The Structure of the Atom

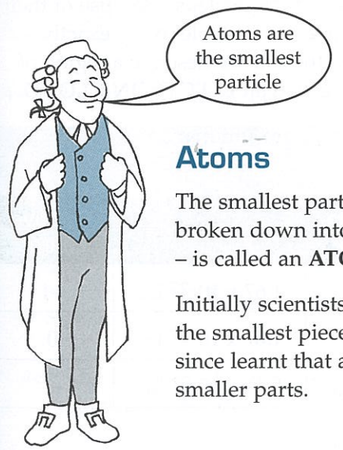
Elements

Some substances cannot be made into simpler substances. These simplest substances are called **ELEMENTS**. Chemistry is the study of these simplest substances and of how they combine/react with each other to form more complex substances (**COMPOUNDS**). One of the first tasks of a chemistry student is to learn the names and symbols of commonly used elements. You should learn the names and symbols for the following elements:

Element	Symbol	Element	Symbol	Element	Symbol
Aluminium	Al	Helium	He	Nitrogen	N
Barium	Ba	Hydrogen	H	Oxygen	O
Bromine	Br	Iodine	I	Phosphorus	P
Calcium	Ca	Iron	Fe	Potassium	K
Carbon	C	Lead	Pb	Silicon	Si
Chlorine	Cl	Lithium	Li	Silver	Ag
Chromium	Cr	Magnesium	Mg	Sodium	Na
Cobalt	Co	Manganese	Mn	Sulfur	S
Copper	Cu	Mercury	Hg	Tin	Sn
Fluorine	F	Neon	Ne	Uranium	U
Gold	Au	Nickel	Ni	Zinc	Zn

Writing the symbols for the elements

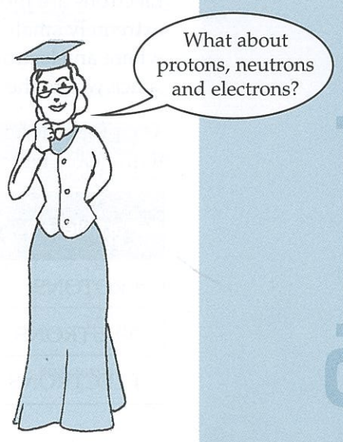
1. The symbol is always printed e.g. Al not *Al*.
2. If an element's symbol has more than one letter, the first letter must be in **CAPITALS** and the others in lower case.



Atoms

The smallest part that an element can be broken down into – without changing it – is called an **ATOM**.

Initially scientists thought that atoms were the smallest pieces of matter but they have since learnt that atoms could be split into smaller parts.



Elements: *are the simplest substances. They cannot be broken down to simpler substance by checmical means.*

Compounds: *are composed of two or more elements chemically joined in a fixed ratio.*

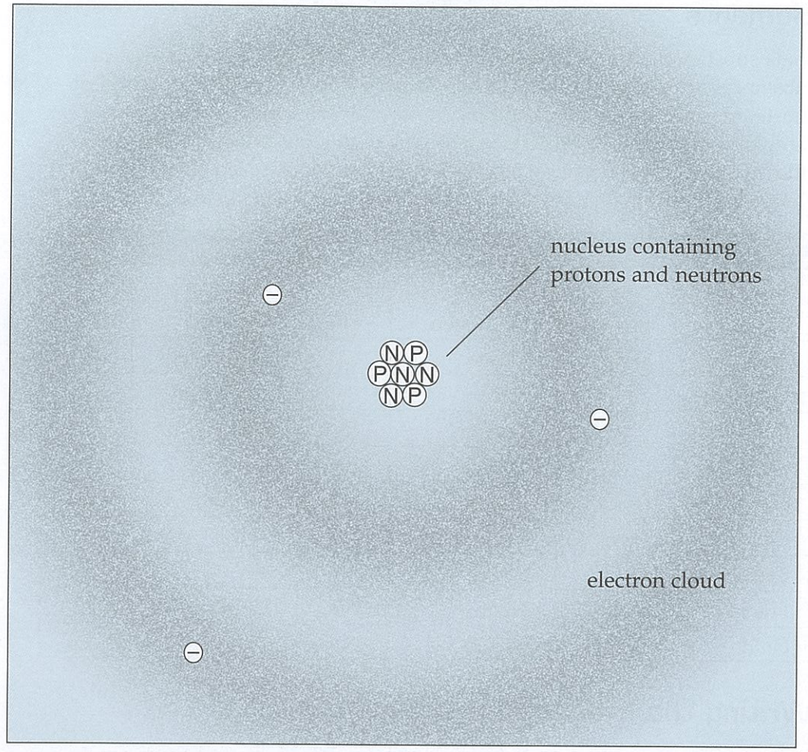
Atoms: *are the smallest parts of an element that can take part in a chemical reaction.*

