Unit 6 The periodic table

How to group elements together?

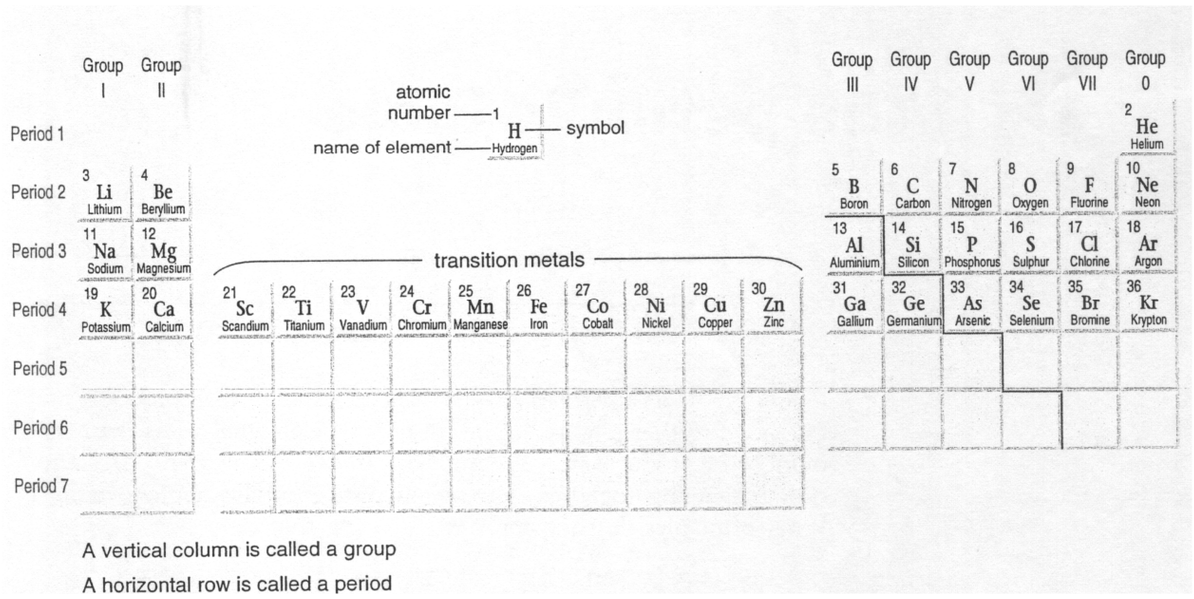
Elements of similar properties would be group together for convenience.

The periodic table

Chemists group elements with similar chemical properties together. This gives rise to the periodic table. In the periodic table, elements are arranged according to the following criteria:

1. in increasing order of atomic numbers and
2. according to the electronic arrangement

The diagram below shows a simplified periodic table with the first 36 elements listed.



Groups

The **vertical columns** in the periodic table are called **groups**. Groups are numbered from I to VII, followed by Group 0 (formerly called Group VIII). [Some groups are without group numbers.]

The table below shows the electronic arrangements of some elements in some groups.

Group I	Group II	Group VII	Group 0
			He (2)
Li (2,1)	Be (2,2)	F (2,7)	Ne (2,8)
Na (2,8,1)	Mg (2,8,2)	Cl (2,8,7)	Ar (2,8,8)
K (2,8,8,1)	Ca (2,8,8,2)	Br (2,8,18,7)	Kr (2,8,18,8)

What is the relationship between the group numbers and the electronic arrangements of the elements?

Group number = the number of outermost shell electrons in an atom of the element

The chemical properties of an element depend mainly on the number of outermost shell electrons in its atoms. Therefore, elements within the same group would have similar chemical properties and would react in a similar way. However, there would be a gradual change of reactivity of the elements as we move down the group.

Periods

The **horizontal rows** in the periodic table are called **periods**. Periods are also numbered from 1 to 7. The following table shows the electronic arrangements of the elements in periods 2 and 3.

Period 2	Li	Be	B	C	N	O	F	Ne
Electronic arrangement of atom	2,1	2,2	2,3	2,4	2,5	2,6	2,7	2,8
Period 3	Na	Mg	Al	Si	P	S	Cl	Ar
Electronic arrangement of atom	2,8,1	2,8,2	2,8,3	2,8,4	2,8,5	2,8,6	2,8,7	2,8,8

What is the relationship between the period numbers and the electronic arrangements of the elements?

