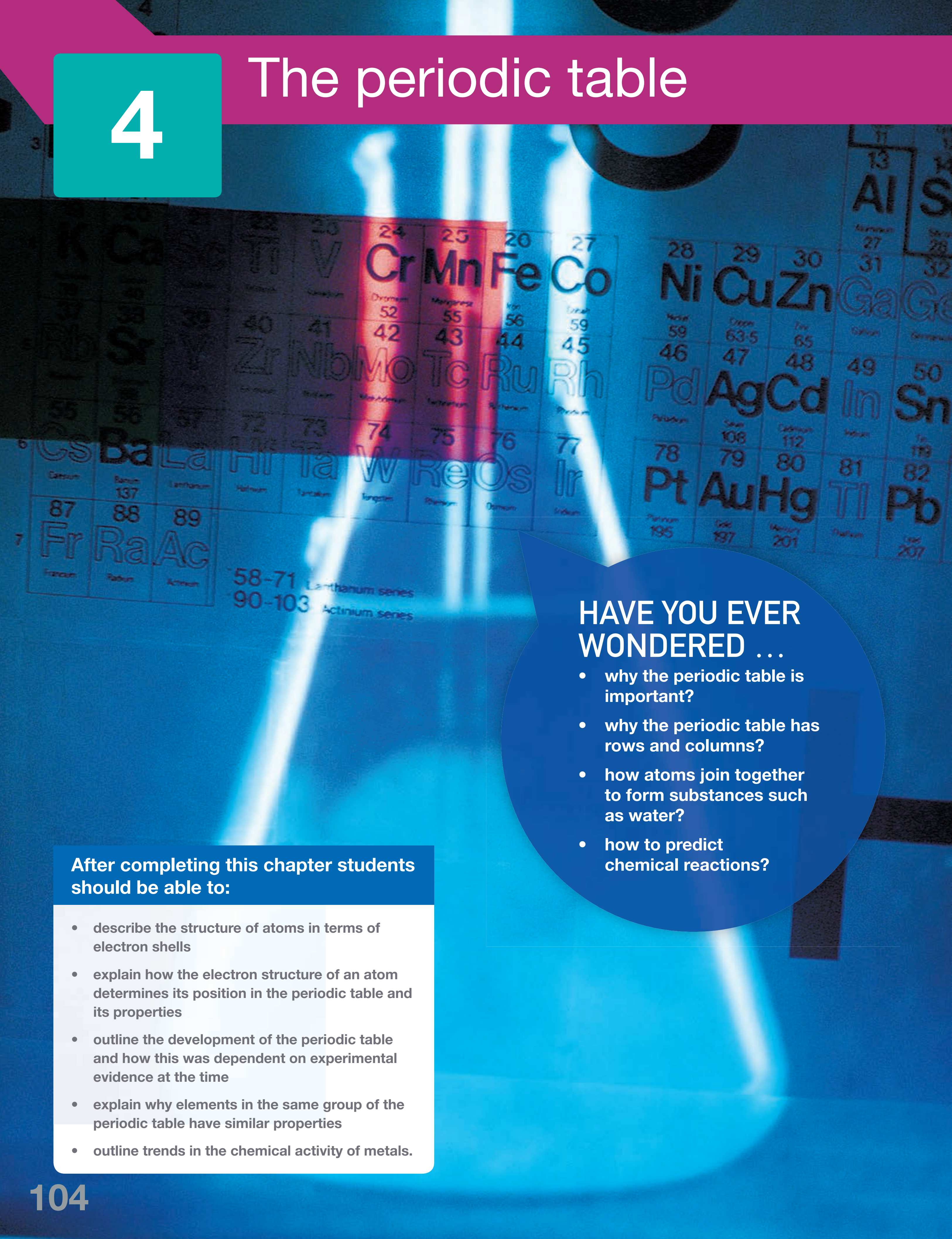
4 The periodic table



HAVE YOU EVER WONDERED …

- why the periodic table is important?
- why the periodic table has rows and columns?
- how atoms join together to form substances such as water?
- how to predict chemical reactions?

