Surfing

NATIONAL CHEMISTRY

Unit 1 Chemical Fundamentals: Structure, Properties and Reactions

Marilyn Schell • Margaret Hogan

Science Press

Science Press
Bag 7023 Marrickville NSW 1475 Australia
Tel: (02) 9516 1122 Fax: (02) 9550 1915
sales@sciencepress.com.au
www.sciencepress.com.au

Contents

Use the table of contents to record your progress through this book. As you complete each chapter, write the date completed, then tick one of the three remaining columns to guide your revision for later. The column headers use the following codes:

?? = Don't understand this very well at all. RR = Need to revise this. OK = Know this.

Introduction

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory parts of the syllabus, along with questions and answers.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions. These cover every aspect of the topic, and are useful for revision and exam practice.

Words To Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

conctruct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

1 Elements and Atoms

Before you get started, you should check that you remember and understand this revision of some junior science. If anything is not clear you should talk to your teacher immediately.

- Each element is a pure substance containing only one type of atom.
- There are 92 elements that occur naturally and make up the entire Universe.
- The periodic table consists of a list of all the elements that exist.
- Elements are listed on the periodic table in order of their atomic number (the number of protons in their atoms).

Elements are classified, according to their physical properties, as **metals**, **non-metals** and **semi-metals**.

On the periodic table you will find metals on the left and non-metals on the right. There are a lot more metals than non-metals.

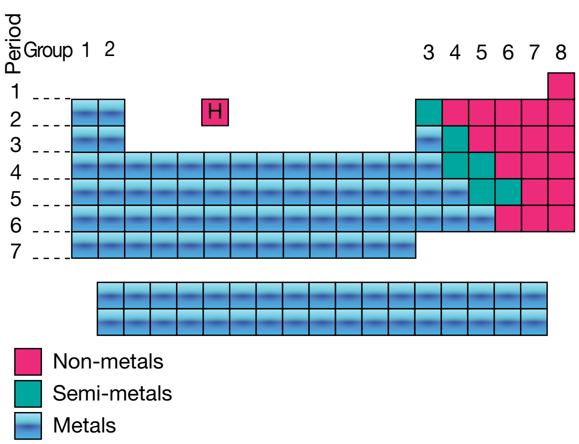


Figure 1.1 Periodic table.

Properties of elements

Metals tend to melt and boil at much higher temperatures than non-metals. Because of this, most metals are hard, shiny solids at room temperature whereas non-metals tend to be gases, or soft solids. Only two elements occur naturally as liquids – the metal mercury and the non-metal bromine.

Metals are better conductors of heat and electricity than non-metals. One exception to this is graphite, a form of the non-metal carbon that is used in 'lead' pencils.

Metals are malleable (can be bent) and ductile (can be stretched into wires). Non-metals are not malleable or ductile.

Semi-metals, also called metalloids, include boron, silicon, germanium, antimony and arsenic. They are found on the periodic table between the metals and non-metals. Like metals, they are all crystalline solids with high melting points. However, they do not conduct electricity as well as metals. Some are used as semiconductors.

Figure 1.2 Non-metals bromine, carbon, phosphorus and sulfur.

Figure 1.3 Metals iron, copper, aluminium, silver, lead, gold.

Atoms

- An **atom** is the smallest part of an element that can take part in a chemical reaction.
- Each element has its own unique atoms that are different to the atoms of every other element.
- A tiny sample of any element contains billions of identical atoms.
- Most of each atom is empty space.
- Atoms have a tiny, central nucleus which contains most of their mass.
- The nucleus of an atom can never be broken down into anything simpler by any chemical reaction. Only nuclear reactions can split the nucleus of an atom.
- An atom is more than 10 000 times bigger than its nucleus.
- The three main particles in atoms are summarised in Table 1.1.

Table 1.1 Particles in atoms.

Particle	Where it is found	Symbol	Relative charge
Proton	Nucleus	p^+	+1
Neutron	Nucleus	n	0
Electron	Orbiting the nucleus	e^-	–1

QUESTIONS

1. Using the positions of elements in the periodic table, classify each of the following elements as a metal, non-metal or semi-metal.

Element	Classification	Element	Classification
Sodium		Germanium	
Chlorine		Carbon	
Gold		Boron	
Nickel		Mercury	
Oxygen		Hydrogen	

2. Name four semi-metals and account for their classification.
3. Describe how you could test the electrical conductivity of an element. Use a circuit diagram in your answer.
4. Copy and complete the table below to summarise differences between physical properties of metals and non-metals.

Physical property	Metals	Non-metals
Melting and boiling points		
Conductivity of heat		
Conductivity of electricity		
Malleable		
Ductile		
Lustre		
State at room temperature		

5. (a) What is an atom?
   (b) Outline the structure of an atom.
6. Use the information in the table below to classify each of the elements P, Q, R and S as a metal or a non-metal.

Element	Melting point (°C)	Boiling point (°C)	Conductivity
P	1490	2900	Good
Q	–7	58	Poor
R	1540	3000	Good
S	114	183	Poor

7. Something is wrong with each of the following statements. Rewrite them as scientifically accurate statements.
   (a) An element is a pure substance containing only one atom.
   (b) Most elements are non-metals.
   (c) Compounds are made of elements mixed together in any ratio.
8. Colour in the periodic table below to illustrate which elements are solids, liquids and gases at room temperature (25°C).

						H											He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Ru	Db													

☐ Gases ☐ Liquids ☐ Solids

9. (a) When substances are heated or cooled they may change state. Copy and complete the diagram below to show the terms used to describe each change of state.

   Solid $\rightleftarrows$ Liquid $\rightleftarrows$ Gas

   (b) Use the information in the table below to decide whether each element (A to F) would occur as a solid, liquid or gas at room temperature (25°C).

Element	Melting point (°C)	Boiling point (°C)
A	1490	2900
B	–7	58
C	1540	3000
D	114	183
E	–210	–196
F	–39	357

10. Check your knowledge with this quick quiz. Identify each of the following.
    (a) An inert non-metal.
    (b) Five metals and their symbols.
    (c) Five non-metals and their symbols.
    (d) The most common element in the Universe.
    (e) A non-metal that is a good electrical conductor.
    (f) Particles found in the atomic nucleus.
    (g) Particles that orbit the atomic nucleus.
    (h) The smallest atom that exists.
    (i) Number of elements that occur naturally.
    (j) The smallest part of an element that can take part in a chemical reaction.
    (k) The term which means 'can be stretched into wires'.
    (l) Which are better conductors of heat and electricity, metals or non-metals?