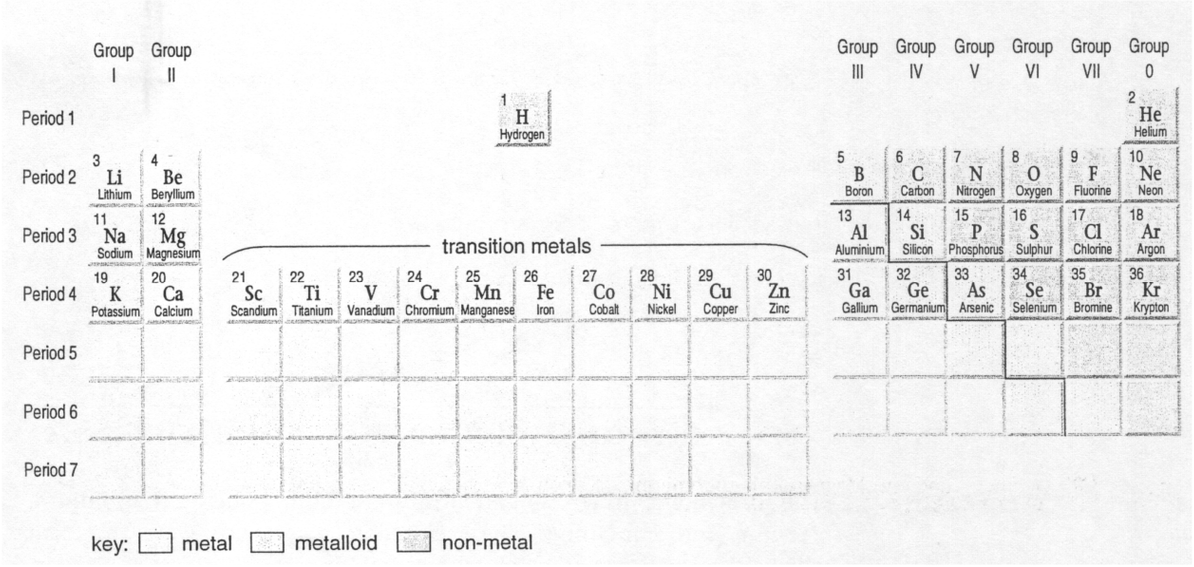
Period number of an element = number of <u>occupied</u> electron shells in an atom of the element

Patterns across the periodic table

The following diagram shows some properties of the elements in period 3. The elements change from metals through metalloids to non-metals across the period. The reactivity of the elements also changes across the period as well.

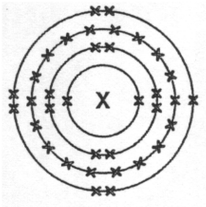
Element	Sodium	Magnesium	Aluminium	Silicon	Phosphorus	Sulphur	Chlorine	Argon
State at room temperature and pressure	solid						gas	
Melting point (°C)	98	650	660	1 410	44	113	–101	–189
Boiling point (°C)	890	1 120	2 450	2 680	280	445	–34	–186
Electrical conductivity	good			moderate	poor			
Type of element	← metals →			metalloid	← non-metals →			
Reactivity	reactive		moderately reactive	very unreactive	moderately reactive		very reactive	extremely unreactive

Elements in the periodic table can also be divided into different blocks. Metals are on the left hand side of the table. Non-metals are on the right hand side. Elements near the zig-zag line are metalloids. Elements between group II and group III are called **transition metals**. They are so called because they have properties which are intermediate between elements on the left hand side (group I and II) and elements on the right hand side (groups III to 0) in the periodic table. The properties of transition metals will be dealt with later. Refer to the diagram below:



Exercise

An atom of an element X has the following structure:



1. To which group and period does element X belong to?

   Group number: 7 Period number: 4
2. What is the atomic number of element X? 35
3. Refer to the complete periodic table, name element X. bromine
4. Name another element you would expect to have similar chemical properties. Chlorine / Fluorine / Iodine / Astatine

Group I elements – alkali metals

The six elements in **Group I** are **lithium**, **sodium**, **potassium**, rubidium, caesium and francium. These elements react with water to form alkalis. Hence they are called **alkali metals**.

The table below shows the electronic arrangements of the first 3 elements in Group I.

Element	Li	Na	K
Electronic arrangement	2,1	2,8,1	2,8,8,1

The table below shows some physical properties of Group I elements.