Structure of the atom

Atoms consist of 3 basic particles – **PROTONS, NEUTRONS** and **ELECTRONS**.

Atoms are mostly empty space through which the light and negatively charged electrons move.

The heavy nucleus typically makes up more than 99.9% of the atoms mass.



Protons and neutrons are extremely tightly packed in the centre or **NUCLEUS** of an atom. They are so tightly held they can only vibrate about fixed positions.

Electrons are moving in the region of space around the nucleus. Because of their extremely small size and wave like properties it is not possible to say exactly where an electron is and how fast it is moving. Instead we describe a region of space where the electron is likely to be – this is called an **ELECTRON CLOUD**.

The properties of the particles that make up atoms are summarised in the table below.

Particle	Position in the atom	Relative mass	Mass	Relative charge
PROTONS	nucleus	1	1.67×10^{-27} kg	+1
NEUTRONS	nucleus	1	1.67×10^{-27} kg	0
ELECTRONS	electron cloud	$^1/_{1836}$	9.11×10^{-31} kg	-1

The structure of a particular atom is often summarised using:

mass number → A

E ← symbol of the element

atomic number → Z

Example 1.1 : Determine the number and type of particles in the nucleus of $^{23}_{11}Na$.

Number of protons = Z = 11

Number of neutrons = A - Z = 23 - 11 = 12

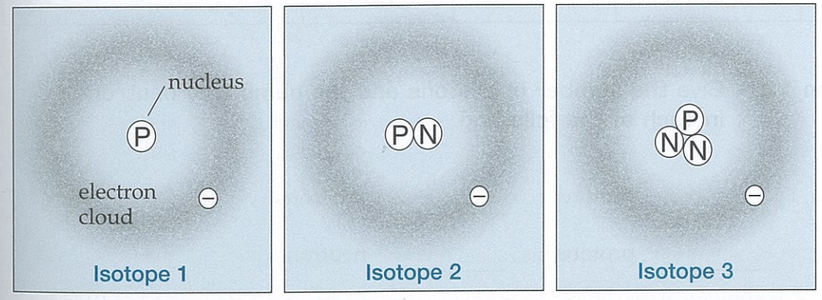
A = mass number = number of protons and neutrons in the nucleus.

Z = atomic number = number of protons in the nucleus.

Isotopes

These are atoms of the same element that contain different numbers of neutrons in the nucleus.

i.e. 3 different atoms of hydrogen.



The following table summarises the nuclear structure of hydrogen's three isotopes.

	No. of protons	No. of neutrons	Atomic number	Mass number	Symbol
Isotope 1	1	0	1	1	^1_1H
Isotope 2	1	1	1	2	^2_1H
Isotope 3	1	2	1	3	^3_1H

Note: The 3 isotopes have the same chemical properties as they are the same element. They differ in mass only.

The identity of each element is determined by its Atomic Number. Each element has its own, unique atomic number.

CHECKPOINT!

Question 1.1 - Complete the following table.

