Collins

Cambridge IGCSE™

Combined Science

STUDENT'S BOOK

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In this section you will extend the work you did in Section 2, Atoms, elements and compounds, and focus in detail on the structure of the Periodic Table and the characteristic properties of particular groups of elements. If you look at the Periodic Table in the back of this book (page 688), you will see that it includes 118 elements. The good news is that you will not have to study the properties of all these elements! Because of the way elements have been arranged in the Periodic Table, learning about one element often provides a very good idea about how other elements may behave. You will study in some detail a group of metals and a group of non-metals, followed by elements known as 'transition elements' and a group known as the noble gases.

STARTING POINTS

1. What is an element – how would you define the term?
2. What does the proton number of an atom tell you about its structure?
3. In terms of electronic configuration what is the main difference between a metal and a non-metal?
4. Helium is a common noble gas. Do you know a use of helium?

SYLLABUS SECTIONS COVERED

C8.1 Arrangement of elements

C8.2 Group I properties

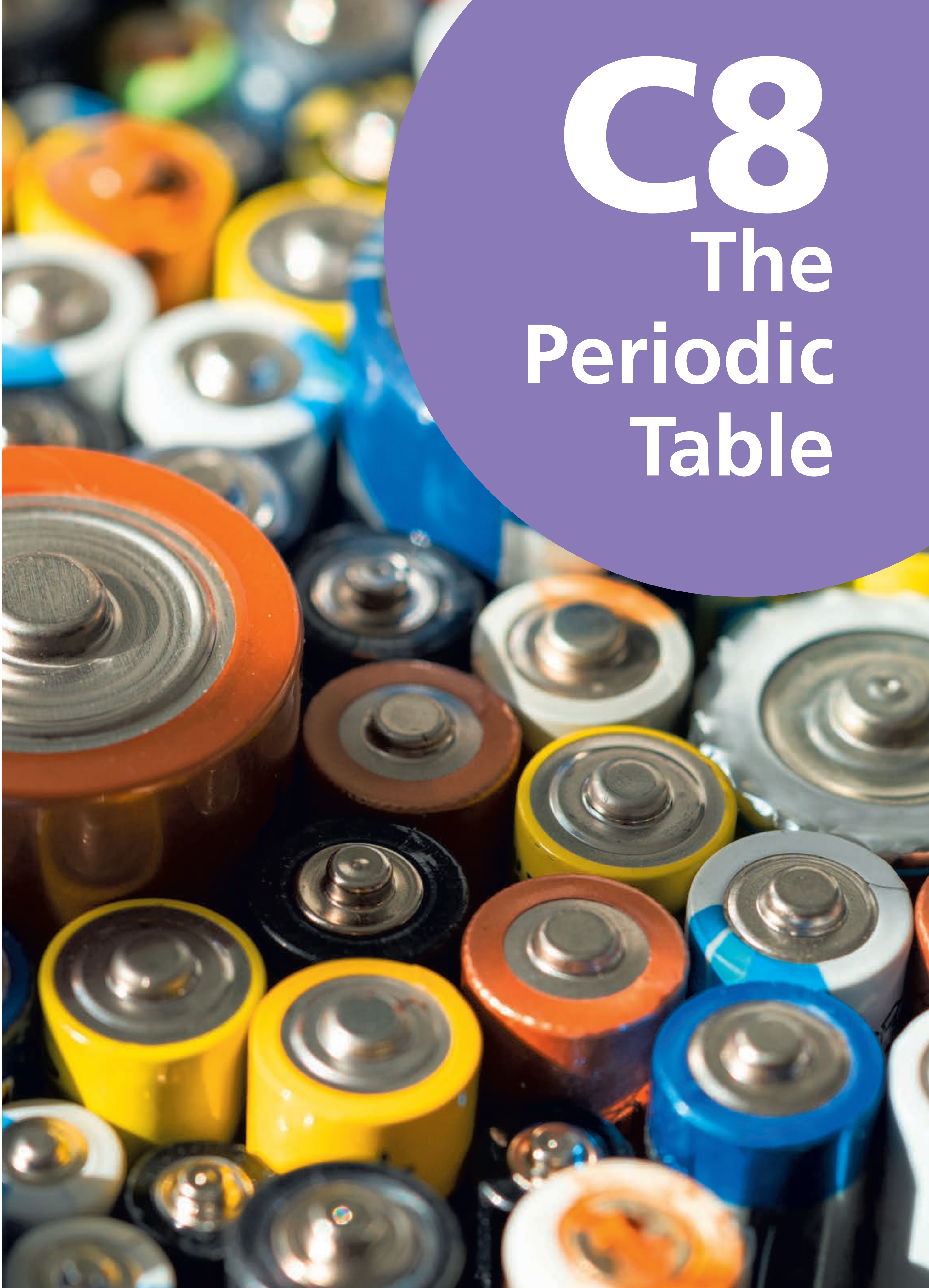
C8.3 Group VII properties

C8.4 Transition elements

C8.5 Noble gases

▷ Many batteries contain lithium, which is a Group I metal.

C8 The Periodic Table



∆ Fig. C8.1 This ordering of elements was first published in 1871 by the Russian chemist Dmitri Mendeleev.