2 Distribution of Elements

There are 92 elements that occur naturally and make up the entire Universe. Most of these 92 elements are chemically reactive, so they combine in fixed ratios with other elements to form compounds. For example:

- Sodium and chlorine occur as sodium chloride ($NaCl$), the main salt in sea water.
- Carbon occurs in many compounds including carbon dioxide (CO_2) and glucose ($C_6H_{12}O_6$).
- Hydrogen occurs as water (H_2O) and in many carbon compounds such as methane (CH_4) in natural gas.

The less reactive elements occur uncombined as the element. For example:

- Gold and silver occur in the Earth's crust as elements.
- Inert gases from group 8, e.g. argon, occur as elements.

Some elements occur both in compounds and also as the element. For example:

- Oxygen occurs as a gas in the atmosphere and in many compounds such as water, carbon dioxide (CO_2) and calcium carbonate ($CaCO_3$).
- Nitrogen gas (N_2) makes up approximately 78% of the atmosphere and it also occurs in compounds such as in proteins.
- Sulfur occurs in the crust as deposits of the element. It also occurs in the ocean as sulfur compounds such as magnesium sulfate.

The origin of elements

The Big Bang theory, which is believed to have started our Universe about 15 million years ago, led to the creation of the smallest atoms, e.g. hydrogen, helium and lithium. All other elements have been created by nuclear fusion reactions in stars and supernovas as the nuclei of smaller atoms combined together. Fusion reactions release a great deal of energy.

Composition of the Universe

Hydrogen is the most common element in the Universe, followed by helium. The composition of the Universe is believed to be similar to that of stars such as our Sun. The Sun is mostly hydrogen and helium, although it does contain about 67 elements and Table 2.1 lists those that are most abundant.

Table 2.1 Abundance of the most common elements in the Sun.

Element	Composition by total number of atoms (%)	Composition by mass (%)
Hydrogen	91.2	71.0
Helium	8.7	27.1
Oxygen	0.08	0.096
Carbon	0.04	0.40
Nitrogen	0.01	0.096
Silicon	0.0045	0.099
Magnesium	0.0038	0.076
Neon	0.0035	0.058
Iron	0.030	0.014

Composition of the Earth's crust

The composition of the **Earth's crust** differs from that of the whole Universe. The main elements in the Earth's crust are shown in Table 2.2.

Table 2.2 Composition of the Earth's crust.

Element	Composition by mass (%)
Oxygen	46.6
Silicon	27.7
Aluminium	8.1
Iron	5.0
Calcium	3.6
Other elements	9.0

The most common atoms in the crust are oxygen atoms – they occur combined in many compounds. Most of the elements in the crust occur as compounds, e.g. silicon dioxide (SiO_2). Silicon dioxide is the main component of sand and quartz. The largest group of rock-forming minerals are silicate compounds – compounds containing silicon and oxygen combined together with metals such as aluminium. Calcium occurs in compounds such as calcium carbonate which is found in marble and limestone.

The **Earth's core** consists of mainly iron and nickel with smaller amounts of the lighter elements such as sulfur and oxygen.

Carbon-based life forms

Life on Earth is carbon based and all living things have similar composition. They are largely made of water and carbon compounds such as carbohydrates, proteins and lipids (fats and oils). For example, compare the elements present in humans and bacteria shown in Table 2.3.

Table 2.3 Elemental composition of humans and bacteria.

Element	Composition by mass (%)	
	Humans	Bacteria
Oxygen	64.00	68.00
Carbon	19.00	15.00
Hydrogen	9.00	10.20
Nitrogen	3.00	9.00
Calcium	1.50	0.25
Phosphorus	0.80	0.83

Techniques used to analyse the elements that make up the structure of objects include:

- **Neutron diffraction** is used to analyse crystalline material without destroying it, e.g. determining the chemical structure of historical artefacts such as ceramics and paintings.
- **Spectral analysis** is a technique which allows scientists to look at the colours of light (spectra) or wavelengths of other forms of radiation (e.g. infra-red, ultraviolet) which are released or absorbed by a substance. This technique has been used to determine the composition of stars, as each star emits a unique spectrum of radiation.

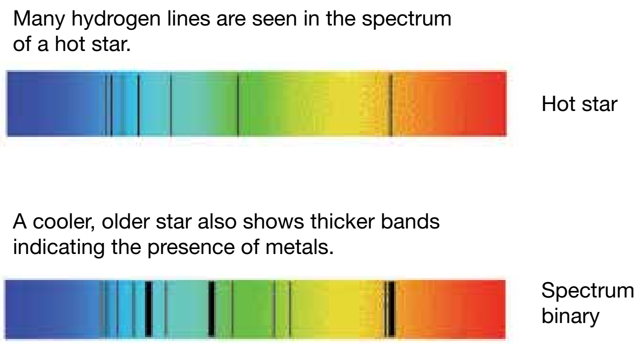


Figure 2.1 Spectral analysis of stars.

The absorption or emission of specific wavelengths is the basis of flame tests and atomic absorption spectroscopy, both of which will be dealt with in more detail later.

QUESTIONS

1. It is interesting to compare the relative abundance of elements in different areas. From the data provided in the text, identify the most commonly occurring:
   (a) Element in the Universe.
   (b) Metal in the Earth's crust.
   (c) Non-metal in the Earth's crust.
2. From data provided in the text:
   (a) Identify the four elements that are most common in the Earth's crust.
   (b) Use a pie graph to illustrate the composition of the Earth's crust. Include a heading and a key.
3. (a) Hydrogen makes up 90% of the atoms in our Sun, but it only makes up 71% of the mass of the Sun. Explain.
   (b) How does the composition of the Earth's crust differ from the composition of the Universe?
4. Research the composition of the Earth's atmosphere to identify the three most common gases present.
5. The composition of the human body is given in one source as mainly oxygen, carbon and hydrogen. Another source claims it is made of mainly carbohydrates, proteins and fats.
   (a) Account for this apparent conflict.
   (b) Name three elements that are present in almost identical concentrations in humans and bacteria.
6. Research to identify some elements and compounds present in the atmosphere, lithosphere and hydrosphere. Tabulate your answer.
7. (a) Name two techniques used to analyse the elemental composition of objects.
   (b) Outline a theory to account for the existence of elements with larger atoms than helium and lithium.
8. Outline ways in which advances in scientific understanding of elements has impacted on one of the following.
   (a) Developments in two other areas of science.
   (b) Society and the environment.
9. Life on Earth is carbon based and yet carbon is not one of the six most common elements in the Earth's crust. Outline the main sources of carbon on Earth.
10. Check your knowledge with this quick quiz.
    (a) Identify the most common element in the Universe.
    (b) Name the most common element in the atmosphere.
    (c) All known life is based on which element?
    (d) Name the technique used to analyse which elements are present in stars.
    (e) Name the three main elements in all living organisms.