Element	State at room temperature and pressure	Melting point (°C)	Boiling point (°C)	Density (g cm^{-3})
Lithium	solid	180	1 330	0.53
Sodium		98	890	0.97
Potassium		64	760	0.86
Rubidium		39	686	1.53
Caesium		29	669	1.88
Francium		27	677	—

The melting points and boiling points of Group I elements decrease as we move down the group.

Similarities of Group I elements

1. They all have relatively low melting and boiling points when compared with other metals.
2. They are all soft and can be cut with a knife.
3. They all have low densities – lithium, sodium and potassium floats on water.
4. They are all reactive metals and must be stored in paraffin oil to prevent them from reacting with the air.
5. They all react vigorously with water to give hydrogen gas and an alkaline solution. For example, sodium reacts with water to give hydrogen and sodium hydroxide (the hydroxide makes the solution alkaline).

   sodium + water $\longrightarrow$ sodium hydroxide + hydrogen
6. They all react with non-metals to form compounds called salts. For example, sodium reacts with chlorine to form a salt called sodium chloride.

   sodium + chlorine $\longrightarrow$ sodium chloride

Differences in reactivity of Group I elements

Group I elements are reactive. The **reactivity increases down the group**. Refer to the table.

Element	Reaction with water
Lithium	Gives out hydrogen steadily but does not melt
Sodium	Melts to form a silvery ball and moves rapidly on the surface of water because of the formation of hydrogen gas
Potassium	Reacts more vigorously than sodium and catches fire immediately

Group II elements – alkaline earth metals

The six elements in **Group II** are **beryllium**, **magnesium**, **calcium**, strontium, barium and radium. These elements are found on earth and they can form alkalis. Hence they are called **alkaline earth metals**.

The table below shows the electronic arrangements of the first 3 elements in Group II.

Element	Be	Mg	Ca
Electronic arrangement	2,2	2,8,2	2,8,8,2

The table below shows some physical properties of Group II elements.

Element	State at room temperature and pressure	Melting point (°C)	Boiling point (°C)	Density (g cm^{-3})
Beryllium	solid	1 280	2 480	1.85
Magnesium		650	1 120	1.74
Calcium		838	1 440	1.55
Strontium		769	1 384	2.60
Barium		725	1 640	3.51
Radium		700	1 137	—

Similarities of Group II elements

1. They all have relatively low melting and boiling points when compared with other metals. except Group I metals)
2. They all have low densities.
3. They are all reactive metals and react readily with dilute hydrochloric acid to give hydrogen gas.
4. They all react with non-metals to form compounds called salts. For example, magnesium reacts with chlorine to form a salt called magnesium chloride.

magnesium + chlorine $\longrightarrow$ magnesium chloride

Differences in reactivity of Group II elements

Group II elements are less reactive than Group I elements. The **reactivity increases down the group**. Refer to the table below:

Element	Reaction with water
Beryllium	Does not react with water
magnesium	Shows little reaction with cold water but reacts readily with steam
Calcium	Reacts readily, giving a steady stream of gas bubbles

Group VII elements – halogens

Group VII of the periodic table consists of the non-metals of **fluorine**, **chlorine**, **bromine**, **iodine** and astatine. They are called **halogens** (means salt formers) because they react with metals to form salts.

The table below shows the electronic arrangements of the first 3 elements in Group VII.

Element	F	Cl	Br
Electronic arrangement	2,7	2,8,7	2,8,18,7

The table below shows some physical properties of Group VII elements.

Element	State at room temperature and pressure	Colour	Melting point (°C)	Boiling point (°C)
Fluorine	gas	pale yellow	–220	–190
Chlorine	gas	greenish yellow	–101	–34
Bromine	liquid	reddish brown	–7	58
Iodine	solid	black	113	184

The melting points and boiling points of Group VII elements increase as we move down the group.

Similarities of Group VII elements

1. They are all poisonous and smelly.
2. They are all non-metals.
3. They all react with metals to form compounds called salts.

Differences in reactivity of Group VII elements

The **reactivity of Group VII** elements **decreases down the group**. For example, group VII elements react with hydrogen to form compounds called hydrogen halides.

hydrogen + halogen $\longrightarrow$ hydrogen halide

The change in reactivity is shown in the table below.