Arrangement of elements

INTRODUCTION

With over 100 different elements in existence, it is very important to have some way of ordering them. The Periodic Table puts elements with similar properties into columns, with a gradual change in properties moving from left to right along the rows. This topic looks at some of the basic features of the Periodic Table. Later topics will look in more detail at particular groups and arrangements of the elements.

KNOWLEDGE CHECK

- ✓ All matter is made up of elements.
- ✓ The proton number of an element gives the number of protons (and the number of electrons) in an atom of the element.
- ✓ Electrons are arranged in shells around the nucleus of the atom.

LEARNING OBJECTIVES

- ✓ Describe the Periodic Table as an arrangement of elements in periods and groups and in order of increasing proton number / atomic number.
- ✓ Describe the change from metallic to non-metallic character across a period.
- ✓ **SUPPLEMENT** Identify trends in groups, given information about the elements.

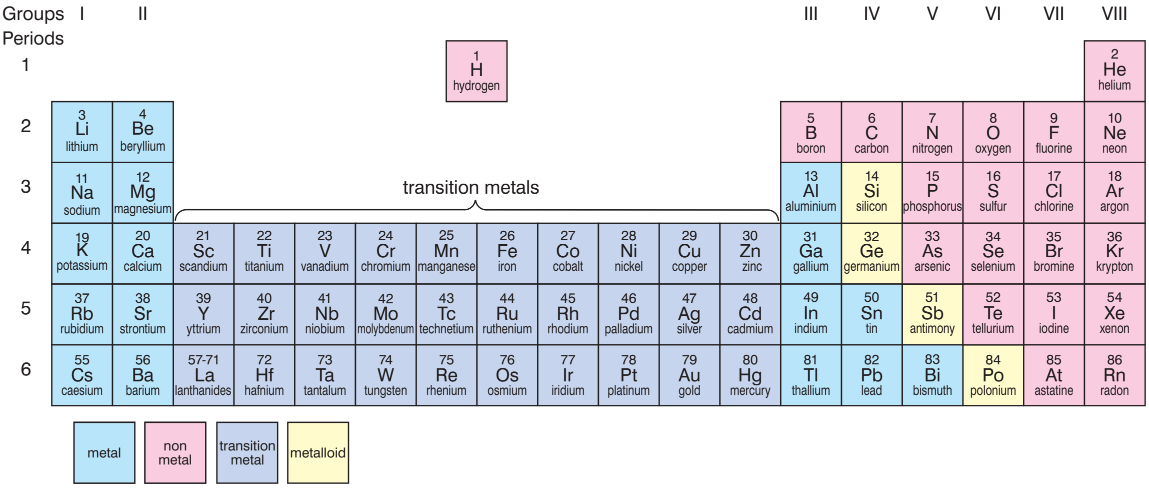
ARRANGEMENT OF ELEMENTS IN THE PERIODIC TABLE

An **element** is a substance that cannot be broken down into other substances by chemical means. As new elements were discovered in the 19th century, chemists tried to organise them into patterns based on the similarities in their properties. John Newlands classified elements according to their properties and Dmitri Mendeleev produced the classification system which is considered to be the basis of the modern Periodic Table. When the structure of the atom was better known, elements were arranged in order of increasing proton number, and then the patterns started to make more sense. (Proton/ atomic number is the number of protons in an atom.)

How are elements classified in the modern Periodic Table?

More than 110 elements have now been identified, and each has its own properties and reactions. In the **Periodic Table**, elements with similar properties and reactions are shown close together.

The modern **Periodic Table** arranges the elements in order of increasing proton number. They are then arranged in periods and groups so that elements with similar properties and reactions are shown close together. The complete Periodic Table on page 688 lists all the known elements. The simplified Periodic Table in Fig C8.2 shows the first 86 elements and the main groups and their names. The number below each element is the atomic number (**proton number**).



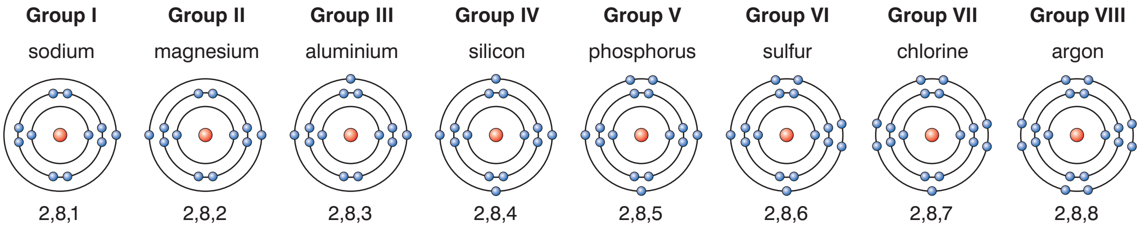
Δ Fig. C8.2 The Periodic Table.

Periods

Horizontal rows of elements are arranged in increasing proton number from left to right. Rows correspond to **periods**, which are numbered from 1 to 7.

Moving across a period, each successive atom of the elements gains one proton and one electron (in the same outer shell).

In Fig. C8.3 you can see how the number of electrons in the outer shell increases across a period, for the elements in Period 3.



Δ Fig. C8.3 Moving across a period shows the electronic configuration of each element.