3 Elements, Trends and the Periodic Table

It is easy to tell whether or not a substance is an element – just look at a periodic table. Every element is there. If it is not there, it is not an element.

The periodic table lists all the elements in order of their **atomic number**, Z. Atomic number is the number of protons in the atoms of an element. For example, the atomic number of oxygen is 8 – it has 8 protons in each atom.

Of the elements in the periodic table, 92 occur naturally. Those with atomic numbers higher than 92 have been made by scientists, usually in nuclear reactors or particle accelerators, and they are unstable. Many have only ever existed for a fraction of a second.

In the periodic table, the elements are arranged in periods and groups and trends in their properties are evident across periods and down groups.

A Russian scientist, **Dmitri Mendeleev**, developed the modern periodic table in 1869. He based his table on observed physical and chemical properties of the elements known at that time, including atomic masses. He predicted the existence of some undiscovered elements (e.g. germanium, gallium, polonium and silicon) and left places for them on the table. At that time nobody knew that the noble gases of group 8 existed, so they were not included in his periodic table.

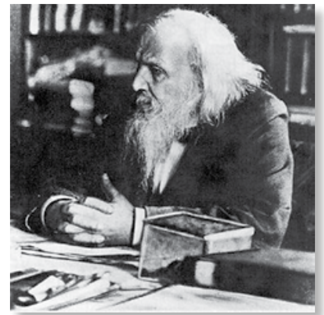


Figure 3.1 Dmitri Mendeleev.

The periodic table can be divided into the **main block** and the **transition block** elements. The lanthanides and actinides are subgroups of the transition elements.

The **transition metals** are in the middle of the table. They have strong metallic bonds so are generally hard, dense metals with high melting points. They include unreactive precious metals and many form coloured compounds.

Vertical columns of the periodic table are called **groups** and the rows are called **periods**.

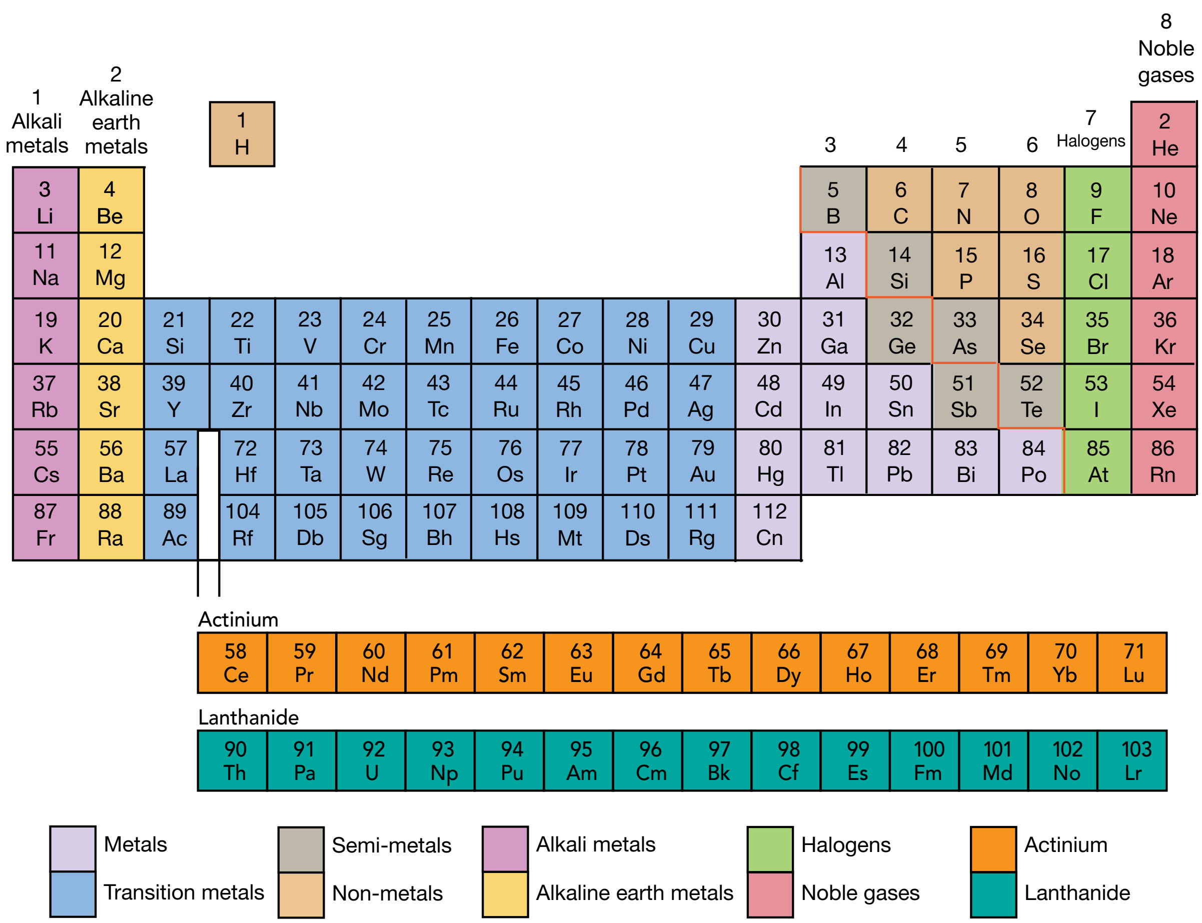


Figure 3.2 The parts of the periodic table.

There are **18 groups**, 8 in the main block. Some chemists number the groups from 1 to 18, but others number the main block groups from 1 to 8. Sometimes group 8 is called group 0.

All the elements in each group have similar chemical properties.

- **Group 1** (alkali metals) and group 2 (alkaline earth metals) are all active metals, and they are shiny, silver solids at room temperature. They have high melting and boiling points and their hydroxides are strong alkalis.
- The elements in **group 7** (halogens) are active non-metals.
- Elements in **groups 3 to 6** become increasingly metallic as you move down the group, e.g. group 5 varies from non-metal to semi-metal to metal.
- **Group 8** elements are all non-metals, they are inert (unreactive) and have low melting and boiling points so they are gases at room temperature.
- The activity of metals increases down groups 1 and 2. For example, potassium is more active than sodium and calcium is more active than magnesium. Also, lithium at the top of group 1 is the least active of the alkali metals while caesium is the most active.