After completing this chapter students should be able to:

- describe the structure of atoms in terms of electron shells
- explain how the electron structure of an atom determines its position in the periodic table and its properties
- outline the development of the periodic table and how this was dependent on experimental evidence at the time
- explain why elements in the same group of the periodic table have similar properties
- outline trends in the chemical activity of metals.

4.1 Atoms and elements

INQUIRY science 4 fun

Element bingo

Collect this ...

- 1 bingo card from your teacher
- 1 pencil, pen or highlighter
- access to a periodic table

No

Do this ...

1. Your teacher will call out clues that will allow you to identify elements of the periodic table.
2. If you have the symbol of that element, then highlight or circle it.
3. When you have a complete row, column, diagonal or card, call out 'Bingo!'

Record this ...

Describe how this activity helps you learn the symbols of the elements.

Explain why this might occur.

Atoms make up everything in the universe. They make up stars, rocks, water, T-shirts, butterflies and you. Like most things, atoms come in different 'varieties' or types. In chemistry, the different types of atoms are known as elements. Elements consist of atoms with the same number of protons. Elements can be thought of as the building blocks from which substances are made.

Atoms

Atoms are the particles that make up all the substances in the universe. Atoms are so small that you can't see them with normal microscopes. Only a powerful scanning tunnelling microscope (STM) allows them to be seen. A typical STM image is shown in Figure 4.1.1 on page 106. However, even an STM is unable to show the smaller protons, neutrons and electrons that make up atoms. Although these particles are 'invisible', scientists have gathered evidence from which they have deduced that the particles exist and how they are arranged in the atom. This type of evidence is known as **indirect evidence** and does not involve direct observation of the particles themselves.

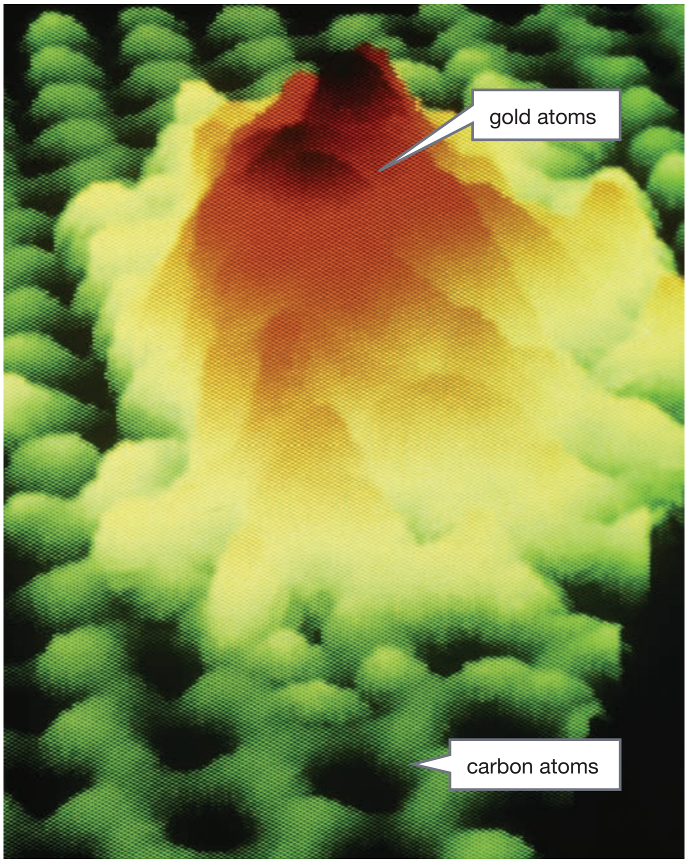


Figure 4.1.1 An STM image of some gold atoms (yellow and brown) on a graphite layer made up of carbon atoms (green)

The nucleus

At the centre of each atom is its **nucleus**, a tight, dense bundle of protons and neutrons. Neutrons are slightly heavier than protons and both are roughly 1800 times heavier than electrons. For this reason, almost all of an atom's mass is in its nucleus. Protons carry a positive charge (+) while neutrons are neutral, having no charge. The positive charges of all those protons in the nucleus give the nucleus a positive charge too.