Moving across a period like Period 3 (sodium to argon), the following trends take place:

- Metals on the left going to non-metals on the right.
- Group I elements are the most reactive metal group, and as you go to the right the reactivity of the groups decreases. Group IV elements are the least reactive.
- Continuing right from Group IV, the reactivity increases until Group VII, the most reactive of the non-metal groups.

Groups

Vertical columns contain elements with the proton number increasing down the column – they are called **groups.** They are numbered from I to VIII (Group VIII is sometimes referred to as Group 0).

Groups are referred to as 'families' of elements because they have similar characteristics, just like families – the alkali metals (Group I), the alkaline earth metals (Group II) and the halogens (Group VII).

Elements in the same group do not have identical physical and chemical properties. For example, within a group there will be a trend (a gradual change between elements as you move down the group) in physical properties, such as melting point and density, and a trend in chemical reactivity. These group characteristics will be covered in more detail in the topics on Group 1 and Group VII elements.

REMEMBER

It is important to understand the relationship between group number, number of outer electrons, and metallic and non-metallic character across periods.

QUESTIONS

1. Find the element calcium in the Periodic Table. Answer these questions about calcium:
   a) What is its proton number?
   b) Describe what information the proton number gives about the structure of a calcium atom.
   c) Which group of the Periodic Table is calcium in?
   d) Which period of the Periodic Table is calcium in?
   e) Is calcium a metal or a non-metal?
2. What is the family name for the Group VII elements?
3. Are the Group VII elements metals or non-metals?
4. **SUPPLEMENT** The table provides information about the melting points and reactivity with cold water of three elements in Group 2.

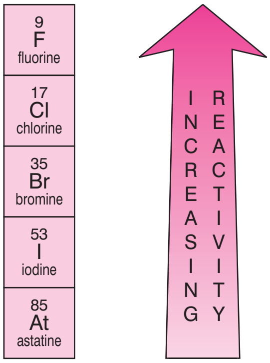
element	melting point /°C	reactivity with cold water
calcium	842	reacts to form bubbles of gas
strontium	777	reacts rapidly to form bubbles of gas
barium	727	reacts very vigorously producing bubbles of gas

   a) What trend is there in the melting points of the three Group 2 elements?
   b) What trend is there in the reactivity with cold water of the three Group 2 elements?'

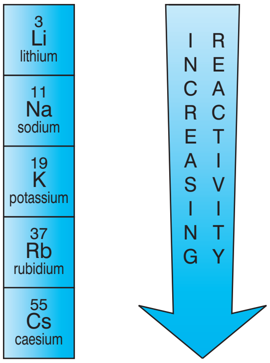
Reactivities of elements

Going from the top to the bottom of a group in the Periodic Table, metals become more reactive, but non-metals become less reactive.

Group VIII elements, known as the noble gases, are very unreactive. They already have full outer electron shells and so rarely react with other elements to form compounds.



Δ Fig. C8.4 The Group VII elements (non-metals) become more reactive further up the group.



Δ Fig. C8.5 Group I elements (metals) become more reactive further down the group.

SCIENCE IN CONTEXT

THE FIRST PERIODIC TABLE

In 1871 the Russian chemist Dmitri Mendeleev published his work on the Periodic Table. It included the 66 elements that were known at the time. Interestingly, Mendeleev left gaps in his arrangement when the next element in his order did not seem to fit. He predicted that there should be elements in the gaps but that they had yet to be discovered. One such element is gallium (discovered in 1875), which Mendeleev predicted would be between aluminium and indium.

In 2022 there were 118 known elements, but only 98 of these occurred naturally – the remaining 24 have been made artificially. Some elements are radioactive – for example the element americium (Am, proton number 95), which is used in smoke detectors.

Challenge Question: The element americium can be represented as $^{243}_{95}Am$. Calculate how many protons, neutrons and electrons this atom has.

End of topic checklist

Key terms

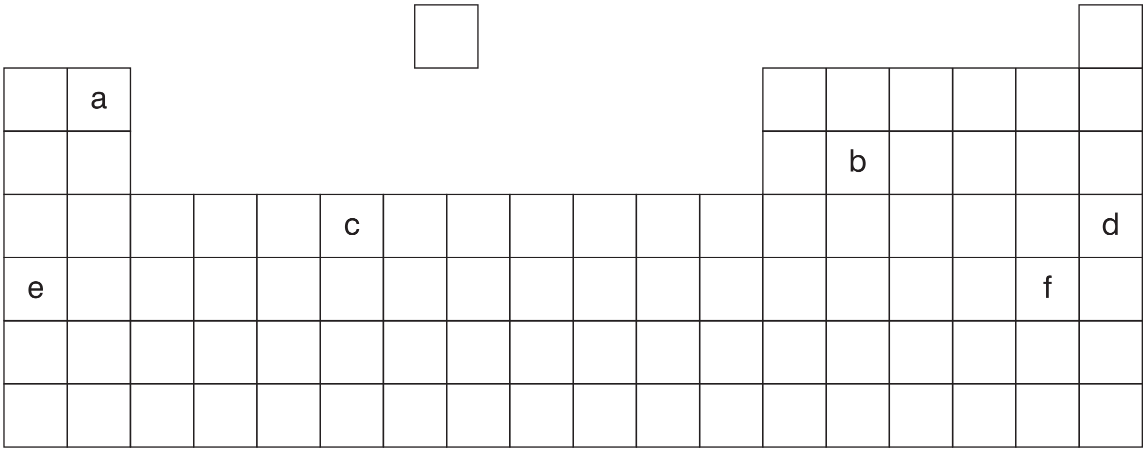
element, group, period, Periodic Table, proton number (atomic number)

During your study of this topic you should have learned:

- ❍ How to describe the Periodic Table as a method of classifying elements into groups and periods.
- ❍ How to describe the change from metallic to non-metallic character across a period.
- ❍ **SUPPLEMENT** How to identify trends in groups from information about the elements.