The **periods** of the periodic table are the horizontal rows. They are numbered from 1 to 7, starting from the top and going down.

- The first period contains only two elements, hydrogen and helium, which are both non-metals.
- The elements in every other period show a range of properties, from metallic on the left to non-metallic on the right. For example, in period 2, lithium and beryllium are metals, boron is a semi-metal, and carbon to neon are non-metals.

1	2	3	4	5	6	7	8
Li	Be	B	C	N	O	F	Ne

Metallic → Semi-metal → Non-metals

Figure 3.3 Elements across period 2.

- The activity of metals decreases across periods of the periodic table. For example, group 1 metals (e.g. sodium and potassium), are more active than group 2 metals (e.g. magnesium and calcium).
- Electrical conductivity decreases across each period; metals are good conductors, non-metals are poor conductors.
- Melting and boiling points increase and then decrease; high for metals, very high for group 4, then lower for non-metals.

QUESTIONS

1. (a) Group 1 elements are called the alkali metals. Use a periodic table to identify the names and symbols for each of the elements in group 1.
   (b) Explain why metals from groups 1 and 2 are never found existing as free elements.
2. (a) Name three elements classified as halogens and state the symbol used for each.
   (b) Research the origin of the term ‘halogen’.
3. (a) Outline the meaning of the term ‘inert’.
   (b) Identify the group of elements on the periodic table that are inert.
   (c) Name and write symbols for these elements.
   (d) Explain why these elements exist as elements rather than compounds.
4. Name and state symbols for four transition metals.
5. Based on their position in the periodic table, predict which element in each of the following pairs of elements would be more active.
   (a) Strontium or magnesium.
   (b) Strontium or potassium.
   (c) Lithium or rubidium.
6. For each of the following elements, write its symbol, then identify the period and group to which it belongs.
   (a) Magnesium. (b) Silicon.
   (c) Chlorine. (d) Aluminium.
   (e) Lithium. (f) Oxygen.
7. Name three elements which you would expect to have very similar chemical properties to chlorine. Justify your selection.
8. Outline the change in melting point across periods of the periodic table.
9. Check your knowledge with this quick quiz. Identify each of the following.
   (a) The group to which argon belongs.
   (b) The group to which carbon belongs.
   (c) The period to which sodium belongs.
   (d) The group of the periodic table in which the most active metals occur.
   (e) The number of naturally occurring elements.
   (f) The characteristic that determines the order of elements on today’s periodic table.
   (g) What we call vertical columns of the periodic table.
   (h) What we call horizontal rows of the periodic table.
   (i) On the periodic table, where would you find the least active elements?

4 History of the Periodic Table

It is only in the last 200 years that scientists have realised that everything is made of atoms and tried to group them together according to their properties. Before that it was believed that all matter was made of four elements, which were believed to be earth, wind, air and fire.

Antoine Lavoisier (1743-1794)

Lavoisier was a Frenchman. He is most famous for his discovery of the role that oxygen plays in combustion. Lavoisier was one of the first to realise that there were simple substances that could not be broken down any further – today we call them elements. In his list he included oxygen, nitrogen, hydrogen, phosphorus, mercury, zinc and sulfur. In 1787, Lavoisier classified the elements known at that time into metals and non-metals, based on their physical and chemical properties. Lavoisier was one of the many people in France beheaded by the guillotine – but not because of his beliefs about chemistry.

(a) Antoine Lavoisier. (b) Johann Dobereiner.

Figure 4.1 Chemists associated with the periodic table.

Johann Wolfgang Dobereiner (1780-1849)

Dobereiner was a German chemist. In 1829 he noticed similarities between some sets of three elements, which he called **triads**. For example, he pointed out the similarities in physical and chemical properties between the metals lithium, sodium and potassium and also between the non-metals chlorine, bromine and iodine.

H						
Li	Be	B	C	N	O	F
Na	Mg	Al	Si	P	S	Cl
K	Ca	Ga	Ge	As	Se	Br
Rb	Sr	In	Sn	Sb	Te	I
Cs	Ba	Tl	Pb	Bi	Po	At

Figure 4.2 Dobereiner's triads.

John Newlands (1837-1898)

John Newlands had Scottish and Italian parents but he lived in England. In 1863, he put forward a '**law of octaves**'.

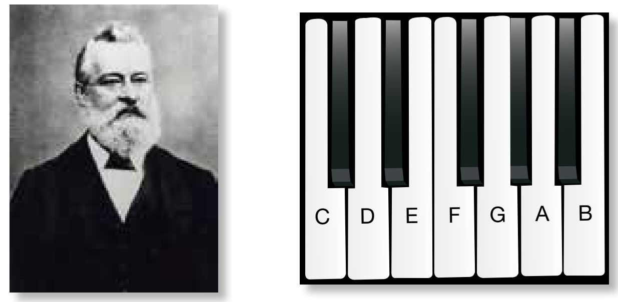


Figure 4.3 John Newlands and an octave on the piano.

He noticed that if the elements were placed in order of increasing atomic mass, then every eighth element had similar properties. This is referred to as **periodicity of the chemical properties** of elements. He likened it to the eight notes in an octave of music.

H	F	Cl	Co/Ni	Br	Pd	I	Pt/Ir
Li	Na	K	Cu	Rb	Ag	Cs	Tl
G	Mg	Ca	Zn	Sr	Cd	Ba/V	Pb
Bo	Al	Cr	Y	Ce/La	U	Ta	Th
C	Si	Ti	In	Zn	Sn	W	Hg
N	P	Mn	As	Di/Mo	Sb	Nb	Bi
O	S	Fe	Se	Ro/Ru/Ag	Te	Au	Os

Figure 4.4 Newland's octaves.

These classifications worked for some elements, but unfortunately not for all of them.

Dmitri Mendeleev (1834-1907)

Dmitri Mendeleev was a Russian chemist. In 1869 he proposed ideas that formed the basis of our modern periodic table. Mendeleev put forward the **periodic law**. He said that if the elements were arranged in order of increasing **atomic mass**, then those with similar physical and chemical properties (including valency) would occur at regular or periodic intervals.

Mendeleev's table was successful because he placed elements where he thought they should go, making allowances for possible inaccurate measurements of atomic mass, and he left gaps for elements he thought would be discovered later. Being able to make predictions from a theory is a very important aspect of the scientific method. Mendeleev went further and predicted the properties of those elements still to be discovered.

Table 4.1 compares the predictions of Mendeleev about an element not yet discovered at that time. Mendeleev predicted in 1869 that an element would be found to fit this position in the table and he called it Eka-silicon because he thought it would have properties similar to silicon and fit just below it in the table. This element, which we now call germanium, was discovered by chemists in 1886 and its properties were found to be very similar to those predicted by Mendeleev.