Electron shells

The electrons spin around in the space around the nucleus. This is shown in Figure 4.1.2. Electrons are negatively charged (–) and are attracted to the positive nucleus. This attraction keeps them from wandering too far from the nucleus but is not enough to pull them in completely.

Atoms are electrically neutral and so the number of electrons is always the same as the number of protons. That is:

Number of electrons in an atom = number of protons

Electrons don't just spin anywhere but spin around the nucleus in regions known as **electron shells** or **energy levels**. The first electron shell is the closest to the nucleus and so the attraction between the nucleus and first-shell electrons is the strongest. This is the lowest energy level for electrons. Electrons in the outermost shell have the highest energy.

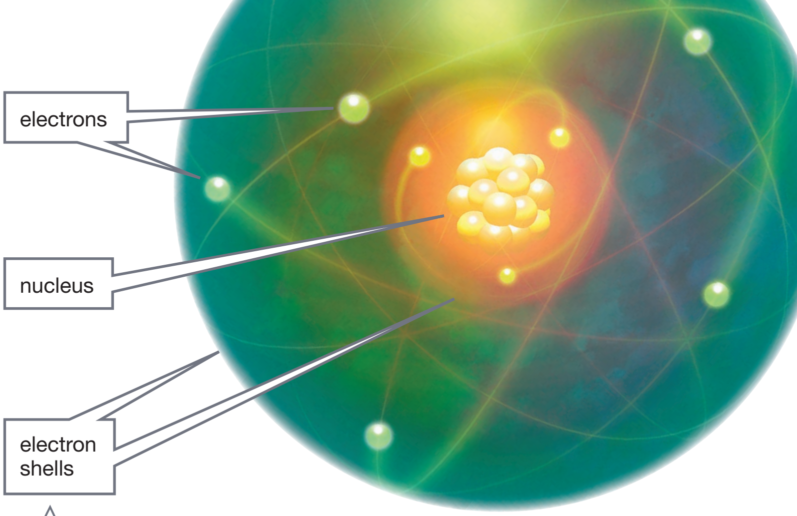


Figure 4.1.2 An atom has a heavy core called the nucleus. Around this are fast-moving electrons, arranged in shells.

The first shell is relatively small and can only hold a maximum of two electrons. Being a little further out, the next electron shell is a little bigger. It can hold eight electrons. The next two shells are bigger again and so are capable of holding even more electrons. The maximum number of electrons that a shell can hold is given by the formula $2n^2$, where n is the number of the shell. This is shown in Table 4.1.1.

Table 4.1.1 Maximum number of electrons held in each shell

Shell	Maximum number of electrons (= $2n^2$)
$n = 1$ (innermost)	2
$n = 2$	8
$n = 3$	18
$n = 4$	32

Electron configuration

Electrons are attracted to the nucleus and this attraction is strongest close to the nucleus. Hence, electrons fill the first shell, then the second shell and so on. When filled in this way, the atom is in its lowest energy state. This is called its **ground state**.

Electron configuration shows how the electrons are arranged in the shells of an atom when it is in its ground state. For example, a sodium atom has 11 electrons. Its electron configuration is 2,8,1. Two electrons are in shell 1, eight are in shell 2 and the remaining electron is in shell 3. Shell 4 is empty. You can see this arrangement in Figure 4.1.3.

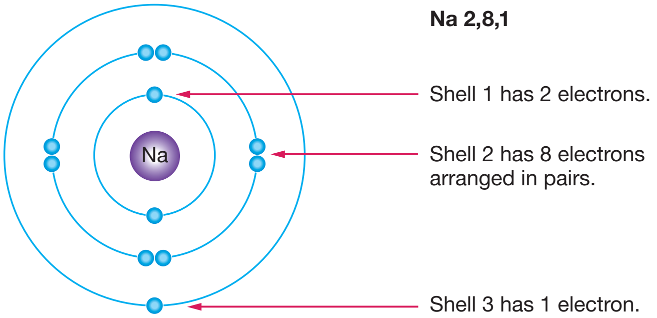


Figure 4.1.3 Sodium's electrons are arranged in its shells according to the electron configuration of 2,8,1. Note that electrons pair up once there are four of them in a shell.