	Element	Z (Atomic number)	A (Mass number)	No. of protons	No. of neutrons
$^{12}_{6}C$	carbon	6	12	6	6
$^{35}_{17}Cl$					
$^{40}_{20}Ca$					
	chromium	24	52		
Cs	caesium			55	78
	copper		64	29	
Cm	curium	96			151
Ce	cerium		140		82
Cd	cadmium	48	112		
Cf	californium	98	251		

Question 1.2 - Give the number of protons and the number of neutrons in each of the following.

a) $^{66}_{30}Zn$: _____ protons , _____ neutrons

b) $^{101}_{44}Ru$: _____ protons , _____ neutrons

c) $^{207}_{82}Pb$: _____ protons , _____ neutrons

d) $^{226}_{88}Ra$: _____ protons , _____ neutrons

e) $^{39}_{19}K$: _____ protons , _____ neutrons

f) $^{55}_{25}Mn$: _____ protons , _____ neutrons

g) $^{35}_{17}Cl$: _____ protons , _____ neutrons

h) $^{238}_{92}U$: _____ protons , _____ neutrons

Review Questions

Set 1 – The structure of the atom

1. Name the following elements.

a) He **b)** Mg **c)** Ba **d)** P **e)** Si

f) Co **g)** Li **h)** N **i)** Fe **j)** Hg

2. Give the symbol for the following elements.

a) Lead **b)** Carbon **c)** Chlorine **d)** Copper **e)** Potassium

f) Gold **g)** Sodium **h)** Tin **i)** Iodine **j)** Chromium

3. State if each of the following statements are true or false. If they are false, alter the statement so that it becomes true.

a) Protons and neutrons have approximately the same mass.

b) In a neutral atom the number of protons equals the number of neutrons.

c) The mass of an electron is one hundredth the mass of a proton.

d) The nucleus consists of protons and neutrons.

e) The atom is mainly empty space.

f) Most of the mass of an atom exists in the electron cloud.

g) An element is the simplest substance. It cannot be broken down to simpler substances by chemical reactions.

h) A compound contains 2 or more elements mixed together.

4. Give the number of protons, neutrons and electrons in each of the following neutral atoms.

a) $^{4}_{2}He$ **b)** $^{64}_{29}Cu$ **c)** $^{40}_{18}Ar$ **d)** $^{127}_{53}I$

e) $^{197}_{79}Au$ **f)** $^{236}_{92}U$

5. Use Co and CO to explain the differences between elements and compounds.

For the experts

6. Deuterium and tritium are isotopes of hydrogen. How are these isotopes similar? How they are different?

2. Electrons

Number of electrons

Normally an atom will contain the same number of electrons and protons. This makes the atom neutral in charge.

The chemical properties of an atom are controlled by its electrons. The nucleus (protons and neutrons) does not affect and is not changed in chemical reactions.

CHECKPOINT!

Question 2.1 - How many electrons are there in a neutral atom of each of the following?

a) $^{3}_{1}H$ _____ b) $^{4}_{2}He$ _____ c) $^{127}_{53}I$ _____

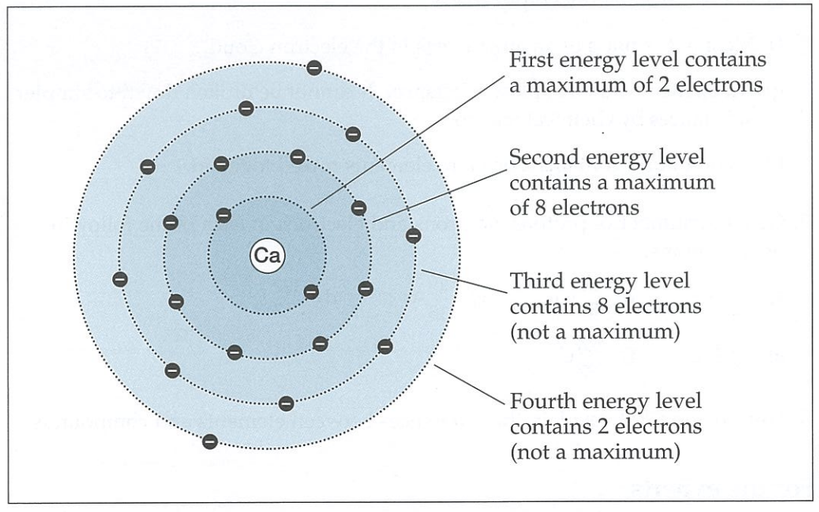
Where are they?

Although they cannot say exactly where an electron is and how fast it is travelling, scientists can determine the arrangement of electrons around the nucleus.