End of topic questions

1. Look at the diagram representing the simplified Periodic Table. The letters stand for elements.



a) State which element is in Group IV:

A e

B c

C b

D d

b) State which element is in the second period.

c) State which element is a noble gas.

d) State which element is a transition metal.

e) State which elements are non-metals.

f) State which element is most likely to be a gas.

2. Determine the electron configuration in the following atoms:

a) sodium (proton number = 11)

b) silicon (proton number = 14)

c) fluorine (proton number = 9).

3. Describe how the metallic and non-metallic nature of the elements changes across Period 3 of the Periodic Table.

4. **SUPPLEMENT** In the Periodic Table, state what is the trend in reactivity:

a) down a group of metals.

b) down a group of non-metals.

Δ Fig. C8.6 Potassium reacting with water.

Group I elements

INTRODUCTION

Metals are positioned on the left-hand side and in the middle of the Periodic Table. Therefore the Group I elements are metals, but they are rather different from the metals in everyday use. In fact, when you see how the Group I metals react with air and water, it is hard to think how they could be used outside the laboratory. This very high reactivity makes them interesting to study. Our focus is on the first three elements in the group: lithium, sodium and potassium. Rubidium, caesium and francium are not available in schools because they are too reactive.

KNOWLEDGE CHECK

✓ Metals are positioned on the left-hand side and middle of the Periodic Table.
✓ Elements in a group have similar electron configurations.
✓ Metal oxides and hydroxides are basic and those that dissolve in water form alkalis.

LEARNING OBJECTIVES

✓ Describe the Group I alkali metals, lithium, sodium and potassium, as relatively soft metals with general trends down the group, limited to: decreasing melting point; increasing density; increasing reactivity with water.
✓ **SUPPLEMENT** Predict the properties of other elements in Group I, given information about the elements.

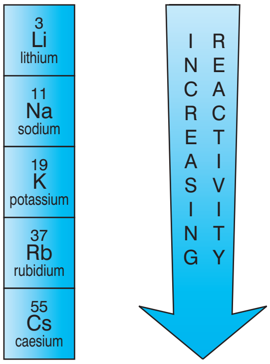
REACTIVITY OF GROUP 1 ELEMENTS

All Group I elements react with water to produce an alkaline solution. This makes them recognisable as a 'family' of elements, often called the **alkali metals.**

These very reactive metals all have only one electron in their outer electron shell. This electron is easily given away when the metal reacts with non-metals.

SUPPLEMENT

Reactivity increases down the group because as the atom gets bigger the outer electron is further away from the attractive force of the nucleus, and so can be removed more easily as the atoms react to form positive ions.



Δ Fig. C8.7 Group I elements become more reactive as you go down the group.

GROUP I PROPERTIES

The properties of Group I metals are as follows:

- Soft to cut.
- Shiny when cut, but quickly tarnish in the air.
- Very low melting points compared with most metals – melting points decrease down the group.
- React very easily with water compared with most metals. Lithium, sodium and potassium float on water. Densities increase down the group.
- React very easily with air, water and elements such as chlorine. The alkali metals are so reactive that they are stored in oil to prevent reaction with air and water. Reactivity increases down the group.

Δ Fig. C8.8 The freshly cut surface of sodium.

QUESTIONS

1. Explain why the Group I elements are known as the *alkali metals*.

2. How many electrons do the Group I elements' atoms have in their outer shell?

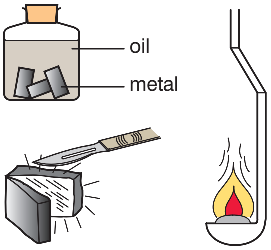
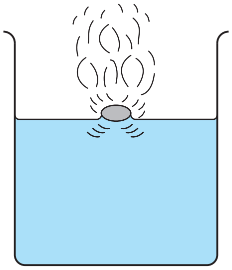
3. The Group I metals are unusual metals. Give one property they have that is different to most other metals.

4. **SUPPLEMENT** The table shows the properties of some elements in Group 1 of the Periodic Table.

Name of element	Melting point (°C)	Reaction with water
Lithium	181	Metal remains solid and a gas is given off
Sodium	98	Metal melts and a gas is given off quickly
potassium	64	Metal melts and the gas given off catches fire
rubidium		

Use the information in the table to predict the melting point and reaction with water of the element rubidium.

5. **SUPPLEMENT** Explain why potassium is more reactive than lithium.