SciFile

Fireworks

The explosive heat of fireworks causes electrons in the atoms to jump from one shell to another. As the electrons return to their ground state, energy is released as light. Different metallic elements release different amounts of energy so each give the fireworks a different colour. This occurs because there are different numbers of protons in atoms of different elements and therefore the attraction of the protons for electrons in the shells is different. So the energy difference between the shells varies.

1 p111

4.1

Elements

The number of protons in the nucleus determines what **element** the atom belongs to.

There are 118 different elements. Twenty-six of these are not found naturally on Earth but are synthetic, having been made in the laboratory. The periodic table in Figure 4.1.8 on page 109 shows all of the known elements. Elements can be thought of as the building blocks from which all substances are made.

The chemical formula of a compound tells you what elements make it up and in what proportions. For example, a molecule of water (H_2O) is made of two atoms of the element hydrogen and one atom of the element oxygen. The formula for the ionic lattice structure of common salt (sodium chloride, NaCl) indicates that there are equal numbers of ions of the element sodium and the element chlorine.

Atomic number

The number of protons in the nucleus of an atom is known as its **atomic number**.

Atomic number = number of protons

Each element has a characteristic and identifying atomic number. For example, all carbon atoms have six protons and so all have an atomic number of 6. All oxygen atoms have eight protons (atomic number of 8), while all uranium atoms have 92 protons (atomic number 92). This makes uranium atoms some of the heaviest known and helps explain why they are unstable and radioactive (Figure 4.1.4). In contrast, a hydrogen atom has only a single proton in its nucleus. Its atomic number is 1, making hydrogen the smallest of all the atoms and the lightest of all the elements. This fact was used in airships like the one in Figure 4.1.5.

Figure 4.1.4 Uranium is the heaviest natural element. Its extreme size makes its nuclei unstable. When these nuclei break apart, massive amounts of energy are released, as is evident in this 1958 atomic bomb test.

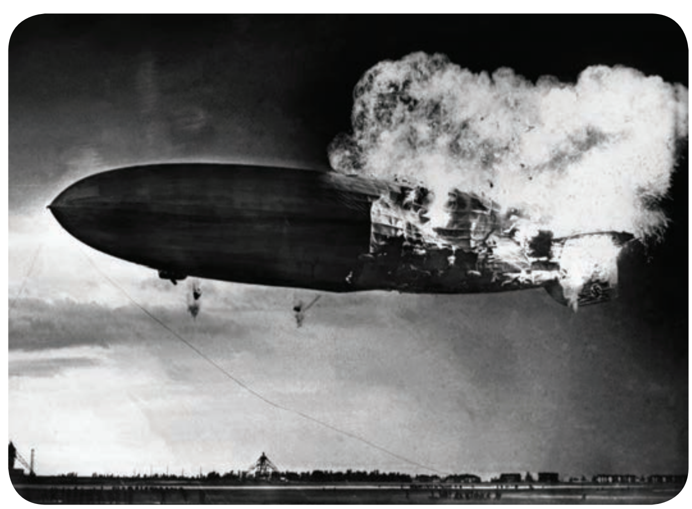


Figure 4.1.5 Hydrogen is lighter than air and so was used in many early airships. Unfortunately, hydrogen is also very explosive, which led to the 1937 Hindenburg disaster shown here.

