	chlorine	Cl
8	oxygen	O	18	argon	Ar
9	fluorine	F	19	potassium	K
10	neon	Ne	20	calcium	Ca

SUMMARY

- Substances can be broken down into elements (*see page 108*).
- Each element is made from atoms which are different from the atoms of other elements (*see page 112*).
- Each element has its own special properties (*see page 112*).
- When elements combine to make a compound, the compound has different properties from the elements from which it is made (*see page 112*).
- There is a chemical symbol for each element (*see page 113*).
- The first twenty elements of the periodic table begins with hydrogen and ends with calcium (*see pages 115 and 116*).

End of chapter questions

1 Look at Table 9.1 and answer the following questions.

a) Which elements are gases at room temperature?

b) Which gaseous elements are coloured and what are their colours?

c) Mercury is one of two liquid elements. What is the other and when was it discovered?

d) What are the most common colours of elements?

e) Name the elements that are red or reddish.

f) Name the elements that appear partly blue.

2 Table 9.4 shows the main elements making up the Earth's crust, the air and the human body. Elements in quantities less than 1% are not shown but may be present in very small amounts.

Table 9.4 The main elements in the Earth's crust, the air and the human body

Element	Earth's crust	Air	Human body
aluminium	8.2%	–	–
carbon	–	–	18%
calcium	4.5%	–	1.5%
hydrogen	–	–	10%
iron	5.6%	–	–
magnesium	2.3%	–	–
nitrogen	–	78%	3%
oxygen	46.1%	21%	65%
potassium	2%	–	–
silicon	28. 2%	–	–
sodium	2.4%	–	–

a) Arrange the elements in the human body in order starting with the most plentiful.

b) Arrange the elements in the Earth's crust in order starting with the most plentiful.

c) Which element is found in large amounts in the Earth's crust, the air and the human body?

d) How does the amount of calcium in the Earth's crust compare with the amount in the human body?

The main elements in the Sun, starting with the most plentiful, are hydrogen, helium, oxygen, carbon, nitrogen, silicon, magnesium, neon, iron and sulfur.

e) Which of the main elements found in the Sun are not found in Table 9.4?

f) Which of the main elements in the Sun are also main elements in the human body?

g) Which of the main elements in the Sun are only found as main elements in the Earth's crust and not in the air or the human body?