Reaction	Observations	Equations
Air or oxygen 	The metals burn easily and their compounds colour flames: lithium – red sodium – orange/yellow potassium – lilac A white solid oxide is formed	lithium + oxygen → lithium oxide $4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$ sodium + oxygen → sodium oxide $4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$ potassium + oxygen → potassium oxide $4K(s) + O_2(g) \rightarrow 2K_2O(s)$
Water 	The metals react vigorously They float on the surface, moving around rapidly With both sodium and potassium, the heat of the reaction melts the metal so it forms a sphere; bubbles of gas are given off and the metal 'disappears' With the more reactive metals (such as potassium) the hydrogen gas produced burns The resulting solution is alkaline	lithium + water → lithium hydroxide + hydrogen $2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$ sodium + water → sodium hydroxide + hydrogen $2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$ potassium + water → potassium hydroxide + hydrogen $2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$

Δ Table C8.1 Reactions of Group I metals.

SCIENCE IN CONTEXT

COMPOUNDS OF THE GROUP I METALS

The compounds of Group I metals are usually colourless crystals or white solids and always have ionic bonding. Most of them are soluble in water. Some examples are sodium chloride (NaCl) and potassium nitrate (KNO_3).

Δ Fig. C8.9 Sodium burning in chlorine.

The compounds of the alkali metals are widely used:

- lithium carbonate – as a hardener in glass and ceramics
- lithium hydroxide – removes carbon dioxide in air-conditioning systems
- sodium chloride – table salt
- sodium carbonate – a water softener
- sodium hydroxide – used in paper manufacture
- monosodium glutamate – a flavour enhancer
- sodium sulfite – a preservative
- potassium nitrate – a fertiliser; also used in explosives.

Challenge Question: Give the chemical formulas for lithium carbonate and lithium hydroxide.

QUESTIONS

1. Describe how the density of potassium compares to that of lithium.
2. What gas is produced when potassium reacts with water? Give the name of the solution formed in this reaction.

SCIENCE IN CONTEXT

FACTS ABOUT THE GROUP I METALS

1. Lithium is found in large quantities (estimated at 230 billion tonnes) in compounds in seawater.

2. Sodium is found in many minerals and is the sixth most abundant element overall in the Earth's crust (amounting to 2.6% by weight).

Δ Fig. C8.10 Lithium is used in all of these batteries.

3. Potassium is also found in many minerals and is the seventh most abundant element in the Earth's crust (amounting to 1.5% by weight).

4. Rubidium was discovered by Bunsen (of Bunsen burner fame) in 1861. It is the 16th most abundant element and is more abundant than copper, about the same as zinc, and is found in very small quantities in a large number of minerals. Because of this low concentration in mineral deposits, only 2 to 4 tonnes of rubidium are produced each year worldwide.

5. Caesium is more abundant than tin, mercury and silver. However, its very high reactivity makes it very difficult to extract from mineral deposits.

6. Francium was discovered as recently as 1939 as a product of the radioactive decay of an isotope of actinium.

Challenge Question: Predict how the properties (for example, melting point, density and reactivity) of caesium compare to those of sodium.

End of topic checklist

Key terms

alkali metal

During your study of this topic you should have learned:

- ❍ How to describe lithium, sodium and potassium in Group I as a collection of relatively soft metals showing trends in melting point, density and reactivity with water.
- ❍ **SUPPLEMENT** How to predict the properties of other elements in Group I, given information where appropriate.

End of topic questions

1. State which of these descriptions of sodium is NOT correct.

   A It is stored under water to prevent its reaction with the air.

   B It is soft and can be easily cut with a knife.

   C It is a solid with a low melting point.

   D It burns in air with an orange/yellow flame, forming sodium oxide.

2. This question is about the Group I elements lithium, sodium and potassium.

   a) State which is the most reactive of these elements.

   b) Explain why the elements are stored in oil.

   c) Explain why sodium floats when added to water.

3. Explain why the Group I elements are known as the 'alkali metals'.

4. Write word equations and balanced equations for the following reactions:

   a) lithium and oxygen

   b) potassium and water.

5. **SUPPLEMENT** This question is about rubidium (symbol Rb), which is a less common Group I element.

   a) Explain what state of matter would you expect rubidium to be in at room temperature and pressure.

   b) When rubidium is added to water:

      i) State which gas is formed.

      ii) State what chemical compound would be formed in solution. Predict what result would be seen if universal indicator was added to the solution.

   c) Would you expect rubidium to be more or less reactive than potassium? Justify your answer.

Group VII elements

INTRODUCTION

Group VII elements are located on the right-hand side of the Periodic Table with the other non-metals. They look very different from each other, so it may seem strange that they are in the same group. However, their chemical properties are very similar, and all of them are highly reactive. This topic focuses on chlorine, bromine and iodine. Fluorine is a highly reactive gas and astatine is a radioactive black solid with a very short half-life (so will exist in only very small quantities).

Δ Fig. C8.11 At room temperature and atmospheric pressure, chlorine is a pale yellow-green gas, bromine a red-brown liquid and iodine is a grey-black solid.

KNOWLEDGE CHECK

✓ Non-metals are positioned on the right-hand side of the Periodic Table.
✓ Elements in a group have similar electron arrangements or configurations.
✓ Oxidation and reduction are important processes.