Table 4.1 Comparison of predicted and discovered element.

Property	Eka-silicon	Germanium
Atomic mass	72	72.3
Melting point	High	937°C
Density	5.5 g mL^{-1}	5.36 g mL^{-1}
Formula of oxide	EkO_2	GeO_2
Density of oxide	4.7 g mL^{-1}	4.7 g mL^{-1}
Formula of chloride	$EkCl_4$	$GeCl_4$
Boiling point of chloride	Just below 100°C	86°C
Density of chloride	1.9 g mL^{-1}	1.88 g mL^{-1}

Henry Mosely (1887-1915)

Mosely was an English physicist. It was Mosely who realised that arranging the elements by atomic number (rather than atomic mass or weight) produced a better repeating pattern of properties. For example, using atomic mass, potassium (39.10) would come before argon (39.5). This would put potassium in group 8 and argon in group 1. Using atomic number, these two elements fit much more logically into the periodic table with potassium in group 1 with other active metals, and argon in group 8 with other inert gases.

Figure 4.5 Henry Mosely.

The **modern table** places the elements in horizontal periods, forming vertical groups of elements with similar chemical properties. It includes the noble gases (group 8) which were discovered around 1895 and slotted into the table between group 7 and group 1 elements.

Many other scientists were then involved in working out theories as to why the elements behave in this periodic fashion and it was realised that this requires an understanding of the electronic structure of the elements' atoms.

QUESTIONS

1. Explain the following terms as associated with the periodic table of elements.
   (a) Group.
   (b) Period.
   (c) Atomic number.
2. Name four scientists who contributed to the development of the modern periodic table – listing them in order of their contributions, from earliest to latest.
3. The form of the periodic table most universally accepted is the one based on the work of Dmitri Mendeleev.
   (a) State the periodic law put forward by Mendeleev.
   (b) Explain why Mendeleev's table was adopted by other chemists.
   (c) What change was Mosely responsible for making in Mendeleev's periodic table?
4. 'Science is a global enterprise.' Discuss this statement with reference to the history of the development of the periodic table.
5. Check your knowledge with this quick quiz.
   (a) Lavoisier divided the elements into .... and ....
   (b) The sets of similar elements, like lithium, sodium and potassium, were called .... by Dobereiner.
   (c) The periodic law of Mendeleev states that similar elements occur at periodic intervals when the elements are placed in order of increasing ....
   (d) In his periodic table, Mendeleev left .... for elements yet to be discovered.
   (e) The modern periodic table is based on placing the elements in increasing order of atomic ....
   (f) In the periodic table, the vertical columns are called ....
   (g) The horizontal rows of the periodic table are called ....

5 Electron Configuration of Atoms

You will recall that an **atom** is the smallest unit of an element that can take part in a chemical reaction and each atom is made of **three types of particles**, called protons, neutrons and electrons. In a neutral atom, the number of positively charged protons is equal to the number of negatively charged electrons. The atoms are held together by electrostatic forces of attraction between the positive nucleus and the negative electrons.

Most of the **mass of atoms** is in the nucleus because protons and neutrons are almost 2000 times heavier than electrons. Atoms of different elements have different masses because they have different numbers of particles in their nuclei.

The **atomic number** (Z) of an element is the number of protons in its atoms.

The **mass number** of an element is the number of protons plus the number of neutrons in the nucleus of its atoms. For example, the mass number of oxygen is 16 as there are 8 protons plus 8 neutrons in the nucleus of each oxygen atom, and this can be written as ${}^{16}_{8}O$ or O-16.

Electron shells/energy levels

Electrons are arranged around the nucleus of each atom in layers. These have distinct energy levels and are called **shells or energy levels**. These shells are numbered starting from the nucleus.

Some chemists call these the K, L, M and N shells, although newer terminology refers to them as shells 1 to 4. The first (K) shell is the shell closest to the nucleus.

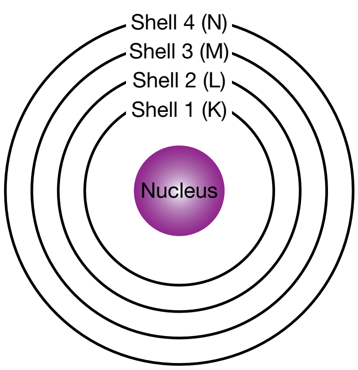


Figure 5.1 Electron shells.

Each shell (energy level) has a maximum possible number of electrons which is given by the formula:

Number of electrons = $2n^2$ where n is the number of the shell, starting from the nucleus, and is called the principal quantum number.

The maximum number of electrons in the outer shell of any atom is eight (an octet). This number of electrons forms the most stable arrangement. The outermost electron shell is called the valence electron shell.

Table 5.1 Electron shells.

Electron shell	Maximum electrons allowed
1 (K)	2
2 (L)	8
3 (M)	18
4 (N)	32

From this you can see that the:

- 1st or innermost shell can only contain 1 or 2 electrons.
- 2nd shell has a maximum of 8 electrons.
- 3rd shell has a maximum of 18 electrons. However, for the first 20 elements, the ones you will mainly deal with in this course, the 3rd shell will only have up to 8 electrons.
- 4th shell has a maximum of 32 electrons.

Electron configuration

The electron configuration is a series of numbers which shows the number and arrangement of the electrons orbiting the nucleus of an atom of an element. For example, the electron configuration of carbon is 2.4. This tells us that each carbon atom has two electrons in the 1st or innermost shell and four electrons in the 2nd or outer shell. Notice that if you add up the numbers of the electron configuration, you get the atomic number of the element. For example, for carbon, the electron configuration is 2.4, and its atomic number is 6.

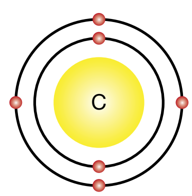


Figure 5.2 Carbon 2.4.

The **properties of atoms**, including their ability to form chemical bonds, can be explained by the arrangement of electrons in the atom, particularly those in the outer valence shell. For most atoms, the most stable arrangement of electrons in the valence shell is 8 electrons arranged as 4 pairs. Atoms with an unstable outer valence shell will react readily, those with a stable outer shell will not react.

The electron configuration of the first 20 elements in the periodic table is shown in Table 5.2. Notice that as you move across the period an extra electron (and of course an extra proton as well) is added to the atoms of each successive element. As one shell fills, the electrons go into the next shell – at each step you move down a group, an extra shell is added.

Table 5.2 Electron configurations of some elements.