2 p112

SKILL BUILDER

Element symbols

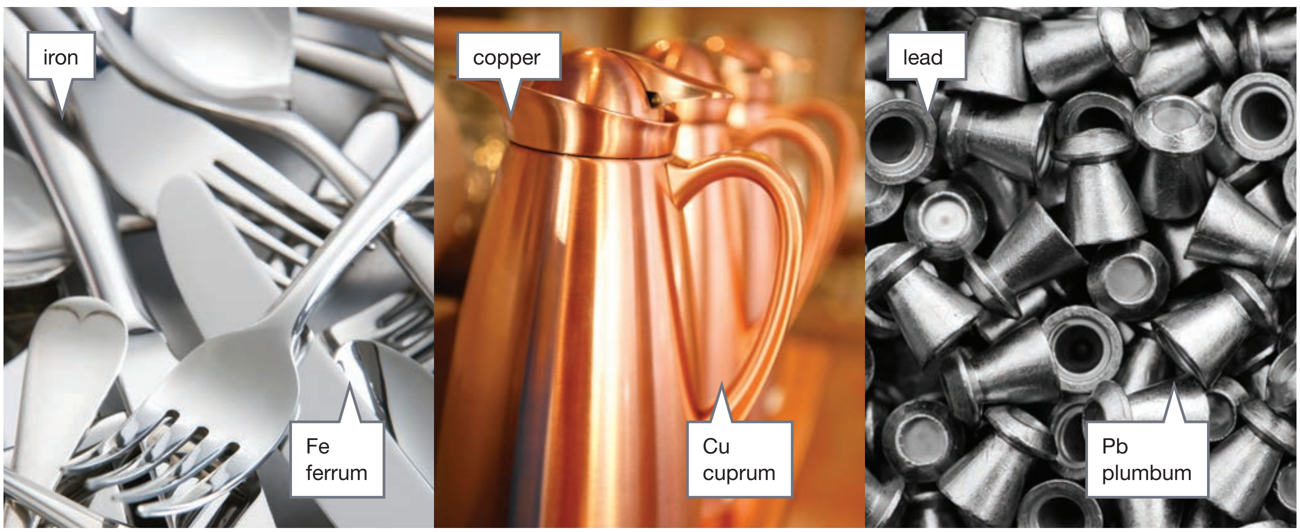
The symbols of most elements use the first letter of their names or two 'logical' letters from them. This makes their symbols relatively easy to predict. Table 4.1.2 shows some of them.

However, a handful of metallic elements have symbols that seem illogical. This is because their symbols are based on their original Latin or Greek names. These 'illogical' symbols are the ones you need to remember. Three of these elements are shown in Figure 4.1.6.

Table 4.1.2 Examples of element symbols

	Name	Symbol
Uses first letter	Oxygen	O
	Fluorine	F
	Sulfur	S
Uses two 'logical' letters	Chlorine	Cl
	Magnesium	Mg
	Calcium	Ca
Based on their original Latin or Greek name	Sodium	Na
	Gold	Au
	Tin	Sn
Temporary	Ununoctium	Uuo

Figure 4.1.6 The symbols of iron (Fe), copper (Cu) and lead (Pb) are based on their respective Latin names *ferrum*, *cuprum* and *plumbum*.



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Don't bother remembering these!

A few heavy, synthetic elements are so radioactive that they only stay around for one-thousandth of a second or so. This makes confirmation of their discovery extremely difficult. Until confirmation happens, they are given temporary symbols of three letters. You don't need to remember these.

Figure 4.1.7 In 1996, a particle accelerator like this one was used to discover an element with the atomic number 112. It was given the temporary name ununbium (Uub). In 2009, the existence of the element was finally confirmed. It was then given the name copernicium (Cn) after the famous astronomer Nicolaus Copernicus (1473–1543).

The periodic table

The periodic table is a list of all known elements (and those still awaiting confirmation). As Figure 4.1.8 shows, the table is arranged:

- in order of increasing atomic number
- in rows (called periods) and columns (called groups)
- with the metals to the left of the table, the non-metals to the far right and the metalloids in between.

	Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period 1	1 **H** hydrogen																	2 **He** helium
Period 2	3 **Li** lithium	4 **Be** beryllium											5 **B** boron	6 **C** carbon	7 **N** nitrogen	8 **O** oxygen	9 **F** fluorine	10 **Ne** neon
Period 3	11 **Na** sodium	12 **Mg** magnesium											13 **Al** aluminium	14 **Si** silicon	15 **P** phosphorus	16 **S** sulfur	17 **Cl** chlorine	18 **Ar** argon
Period 4	19 **K** potassium	20 **Ca** calcium	21 **Sc** scandium	22 **Ti** titanium	23 **V** vanadium	24 **Cr** chromium	25 **Mn** manganese	26 **Fe** iron	27 **Co** cobalt	28 **Ni** nickel	29 **Cu** copper	30 **Zn** zinc	31 **Ga** gallium	32 **Ge** germanium	33 **As** arsenic	34 **Se** selenium	35 **Br** bromine	36 **Kr** krypton
Period 5	37 **Rb** rubidium	38 **Sr** strontium	39 **Y** yttrium	40 **Zr** zirconium	41 **Nb** niobium	42 **Mo** molybdenum	43 **Tc** technetium	44 **Ru** ruthenium	45 **Rh** rhodium	46 **Pd** palladium	47 **Ag** silver	48 **Cd** cadmium	49 **In** indium	50 **Sn** tin	51 **Sb** antimony	52 **Te** tellurium	53 **I** iodine	54 **Xe** xenon
Period 6	55 **Cs** caesium	56 **Ba** barium	57–71 lanthanides	72 **Hf** hafnium	73 **Ta** tantalum	74 **W** tungsten	75 **Re** rhenium	76 **Os** osmium	77 **Ir** iridium	78 **Pt** platinum	79 **Au** gold	80 **Hg** mercury	81 **Tl** thallium	82 **Pb** lead	83 **Bi** bismuth	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
Period 7	87 **Fr** francium	88 **Ra** radium	89–103 actinides	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium	110 **Ds** darmstadium	111 **Rg** roentgenium	112 **Cn** copernicium	113 **Uut** ununtrium	114 **Uuq** ununquadium	115 **Uup** ununpentium	116 **Uuh** ununhexium	117 **Uus** ununseptium	118 **Uuo** ununoctium

atomic number — 13
symbol — **Al**
name — aluminium

Lanthanides	57 **La** lanthanum	58 **Ce** cerium	59 **Pr** praseodymium	60 **Nd** neodymium	61 **Pm** promethium	62 **Sm** samarium	63 **Eu** europium	64 **Gd** gadolinium	65 **Tb** trebium	66 **Dy** dysprosium	67 **Ho** holmium	68 **Er** erbium	69 **Tm** thulium	70 **Yb** ytterbium	71 **Lu** lutetium
Actinides	89 **Ac** actinium	90 **Th** thorium	91 **Pa** protactinium	92 **U** uranium	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium	96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fremium	101 **Md** mendelevium	102 **No** nobelium	103 **Lr** lawrencium

KEY Non-metals Metals Metalloids

Figure 4.1.8 The periodic table is a list of all the known elements arranged in order of increasing atomic number.

4.1 Unit review

Remembering

1 **Name** the particles in the:
  a nucleus
  b space around the nucleus.

2 **List** the following in order from smallest to largest: atom, electron, proton, neutron.

3 A particular atom has 8 protons, 8 electrons and 9 neutrons. **State** its atomic number.

4 **State** the element symbols for:
  a oxygen
  b chlorine
  c magnesium
  d iron.

5 **Name** the following elements.
  a F
  b Ca
  c Na
  d Pb

6 **State** the electric charge of each of:
  a a proton
  b an electron
  c a neutron
  d a nucleus
  e an atom.

7 **State** the number of electrons that can fit in each of the first four electron shells.

8 **State** how many electrons are in an atom that has an electron configuration of 2,8,8.

Understanding

9 **Define** the following terms.
  a STM
  b indirect evidence
  c atomic number

10 **Explain** why most of an atom's mass is due to its nucleus.

11 a You are watching a replay of a football match on TV. You cannot see the sky but immediately deduce that it was a day match. **Describe** the indirect evidence that would lead you to this conclusion.
  b Another replay comes on and you know that this match was a night match despite not being able to see the sky or light towers. **Describe** the indirect evidence that now suggests it is night.