LEARNING OBJECTIVES

✓ Describe the Group VII halogens, chlorine, bromine and iodine, as diatomic non-metals with general trends down the group, limited to: increasing density; decreasing reactivity.
✓ State the appearance of the halogens at room temperature and pressure, r.t.p., as: chlorine, a pale yellow-green gas; bromine, a red-brown liquid; iodine, a grey-black solid.
✓ **SUPPLEMENT** Describe and explain the displacement reactions of halogens with other halide ions.
✓ **SUPPLEMENT** Predict the properties of other elements in Group VII, given information about the elements.

REACTIVITY OF GROUP VII ELEMENTS

The Group VII elements are sometimes referred to as the **halogen** elements or halogens.

'Halogen' means 'salt-maker' – halogens react with most metals to make salts.

Halogen atoms have seven electrons in their outermost electron shell, so they need to gain only one electron to obtain a full outer shell.

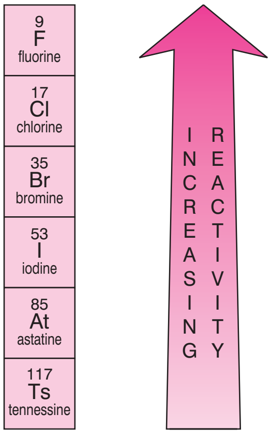
This is what makes them very reactive. They react with metals, gaining an electron and forming a singly charged negative ion.

The reactivity of the elements decreases down the group.

GROUP VII PROPERTIES

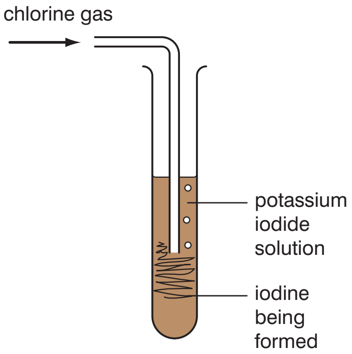
The properties of the Group VII elements are as follows:

- The density of the elements increases down the group.
- Fluorine is a pale yellow gas; chlorine is a pale yellow-green gas; bromine is a red-brown liquid; iodine is a grey-black shiny solid.
- All the atoms have seven electrons in their outermost electron shell.
- All exist as **diatomic** molecules – each molecule contains two atoms. For example, F_2, Cl_2, Br_2, I_2.
- **SUPPLEMENT** They undergo **displacement reactions**.



Δ Fig. C8.12 Increasing reactivity up Group VII.

SUPPLEMENT

Reaction	Observations	Equations
Displacement 	A more reactive halogen will displace a less reactive halogen from a solution of a salt	
	Chlorine displaces bromine from sodium bromide solution. The colourless solution (sodium bromide) turns orange when chlorine is added due to the formation of bromine	chlorine + sodium bromide → sodium chloride + bromine $Cl_2(g) + 2NaBr(aq) \rightarrow 2NaCl(aq) + Br_2(aq)$
	Chlorine displaces iodine from sodium iodide solution. The colourless solution (sodium iodide) turns brown when chlorine is added due to the formation of iodine	chlorine + sodium iodide → sodium chloride + iodine $Cl_2(g) + 2NaI(aq) \rightarrow 2NaCl(aq) + I_2(aq)$

Δ Table C8.2 Properties of the Group VII elements.

In the **displacement reactions** between halogens and solutions of halide ions (shown above) the sodium ions (Na^+) play no part in the reaction, so if the reaction between chlorine and sodium bromide solution is written with them removed, we can write an **ionic equation**:

$$Cl_2(aq) + 2Br^-(aq) \rightarrow 2Cl^-(aq) + Br_2(aq)$$

It is possible to predict information about the Group 1 elements using information about the trend in physical or chemical properties. For example, look at the following melting point information:

Group 1 element	melting point /°C
lithium	181
sodium	98
potassium	64
rubidium	
caesium	28

The overall trend in melting points is clearly a decrease down the group. It is possible to make a prediction about the likely melting point of rubidium. The drop in melting points between one element and the next is not the same in each case. It is very likely to be between 64°C and 28°C, slightly below the mid-point of 46°C (the melting point of sodium is below the mid-point between the melting points of lithium and potassium). The melting point of rubidium is actually 40°C.

QUESTIONS

1. State which is the most reactive element in Group VII.
2. How many electrons do Group VII element atoms have in their outer shell?
3. Explain why the Group VII elements are particularly reactive when compared to other non-metals.
4. Chlorine exists as diatomic molecules. Explain what this means.
5. **SUPPLEMENT** Astatine is an element in Group VII. Predict whether you would expect it to be a solid, liquid or gas at room temperature. Explain your answer.
6. **SUPPLEMENT** Explain what a 'displacement reaction' is, involving the Group VII elements.
7. **SUPPLEMENT** Bromine displaces iodine from potassium iodide solution. Write an ionic equation for this reaction.