A simple model that shows how electrons exist around the atom is shown below for an atom of calcium. The electrons occupy **ENERGY LEVELS**.

Electrons can only be in an energy level if they have exactly the correct amount of energy.

Energy levels can contain sub-levels called ORBITALS. Any one orbital can contain a maximum of two electrons.



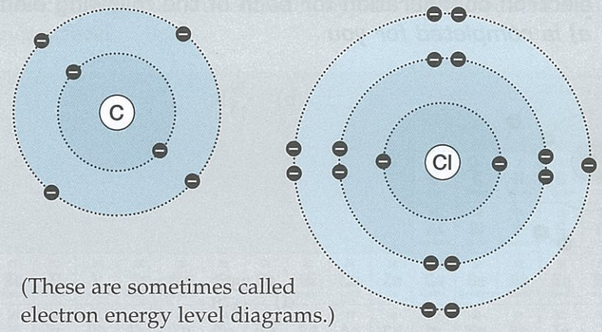
An abbreviated way of writing this electron structure for calcium would be:

Ca 2 , 8 , 8 , 2

This is called its **ELECTRON CONFIGURATION.**

Example 2.1 : Show the arrangement of electrons around:

a) carbon ($^{12}_{6}C$) **b)** chlorine ($^{35}_{17}Cl$)



(These are sometimes called electron energy level diagrams.)

Example 2.2 : Write the electron configurations for the two atoms from Example 2.1.

a) carbon: 2 , 4 **b)** chlorine: 2 , 8 , 7

Energy level diagrams are sometimes drawn with electrons in pairs, showing they occupy the same orbital. This is only done if an energy level contains more than 4 electrons.

CHECKPOINT!

Question 2.2 - Write the electron configuration for each of the following elements:

a) $^{4}_{2}He$ _____ b) $^{10}_{4}Be$ _____

c) $^{40}_{20}Ca$ _____ d) $^{14}_{7}N$ _____

e) $^{27}_{13}Al$ _____ f) $^{20}_{10}Ne$ _____

g) $^{32}_{16}S$ _____ h) $^{23}_{11}Na$ _____

i) $^{31}_{15}P$ _____ j) $^{16}_{8}O$ _____

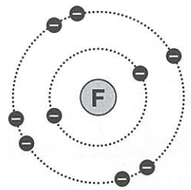
k) $^{9}_{4}Be$ _____ l) $^{28}_{14}Si$ _____

m) $^{40}_{18}Ar$ _____ n) $^{39}_{19}K$ _____

CHECKPOINT!

Question 2.3 - Draw the electron energy level diagrams and state the electron configuration for each of the following elements.
a) is completed for you

a) $^{19}_{9}F$



2, 7

b) $^{39}_{19}K$

c) $^{1}_{1}H$

d) $^{28}_{14}Si$

e) $^{24}_{12}Mg$

f) $^{40}_{18}Ar$

Example 2.3 : How many electrons in the outermost energy level of calcium?

Electron configuration of Ca = 2 , 8 , 8 , 2 Answer = 2

CHECKPOINT!

Question 2.4 - How many electrons in the outermost energy level of:

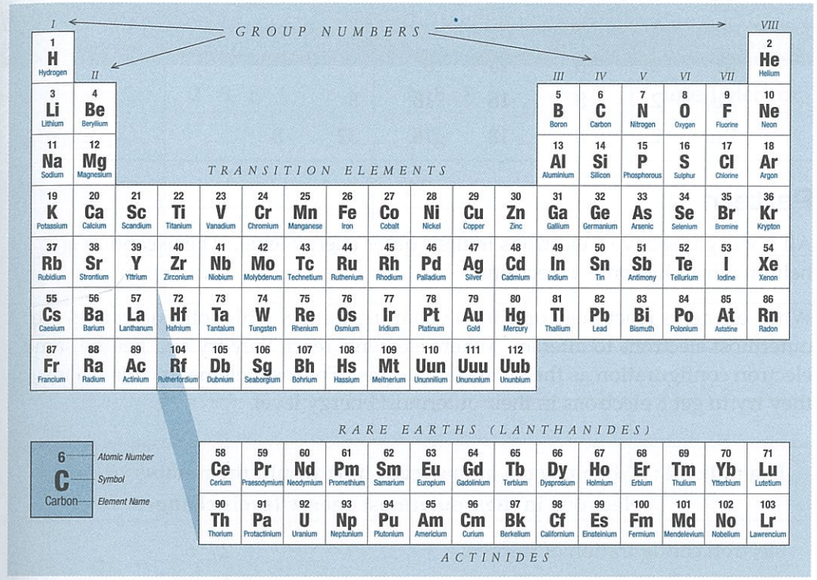
a) $^{16}_{8}O$ _____ b) $^{32}_{16}S$ _____