Element	**Reaction with hydrogen**
Fluorine	Reacts explosively
Chlorine	Reacts explosively but less vigorous when compared with fluorine
Bromine	Reacts only on heating
Iodine	Does not react completely with hydrogen even on heating

Group 0 elements – noble gases

The six elements in **Group 0** are **helium**, **neon**, **argon**, krypton, xenon and radon. They are called **noble gases** because they rarely react with other substances.

The table below shows the electronic arrangements of the first 3 elements in Group 0.

Element	He	Ne	Ar
Electronic arrangement	2	2,8	2,8,8

The table below shows some physical properties of Group 0 elements.

Element	State at room temperature and pressure	Melting point (°C)	Boiling point (°C)	Density (g cm^{-3})
Helium	gas	–270	–269	0.000179
Neon		–249	–246	0.000900
Argon		–189	–186	0.00178
Krypton		–157	–152	0.00373
Xenon		–112	–107	0.00589
Radon		–71	–62	0.00973

The melting points, boiling points and densities of Group 0 elements increase as we move down the group. Helium and neon is lighter than air while the other noble gases are heavier than air.

Similarities of Group 0 elements

1. They are all colourless gases at room temperature and pressure.
2. They all have very low melting and boiling points.
3. They are all very unreactive.

Stability of Group 0 elements

Since the chemical properties of an element depend mainly on the number of electrons in the outermost shell of an atom of the element, the lack of reactivity of noble gases indicates that if an atom can change the outermost shell electronic arrangement to that of noble gases, it will become stable.

Except helium (a period 1 element), all noble gases have 8 electrons in the outermost shells of their atoms. The model of chemical stability is called the **octet rule (octet means having 8 electrons)**. It suggests that atoms become stable by having eight electrons in their outermost shell (except period 1 elements). The octet rule plays an important part in chemical bond formation in joining atoms together. A more complete discussion of this rule will be done in the next two units.

Uses of noble gases

The following table shows some uses of some noble gases.

Noble gas	Use(s)	Reason(s)
Helium	In balloons and airships	Light and unreactive
Neon	In advertising signs	Glows red when an electric current is passed through it
Argon	Filling electric bulbs	Does not react with metal filament in the light bulb

Predicting the chemical properties of unfamiliar elements

We can estimate some properties of an element by averaging the respective properties of elements located just above and just below it in the periodic table. This is how Mendeleev predicted the properties of several elements unknown in his time.

We can use the periodic table to predict chemical properties of unfamiliar elements as well. For example, sodium and potassium are Group I elements. Both of them react with water vigorously. Rubidium belongs to the same group. Therefore, we expect it to react with water vigorously as well.

Example

Caesium is a Group I element below potassium in the periodic table.

a) How many outermost shell electron(s) is / are there in a caesium atom? Explain your answer.

b) Predict the state of caesium at room temperature and pressure.

c) Predict the observation when caesium reacts with cold water.

d) Which of the metals, potassium or caesium, is more reactive? Explain your answer.

e) Suggest ONE method to store caesium safely in the laboratory.

f) Suggest ONE safety precaution for an experiment involving caesium.

Solution

a) There is one outermost shell electron in a caesium atom. This is because caesium belongs to Group I of the periodic table.

b) Caesium is a solid at room temperature and pressure.

c) Caesium would react explosively with cold water.

d) Caesium is more reactive as the reactivity of Group I elements increases down the group.

e) It should be stored in paraffin oil.

f) Use a safety screen.

There are more uses of the periodic table. These uses are related to the properties of the elements in chemical bonds formation. They will be discussed in the next two units.

Exercise

1 Mendeléev knew that silicon tetrachloride ($SiCl_4$) existed. Using his periodic table, he correctly predicted the existence of *ekasilicon*, an element just below silicon in the periodic table.

Predict the chemical formula for the compound formed between ekasilicon and chlorine.

2 A, B and C are three different elements belonging to the same group. The electronic arrangements of their atoms are as follows:

Element	Electronic arrangement of atom
A	2,8,2
B	2,8,8,2
C	*p*,*q*,18,8,*r*

a) Name the group of elements to which they belong.

b) What are the numerical values for *p*, *q* and *r* in the electronic arrangement of an atom of C?

c) Predict the state of element C at room temperature and pressure.

d) Point out which of the elements would have the highest boiling point.

e) Predict which of the elements would react most vigorously with water. Explain your answer.