SUPPLEMENT

Developing practical skills

A student was provided with three aqueous solutions containing chlorine, bromine and iodine. She added a few drops of a non-polar solvent to each solution in separate test-tubes and then stirred each with a clean glass rod. A non-polar solvent forms a separate layer when in aqueous solution. It floated on top of the student's solutions. When the non-polar solvent layer separated from each solution, she recorded the colours of the non-polar solvent layers in the table:

Solution in water	Colour of the non-polar solvent layer
chlorine	colourless
bromine	orange
iodine	violet

She cleaned out the tubes and then performed a series of test-tube reactions as indicated in the table below. In each case she mixed small quantities of solution A with twice the volume of solution B, added 10 drops of the non-polar solvent and then stirred the mixture with a clean glass rod. Once the layers had separated, she recorded her results.

Solution A	Solution B	Colour of non-polar solvent layer
aqueous chlorine	sodium bromide	orange
aqueous chlorine	sodium iodide	violet
aqueous bromine	sodium chloride	orange
aqueous bromine	sodium iodide	violet
aqueous iodine	sodium chloride	violet
aqueous iodine	sodium bromide	orange

Safety note: Eye protection and gloves should be worn when using or being exposed to chlorine or bromine.

Apparatus and techniques

1. The non-polar solvent is highly flammable and toxic and the chlorine and bromine solutions are both irritants. Describe the precautions the student should have taken when doing this experiment.

Interpret observations and data

2. What can you deduce about the relative reactivity of chlorine, bromine and iodine from the first two results in the second table?
3. Write an equation for the reaction indicated by result four in the second table.

Evaluate methods

4. The student made a mistake in recording one of her results. Identify which one. Explain how you know.

SCIENCE IN CONTEXT

USES OF HALOGENS

Halogens and their compounds have a wide range of uses:

- fluorides – in toothpaste help prevent tooth decay
- fluorine compounds – making plastics like the non-stick surface on pans
- chlorofluorocarbons – propellants in aerosols and refrigerants (now being replaced because of their damaging effect on the ozone layer)

- chlorine – purifying water
- chlorine compounds – household bleaches
- hydrochloric acid – widely used in industry
- bromine compounds – making pesticides
- silver bromide – the light-sensitive film coating on photographic film
- iodine solution – an antiseptic.

FLUORINE

Fluorine is the most reactive non-metal in the Periodic Table. It reacts with most other elements except helium, neon and argon. These reactions are often sudden or explosive. Even radon, a very unreactive noble gas, burns with a bright flame in a jet of fluorine gas. All metals react with fluorine to form fluorides. The reactions of fluorine with Group I metals are explosive.

Early scientists tried to make fluorine from hydrofluoric acid (HF(aq)) but this proved to be highly dangerous, killing or blinding several scientists who attempted it. They became known as the 'fluorine martyrs'. Today fluorine is manufactured by the electrolysis of the mineral fluorite, which is calcium fluoride.

Fluorine is not an element to play with. You will certainly not see it in your laboratory!

Challenge Question: This question is about calcium fluoride.

a) Determine the chemical formula of calcium fluoride.

b) State the charges on the calcium and fluoride ions.

c) In the electrolysis of molten calcium fluoride, state at which electrode the fluorine would be produced.

End of topic checklist

Key terms

diatomic, halogens

SUPPLEMENT displacement reactions, ionic equations

During your study of this topic you should have learned:

- ❍ How to describe chlorine, bromine and iodine in Group VII as a collection of diatomic non-metals showing trends in appearance, density and reactivity.
- ❍ **SUPPLEMENT** How to describe and explain the displacement reactions of halogens with other halide ions.
- ❍ **SUPPLEMENT** How to predict the properties of other elements in Group VII, given information about the elements.

End of topic questions

1. This question is about the Group VII elements: chlorine, bromine and iodine.

a) State which is the most reactive of these elements.

b) State which of the elements exists as a liquid at room temperature and pressure.

c) State which of the elements exists as a solid at room temperature and pressure.

d) Describe the appearance of bromine.

2. Write word and balanced equations for the following reactions:

a) sodium and chlorine

b) potassium and bromine

c) lithium and fluorine.

3. **SUPPLEMENT** Determine which of these equations correctly shows a displacement reaction of the halogen elements.

A $2NaCl + Br_2 \rightarrow 2NaBr + Cl_2$

B $2NaCl + I_2 \rightarrow 2NaI + Cl_2$

C $2NaI + Cl_2 \rightarrow 2NaCl + I_2$

D $2NaBr + I_2 \rightarrow 2NaI + Br_2$

4. **SUPPLEMENT** Aqueous bromine reacts with sodium iodide solution.

a) State what type of chemical reaction this is.

b) Write a balanced equation for the reaction.

Δ Fig. C8.13 This incandescent light bulb contains unreactive argon instead of air.

Transition metals and noble gases

INTRODUCTION

There are two other important 'families' of elements. The first are the transition elements, which are a 'block' of metals that includes more 'everyday' metals than Group I.

The second is the noble gases (Group VIII), a group of elements of interest because of their uses rather than their chemical reactions.

KNOWLEDGE CHECK

✓ Metals are positioned on the left side and the middle of the Periodic Table.
✓ Non-metals are positioned on the right side of the Periodic Table.
✓ Elements in a group have similar electron configuration.

LEARNING OBJECTIVES

✓ Describe the transition elements as metals that: have high densities; have high melting points; form coloured compounds; often act as catalysts as elements and in compounds.
✓ Describe the Group VIII noble gases as unreactive, monatomic gases and explain this in terms of electronic configuration.

