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.

6 — Atomic number
C — Chemical symbol
12.01 — Atomic mass
Carbon — Name of element

Transition metals (groups 3–12); Non-metals (groups 13–17); Metals

	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.

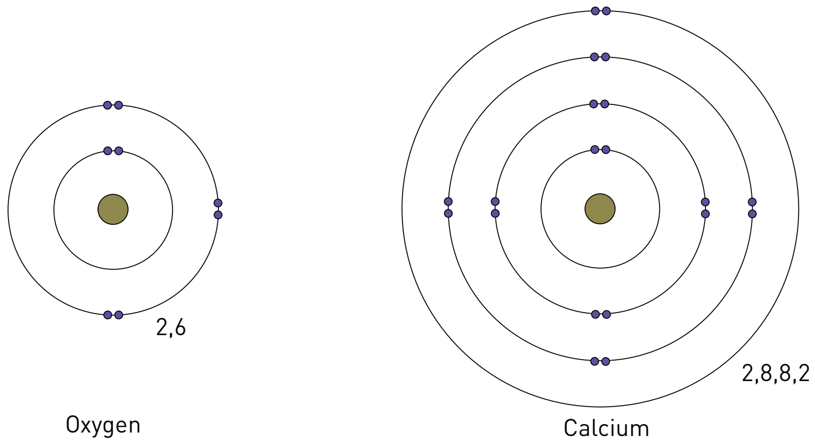

Figure 3.10 The electronic configurations for oxygen and calcium are shown as simple shell diagrams.

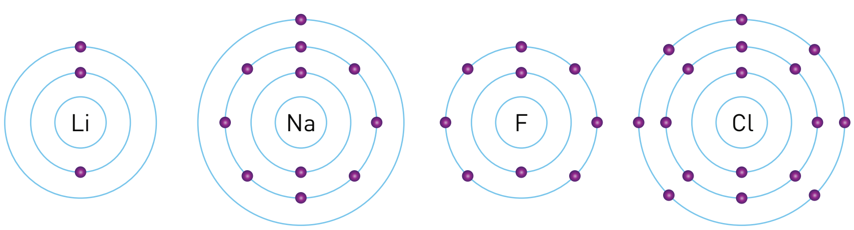

Figure 3.11 In group 1, the electronic configuration of lithium is 2,1, whereas that of sodium is 2,8,1 and that of potassium is 2,8,8,1. The atoms of all other group 1 elements also have one electron in their outer valence shell of electrons.

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		