Element	Atomic number	Electron configuration
Hydrogen	1	1
Helium	2	2
Lithium	3	2.1
Beryllium	4	2.2
Boron	5	2.3
Carbon	6	2.4
Nitrogen	7	2.5
Oxygen	8	2.6
Fluorine	9	2.7
Neon	10	2.8
Sodium	11	2.8.1
Magnesium	12	2.8.2
Aluminium	13	2.8.3
Silicon	14	2.8.4
Phosphorus	15	2.8.5
Sulfur	16	2.8.6
Chlorine	17	2.8.7
Argon	18	2.8.8
Potassium	19	2.8.8.1
Calcium	20	2.8.8.2

The periodic table and electron configuration

The arrangement of elements in the modern periodic table is based on atomic number and electron configuration. **In each period of the table**, an additional electron shell is added and being filled. For example:

- In period 1, there are only 2 elements, hydrogen and helium, and the first electron shell is being filled (maximum 2 electrons in the first shell).
- In period 2, from lithium to neon, the second electron shell is being filled. Neon is stable with 8 electrons in its valence shell.
- In period 3, from sodium to argon, the third electron shell gains electrons until there are 8 electrons (in argon atoms).

Each group of the periodic table contains elements with the same number of electrons in the outer shell of their atoms. This is why they have the same valency (combining power) and similar chemical properties.

Table 5.3 Groups of the periodic table.

Groups	1	2	3	4	5	6	7	8
Electrons in valence shell	1	2	3	4	5	6	7	8
Valency	1	2	3	4	3 and 5	2 and 6	1	0

QUESTIONS

1. Copy and complete the table to summarise the structure of atoms.

Particles in atoms	Where it is found	Symbol	Relative charge	Relative mass
Proton				1
	Nucleus		0	
		e^-		1/1835

2. Identify what happens to the number of electrons in the outer shell of atoms of elements:
   (a) Across period 1, 2, or 3 of the periodic table.
   (b) Down a group of the periodic table.
3. State the electron configuration for atoms of the following elements, state how this is determined and indicate the valency of each element.
   (a) Carbon. (b) Calcium.
4. Sodium is element 11 in the periodic table.
   (a) What is the electron configuration of sodium?
   (b) Identify the group to which sodium belongs.
   (c) Identify the period to which sodium belongs.
   (d) How many shells of electrons are present in atoms of sodium?
   (e) What is the valency of sodium?
   (f) How many electrons does sodium have in the outer electron shell of its atoms?
5. Check your knowledge with this quick quiz.
   (a) The arrangement of electrons in shells is called the electron ....
   (b) Elements in the same group of the periodic table have the same number of .... in the outer electron shell of their atoms.
   (c) The number of electrons in the outer shell of atoms of elements increases across a .... of the periodic table.
   (d) The elements that have stable outer electron shells in their atoms make up group .... of the periodic table.

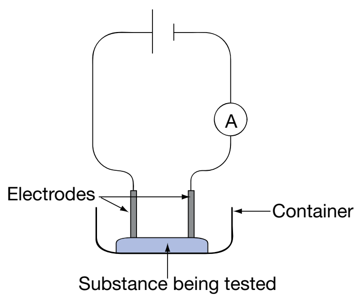
Answers

1 Elements and Atoms

1.

Element	Classification	Element	Classification
Sodium	Metal	Germanium	Semi-metal
Chlorine	Non-metal	Carbon	Non-metal
Gold	Metal	Boron	Semi-metal
Nickel	Metal	Mercury	Metal
Oxygen	Non-metal	Hydrogen	Non-metal

2. Semi-metals are boron, silicon, germanium, arsenic, antimony, tellurium and polonium. They are classified as semi-metals as they have properties of both metals and non-metals. Like metals they are crystalline solids with high melting points, but they also resemble non-metals, for example they are poorer conductors of electricity than metals.
3. *Note:* Any diagrams you draw in chemistry should be in pencil, large enough to clearly see how the apparatus is connected and used, and they must always be fully labelled.
Set up a circuit as shown in the following diagram.



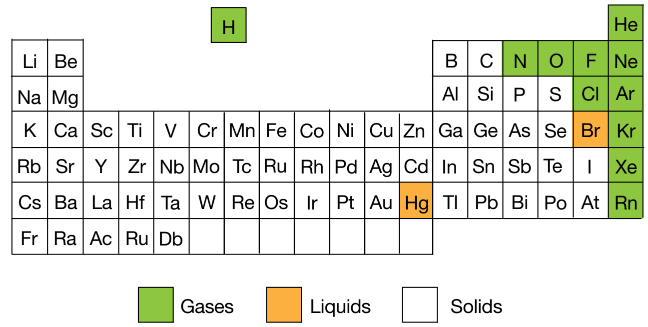
Place each element to be tested in the container, one at a time, and touch the ends of the sample with the electrodes. If the element conducts electricity, the ammeter will show a current is flowing (you could also use a light globe in the circuit).

4.

Physical property	Metals	Non-metals
Melting and boiling points	High	Low
Conductivity of heat	Good	Poor
Conductivity of electricity	Good	Poor (except graphite)
Malleable	Malleable	Not malleable
Ductile	Ductile	Not ductile
Lustre	Shiny lustre	Dull, no lustre
State at room temperature	All solids except mercury which is liquid.	Mostly soft solids or gases except bromine which is liquid.

5. (a) An atom is the smallest part of an element that can take part in a chemical reaction.
(b) The central part of an atom is called the nucleus and it contains positively charged particles called protons and neutral particles called neutrons. Most of the mass of an atom is in the nucleus. Tiny, negatively charged particles called electrons orbit the nucleus of the atom in shells.
6. P – metal, Q – non-metal, R – metal, S – non-metal.
7. (a) An element is a pure substance containing only one type of atom.
(b) Most elements are metals.
(c) Compounds are made of elements chemically combined together in a fixed ratio.

8.