Applying

12 **Use** the formula $2n^2$ to **calculate** the maximum number of electrons held by shell 5 ($n = 5$).

13 **Demonstrate** how to write electron configurations by writing them for the following atoms.
  a lithium (with 3 electrons)
  b carbon (with 6 electrons)
  c sodium (with 11 electrons)
  d chlorine (with 17 electrons)

14 **Identify** the type of atoms and the number of each type in a single molecule of:
  a methane, CH_4
  b nitric acid, HNO_3
  c glucose, $C_6H_{12}O_6$
  d ethanoic acid (vinegar), CH_3COOH.

Analysing

15 **Compare** a proton with a neutron by listing their similarities and differences.

16 **Use** the periodic table on page 109 to **contrast** an atom of aluminium with an atom of carbon.

Evaluating

17 **Propose** a meaning for the term *subatomic particle*.

Creating

18 **Construct** simple diagrams showing how the electrons are arranged in shells for the atoms listed in Question 13.

19 **Construct** a way of remembering those element symbols that don't seem to match their names.

Inquiring

1 Curie, Mendeleev, Einstein, Rutherford, Roentgen and Nobel all have elements named after them. Research what important work these scientists did, write a few sentences on their achievements, state which elements were named after them and write their element symbols.

2 Research what the term *isotope* means. List the isotopes of hydrogen, carbon, oxygen, chlorine and uranium.

4.1 Practical activities

1 Firework colours

Purpose

To observe the colours that metal salts produce when heated.

SAFETY

Turn the Bunsen burner to the yellow flame or off when not using it.

Tie long hair back.

Do not allow the icy-pole stick to catch fire.

Do not point the spectroscope directly at the Sun.

Materials

- Bunsen burner, bench mat and matches
- tongs
- wooden icy-pole sticks soaked overnight in distilled water or deionised water and solutions of barium chloride, copper chloride, potassium chloride, sodium chloride and strontium chloride
- spectroscope (optional)

Procedure

1 Use tongs to hold the icy-pole stick soaked in water in the hottest part of a blue Bunsen flame. Hold it there for a few seconds only and remove it before it can catch fire.

2 Observe what colour the stick gives to the flame and record the colour in a table like that shown in the results section.

3 Repeat steps 1 and 2 for the other sticks.

Extension

4 Point a spectroscope towards a bright portion of the sky (not the Sun). Sketch the spectrum you see.

5 Observe each of the coloured flames through the spectroscope (Figure 4.1.9). Record what you see.

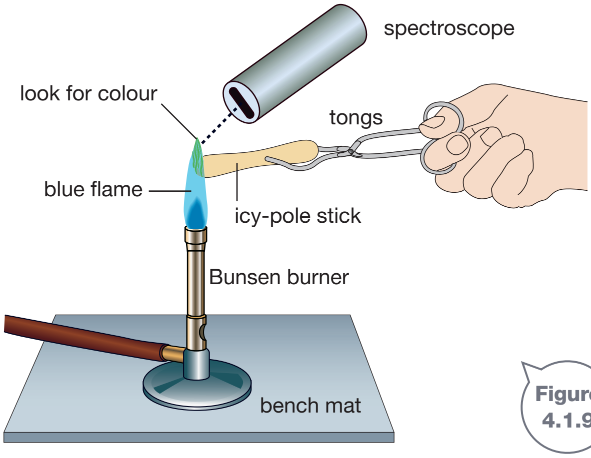

Figure 4.1.9

Results

Copy the following table into your workbook. List all the solutions you tested.

Solution tested	Formula	Colour of flame	Metallic element in solution	Non-metallic element in solution
Distilled water	H_2O		None	H, O
Barium chloride	$BaCl_2$		Ba	Cl, H, O

Discussion

1 Modern fireworks include metal salts to colour them. **Identify** which of the metal salts would make a firework:

a red

b green

c blue-green.

2 As Figure 4.1.10 shows, the grains in fireworks that spray out and give colour are made of starch soaked in the appropriate salt. **Construct** a diagram of a grain that would burn and give the colours:

a blue-green, then purple

b red, then green.