TRANSITION ELEMENTS

The **transition metals** are grouped in the centre of the Periodic Table and include iron, copper, zinc and chromium.

All the transition metals have more than one electron in their outer electron shell. They are much less reactive than Group I and Group II metals and so are more 'everyday' metals. They have much higher melting points and densities. They react much more slowly with water and with oxygen.

They are widely used as construction metals (particularly iron through steel).

One of the typical properties of transition metals and their compounds is their ability to act as **catalysts** and speed up the rate of a chemical reaction.

Property	Group I metal	Transition metal
melting point	low	high
density	low	high
colour of compounds	white	mainly coloured
reactions with water/air	vigorous	slow or no reaction
reactions with an acid	violent (dangerous)	slow or no reaction

Δ Table C8.3 Properties of the Group I metals and the transition metals.

The compounds of the transition metals are usually coloured. Copper compounds are usually blue or green; iron compounds tend to be either green or brown. When sodium hydroxide solution is added to a solution of a transition metal compound, a precipitate of the metal hydroxide is formed. The colour of the precipitate helps to identify the metal, as you will learn about in Section 12. For example:

copper(II) sulfate + sodium hydroxide → copper(II) hydroxide + sodium sulfate

$CuSO_4(aq) + 2NaOH(aq) \rightarrow Cu(OH)_2(s) + Na_2SO_4(aq)$

Colour of metal hydroxide	Likely metal present
blue	copper(II) Cu^{2+}
green	nickel(II) Ni^{2+}
green turning to brown	iron(II) Fe^{2+}
orange/brown	iron(III) Fe^{3+}

Δ Table C8.4 Transition metal hydroxides and their colours.

QUESTIONS

1. Find the element zinc in the Periodic Table. Answer these questions about zinc:

a) What is its proton number?

b) Describe what information the proton number gives about the structure of a zinc atom.

c) State which period of the Periodic Table zinc is in.

d) State whether zinc is a metal or a non-metal.

2. Would you expect a reaction to happen between copper and water?

3. a) **SUPPLEMENT** Write a fully balanced equation for the reaction between iron(II) sulfate solution and sodium hydroxide solution.

b) Describe the colour of the precipitate formed.

NOBLE GASES

This is actually a group of very unreactive non-metals. They used to be called the inert gases as it was thought that they didn't react with anything. But scientists later managed to produce fluorine compounds of some of the noble gases. As far as your school laboratory work is concerned, however, they are completely unreactive.

Name	Symbol
Helium	He
Neon	Ne
Argon	Ar
Krypton	Kr
Xenon	Xe
Radon	Rn

Δ Table C8.5 The noble gases.

The unreactivity of the noble gases can be explained in terms of their **electronic configurations**. The atoms all have complete outer electron shells or eight electrons in their outer shell. They don't need to lose electrons (as metals do), or gain electrons (as most non-metals do).

Similarities of the noble gases

- Full outer electron shells
- Very unreactive
- Gases
- Exist as single atoms – they are **monatomic** (He, Ne, Ar, Kr, Xe, Rn).

How are the noble gases used?

- Helium – in balloons
- Neon – in red tube lights
- Argon – in lamps and light bulbs.

QUESTIONS

1. Why is helium unreactive?

2. Neon is monatomic. What does this mean?

3. Find argon on the Periodic Table.

a) What is its proton number?

b) What is its period number, and what does this tell you about the number of occupied electron shells?

c) How many electrons does argon have in its outer electron shell?

d) Write the electronic configuration of argon.

End of topic checklist

Key terms

catalyst, electronic configuration, monatomic, transition metal

During your study of this topic you should have learned:

❍ How to describe the transition elements as a collection of metals with high densities and high melting points, forming coloured compounds and often acting as catalysts.

❍ That the noble gases are unreactive, monatomic gases as result of their electronic configurations.

End of topic questions

1. State which of the following is a typical property of a transition element:

A low density

B high melting point

C form white compounds

D react vigorously with cold water.

2. This question is about the transition elements.

a) Give two differences in the physical properties of the transition metals compared with the alkali metals.

b) Transition metals are used as catalysts. Define the term 'catalyst'.

c) Suggest why the alkali metals are more reactive than the transition metals.

3. Analyse the table of observations.

Compound tested	Colour of compound	Effect of adding sodium hydroxide solution to a solution of the compound
A	white	no change
B	blue	blue precipitate formed
C	white	white precipitate formed

a) State which of the compounds, A, B or C, contains a transition metal. Explain your answer.

b) State which transition metal you think it is.

c) **SUPPLEMENT** Compound B is a metal sulfate. Write a balanced equation for the reaction between a solution of this compound and sodium hydroxide solution.

4. Iron forms two hydroxides, iron(II) hydroxide and iron(III) hydroxide.

   a) Explain what the Roman numerals indicate about the iron in these compounds.

   b) Write the chemical formulas of these two hydroxides.

5. Explain why the noble gases are so unreactive.

6. The noble gases are monatomic. Describe what this means.

7. Although the noble gases are generally very unreactive, reactions do occur with very reactive elements such as fluorine. State which of the noble gases are more likely to react – helium at the top of the group or xenon near the bottom of the group?