9. (a) Solid $\xrightleftharpoons[\text{Freezing/solidifying}]{\text{Melting}}$ Liquid $\xrightleftharpoons[\text{Condensing}]{\text{Evaporating}}$ Gas

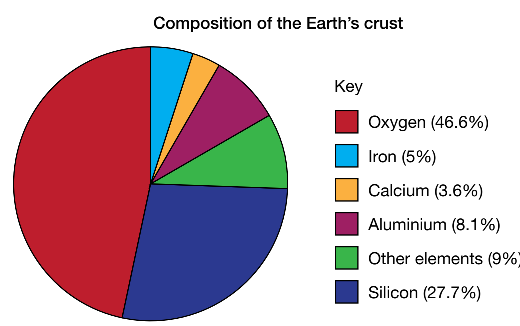
(b)

Element	Melting point (°C)	Boiling point (°C)	State at room temperature
A	1490	2900	Solid
B	–7	58	Liquid
C	1540	3000	Solid
D	114	183	Solid
E	–210	–196	Gas
F	–39	357	Liquid

10. (a) Any element in group 8, e.g. helium.
(b) Various, e.g. sodium Na, calcium Ca, iron Fe, tin Sn, cobalt Co.
(c) Various, e.g. chlorine Cl, argon Ar, nitrogen N, sulfur S, fluorine F.
(d) Hydrogen.
(e) Carbon (in the form of graphite).
(f) Protons and neutrons.
(g) Electrons.
(h) Hydrogen.
(i) 92
(j) An atom.
(k) Ductile.
(l) Metals.

2 Distribution of Elements

1. (a) Hydrogen (b) Aluminium
(c) Oxygen
2. (a) Oxygen, silicon, aluminium, iron.
(b) (*Note*: Graphs should be drawn in pencil, and always have a title and a key.)



3. (a) There are lots of hydrogen atoms, but each hydrogen atom is tiny (hydrogen atoms have the lowest mass of all atoms).
(b) The Universe is made almost entirely of hydrogen and helium gas. The most common elements in the Earth's crust are oxygen, silicon and aluminium.
(Hydrogen and helium gases have presumably been lost to space from the Earth's atmosphere and crust due to their low densities. But some hydrogen has remained, combined with oxygen in water (H_2O) and also combined in other compounds such as carbohydrates and hydrocarbons.)

4. The Earth's atmosphere is composed of mainly nitrogen 78.1%, oxygen 21% and argon 0.9%.
5. (a) The human body does consist of mainly the elements carbon, hydrogen, and oxygen (19%, 9% and 64% by mass). However, these are active elements, so they occur in the body not as elements but combined together as compounds such as water, carbohydrates, proteins and fats. The compounds carbohydrates, proteins and fats are mostly made of the elements carbon, hydrogen and oxygen.
   (b) Three of the following – oxygen, carbon, hydrogen, phosphorus. (Not nitrogen as it is present in a 3 times greater percentage in bacteria than in humans, and not calcium as bacteria do not have shells or bones.)
6. (*Note:* When drawing a table, make sure that you always rule the vertical lines, the lines between sections and the line at the end of the table.) Various, e.g.

Sphere	Elements	Compounds
Atmosphere	Nitrogen Oxygen Argon	Water Carbon dioxide Sulfur dioxide
Lithosphere	Carbon (coal) Gold Copper	Aluminium silicate Silicon dioxide Iron oxide Calcium carbonate
Hydrosphere	Oxygen (dissolved in water)	Water Sodium chloride Magnesium chloride Calcium chloride

7. (a) Various, e.g. spectral analysis and neutron diffraction.
   (b) The Big Bang theory – Hydrogen, helium and lithium were formed in stars during the Big Bang when the Universe originated. Nuclear fusion of these small atoms in stars and supernovas eventually formed all the elements with larger atoms.
8. (a) Various – outline any two areas. For example:
   Biology:
   - Calcium is a major element in the Earth's crust and its abundance helps explain the evolution of its use in the shells and bones of multicellular animals. Calcium was excluded from bacterial cells and hence accumulated in ancient seas.
   - Our understanding of isotopes has led to the use of C-14 dating of fossils. The study of fossils (palaeontology) provides evidence for the theory of evolution.

   Cosmology:
   - Our knowledge of elements has led to the use of spectral analysis to determine the composition of stars and changes in their life cycles. In turn this enables the age of a star to be determined and the fate of a star to be predicted.

   Archaeology:
   - Artefacts are objects from past civilisations. They provide historical information about past societies. The elemental composition of artefacts can be determined by analysis and matched to the composition of the crust. This allows scientists to identify the source of the artefact and provides information about the technology of the society that used the artefacts.

   (b) Various, for example:
   Our knowledge of the composition of the Earth's crust has enabled the extensive mining of minerals and their uses in modern society, e.g. metals used in construction, uranium for nuclear power, titanium in artificial joints used by surgeons to replace damaged joints. However, mining has also resulted in environmental damage such as loss of vegetation, habitats for flora and fauna and pollution of air and water.
9. Carbon atoms are also less common in the crust than in the Universe. On Earth, carbon has combined with oxygen to form carbon dioxide in the atmosphere, and carbon is present in the form of coal and other fossil fuels. Carbon is also locked into the carbon compounds that make up living organisms. When they die it will be released and recirculated.
10. (a) Hydrogen.
    (b) Nitrogen.
    (c) Carbon.
    (d) Spectral analysis.
    (e) Carbon, hydrogen, oxygen.

3 Elements, Trends and the Periodic Table

1. (a) Lithium Li, sodium Na, potassium K, rubidium Rb, caesium Cs, francium Fr.
   (b) Elements in groups 1 and 2 are very active metals, they readily form compounds with other elements in the environment such as oxygen and halogens, so they are only found in nature as compounds.
2. (a) Halogens are elements in group 7 – fluorine F, chlorine Cl, bromine Br, iodine I, astatine As.
   (b) Halogen means from salt or sea. The reactive halogen elements combine with metals to form substances which are found in salt water, e.g. sodium chloride.
3. (a) Inert means will not react.
   (b) Group 8 elements are inert.
   (c) Helium He, neon Ne, argon Ar, krypton Kr, xenon Xe, radon Ra.
   (d) As they are unreactive, they will not form compounds, so they exist as uncombined elements.
4. Various – transition metals include vanadium V, cobalt Co, zinc Zn, silver Ag, gold Au, cadmium Cd.
5. (a) Strontium.
   (b) Potassium.
   (c) Rubidium.
6. (a) Magnesium – Mg, period 3, group 2.
   (b) Silicon – Si, period 3, group 4.
   (c) Chlorine – Cl, period 3, group 7.
   (d) Aluminium – Al, period 3, group 3.
   (e) Lithium – Li, period 2, group 1.
   (f) Oxygen – O, period 2, group 6.
7. Fluorine, bromine and iodine – as they are all in group 7 they will have similar chemical properties – they all have atoms with 7 electrons in their valence shells, so they all need to gain one electron to form atoms which are stable.
8. Melting points across periods are high in group 1, increase to group 4, then decrease to group 8.
9. (a) Group 8.
   (b) Group 4.
   (c) Period 3.
   (d) Group 1.
   (e) 92
   (f) Atomic number (number of protons in the nucleus of atoms).
   (g) Groups.
   (h) Periods.
   (i) Group 8.