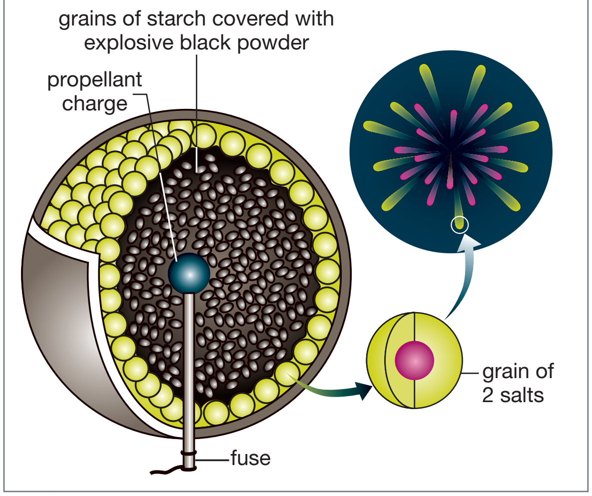

Figure 4.1.10 A firework 'grain'

Firework colours continued on next page

Firework colours continued

3 Firework colours come from electrons changing energy levels. Heat gives electrons energy to jump from one energy level to another. **Describe** where they get this energy from.

4 When the electrons jumped back to their original shells, they released all that energy. **State** the evidence that energy is released.

5 **Identify** the purpose of the stick soaked in water only.

6 **Explain** why distilled water or deionised water was used rather than tap water.

7 The non-metallic element did not add colour to the flame. **Outline** the evidence that supports this statement.

2 Properties of elements

Purpose

To compare the properties of metals and non-metals.

Materials

- samples of sulfur, aluminium, carbon, silicon, tin, zinc, lead, magnesium, iron
- steel wool
- 3 or 4 test-tubes and rack
- power pack or battery (about 2 V)
- wires with alligator clips
- light globe

SAFETY

Turn the Bunsen burner to the yellow flame or off when not using it.

Tie long hair back.

Procedure

1 Use the periodic table in Figure 4.1.8 on page 109 to determine whether the element you are testing is a metal or a non-metal.

2 Record the appearance of each sample in a table as shown in the results section.

3 'Polish' each sample with the steel wool. Record its appearance now.

4 Try and bend the sample. Record whether it bends or crumbles.

5 Place some of the sample in a test-tube with water. Record whether it floats or not and whether any change is obvious. For example, does it dissolve or react?

6 Use a circuit similar to the one in Figure 4.1.11 to test if the sample conducts electricity.

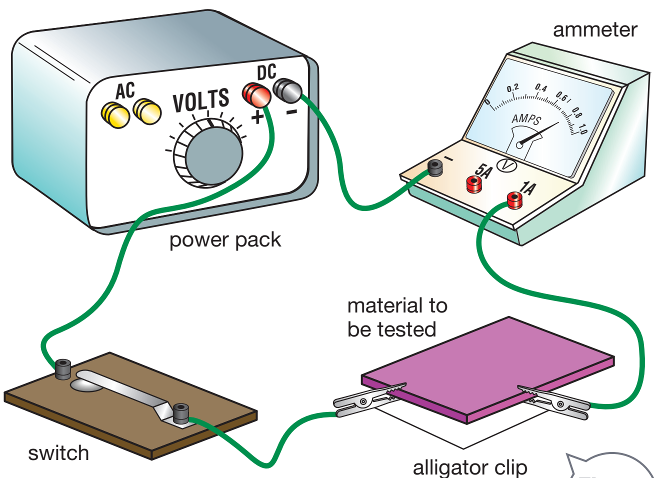

Figure 4.1.11

Results

Construct a table in your workbook like the one below.

Element	Metal or non-metal	Appearance when polished	Bends or crumbles	Float or sinks	Action with water	Electrical conductivity

Discussion

1 Metals share certain physical properties. From your observations, **list** them.

2 **List** the properties that were common in all the non-metals you tested.