4 History of the Periodic Table

1. (a) A vertical list of elements in the periodic table.
   (b) A horizontal row of elements in the periodic table.
   (c) The number of protons in the nucleus of atoms of an element.
2. Lavoisier, Dobereiner, Mendeleev, Mosely.
3. (a) When the elements are arranged in order of increasing atomic mass, they show a periodicity of properties – a repeating pattern.
   (b) Mendeleev's table used information about the known elements to classify them in a logical manner. Mendeleev left spaces for elements that were not yet discovered and predicted what their properties would be. When these elements were discovered, they were found to have properties very similar to those predicted by Mendeleev, e.g. Germanium matched Mendeleev's Eka-silicon.

(c) Moseley placed the elements in order of increasing atomic number rather than Mendeleev's order based on increasing atomic mass.

4. Various. The periodic table was not just developed by one person. It is the results of much thought and collaboration of many scientists from a number of countries, e.g. Lavoisier from France, Dobereiner from Germany, Mendeleev from Russia, Mosely from England.

5. (a) Metals, non-metals.
   (b) Triads.
   (c) Atomic mass/weight.
   (d) Spaces.
   (e) Number.
   (f) Groups.
   (g) Periods.

5 Electron Configuration of Atoms

1.

Particles in atoms	Where it is found	Symbol	Relative charge	Relative mass
Proton	Nucleus	p^+	+1	1
Neutron	Nucleus	n	0	1
Electron	Orbiting nucleus	e^-	–1	1/1835

2. (a) Electrons increase in number across periods 1, 2 and 3.
   (b) There is no change in the number of outer shell electrons as you go down a group of the periodic table. At each step there will be an extra shell of electrons, but the number of electrons in the outer shell is the same for all elements in the same group.

3. (a) 2.4. There are 2 electrons in the first shell and 4 electrons in the second (valence) shell. Valency 4.
   (b) 2.8.8.2. There are 2 electrons in the first shell, the second shell is full with 8 electrons, the third shell has 8, and there are 2 electrons in the fourth (valence) shell. Valency 2.

4. (a) 2.8.1.
   (b) Group 1.
   (c) Period 3.
   (d) 3
   (e) 1
   (f) 1

5. (a) Configuration.
   (b) Electrons.
   (c) Period.
   (d) 8

6 Group 1 and 2 Metals

Note: Some schools teach balanced equations earlier than others. If you have already studied this topic then go ahead and write equations in words and symbols. If not, your teacher might prefer you to write word equations only at present and leave the symbolic equations until a little later. We have provided both in the text and answers.

1. (a) Various, for example:
   - Both groups are metals.
   - Both have high melting points.
   - Both groups are good conductors of electricity (and also heat).
   - Members of both groups react with water forming hydrogen and a basic oxide or hydroxide.
   - They all burn (undergo combustion) to form an oxide.
   - They all have basic oxides and hydroxides.
   - Their compounds tend to be stable.
   - The metals at the bottom of both groups 1 and 2 have the biggest atoms and are the most reactive.

   (b) Various, e.g.
   - Group 2 metals have slightly higher melting and boiling points then than group 1.
   - Group 2 metals have stronger metallic bonding which makes them slightly less reactive than group 1.
   - Atoms of group 1 elements have 1 electron in their outer valence shell (electron configuration ends in 1, whereas group 2 have 2 electrons (electron configuration ends in 2).

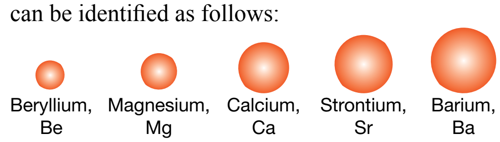
2. Elements of groups 1 and 2 are too reactive to exist as elements – they would react with oxygen and water in the environment. Thus they occur naturally as compounds.

3. (a) Sodium + water → hydrogen + sodium hydroxide
   $2Na(s) + H_2O(l) \rightarrow H_2(g) + Na_2O(aq)$
   $Na_2O + H_2O(l) \rightarrow 2NaOH(aq)$
   (b) Magnesium + hot water → hydrogen + magnesium hydroxide
   $Mg(s) + 2H_2O(l) \rightarrow H_2(g) + Mg(OH)_2(aq)$

4. (a) Magnesium + oxygen → magnesium oxide
   $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
   (b) Various, e.g. Do not look at the magnesium burning as the light is very bright and could damage your eyes. Place the magnesium in a crucible or hold it with tongs over a container to catch the hot magnesium oxide as it forms so it does not burn the bench.

5. (a) The two models are similar in that both consist of cations (positive ions) and electrons. A is a model of a group 1 metal and B is a model of a group 2 metal.
   Model B has twice as many electrons per positive ion. This would be expected as each atom of a group 2 element loses 2 electrons to become an ion with a +2 charge, whereas each atom of a group 1 element only loses 1 electron to form an ion with a +1 charge.

6. (a) Various, e.g. Reactivity increases and atomic radius increases as you move down groups 1 and 2.
   (b) Alkaline earth metals are group 2 of periodic table, so they can be identified as follows:



7. (a) Basic.
   (b) Various, e.g. Bases turn red litmus paper blue and blue litmus stays blue.

8.

Element	Symbol	Atomic number	Electron configuration	Valency
Lithium	Li	3	2.1	1
Sodium	Na	11	2.8.1	1
Potassium	K	19	2.8.8.1	1
Beryllium	Be	4	2.2	2
Magnesium	Mg	12	2.8.2	2
Calcium	Ca	20	2.8.8.2	2

9. (a) Various, e.g. Magnesium metal is used in aeroplane construction alloyed with aluminium. It is also used in flares, bullets, bombs and fireworks.
   (b) Various, e.g. Sodium chloride is table salt which is used to flavour food, to preserve food, as an intravenous solution in hospitals and to melt ice on frozen roads in cold climates. It is also used in the manufacture of sodium hydroxide, making glass, pottery, textiles, dyes, soap, chlorine, sodium hydroxide and sodium carbonate.

10. (a) Magnesium oxide.
    (b) Calcium hydroxide.
    (c) Lithium hydroxide.
    (d) Sodium oxide.

11. A

12. C

13. (a) The liquid in the beaker is clear (transparent) and colourless and it turns red litmus blue. (Note that these are two different properties. Also you cannot observe that the liquid is an acid – that is an inference based on the fact that it changes the colour of the indicator.)
    (b) It is acidic as it turns red litmus paper blue.

14. (a) Alkali metals.
    (b) Alkaline earth metals.
    (c) Group 1.
    (d) Hydrogen.