c) $^{9}_{4}Be$ _____ d) $^{7}_{3}Li$ _____

e) $^{40}_{18}Ar$ _____

Electron configurations and the periodic table

The position of an element in the Periodic Table can tell us the number of electrons it has in its outermost energy level. This is important because an element's chemical properties are controlled by how many electrons are in its outermost energy level.



Group numbers *(I to VIII) give the number of electrons in the outermost energy level for all elements in that group.*

The column number (from left to right) is often referred to as the Group Number. This Group Number tells us the number of electrons in the outermost energy level of each element in that column (group).

Because they have the same number of electrons in their outermost energy level, elements in the same group have similar chemical properties.

CHECKPOINT!

Question 2.5 - How many electrons in the outermost energy level of:

a) nitrogen _____ b) aluminium _____

c) helium _____ d) potassium _____

e) phosphorus _____ f) Li _____

g) B _____ h) Kr _____

i) As _____ j) Rb _____

Noble Gases 18

Periodic Table of the Elements

Alkali Metals 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

Noble Gases: Chemistry's role models

The Noble Gases are very unreactive, they are inert gases.
The reason why noble gases are inert is found in their electron configuration.

Noble Gas configuration - *atoms have a tendency to get the same configuration as the nearest noble gas.*

Nearest means noble gas with the most similar atomic number

He	2					
Ne	2	8				
Ar	2	8	8			
Kr	2	8	18	8		
Xe	2	8	18	18	8	
Rn	2	8	18	18	32	8

Pattern

All noble gases have 8 electrons in their outer energy level. The exception is helium which has only 2 electrons.

When elements react the atoms involved must collide. This collision causes the outermost electrons to interact. Where elements react, they try and get the same electron configuration as the nearest noble gas. For most elements, this means they try to get 8 electrons in their outermost energy level.

Example 2.4 : When oxygen atoms react, how would the number of electrons in their outermost energy levels change?

electron configuration of oxygen : 2 6

electron configuration of nearest noble gas (neon) : 2 8

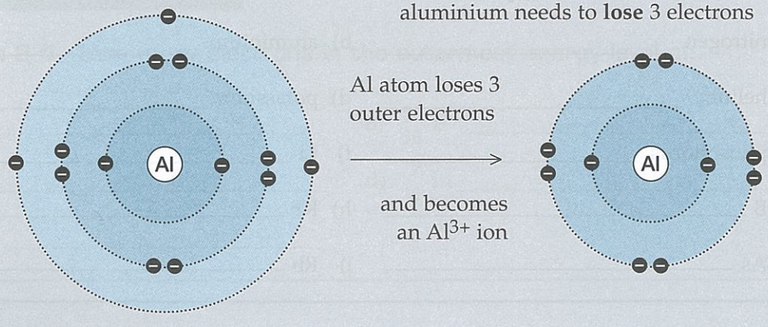
oxygen's electron change : it would need to **gain** 2 electrons from another element

Example 2.5: How could an atom of Al get a full outer energy level?

electron configuration of Al : 2 8 3

nearest noble gas : 2 8 (NOT 2 8 8)

aluminium needs to **lose** 3 electrons



CHECKPOINT!

Question 2.6 - Complete the following table to decide how each element could get the same configuration as the nearest noble gas. Hint: refer to the periodic table to check Atomic Numbers.

Element	Electron configuration	Configuration of nearest noble gas	Change to element's configuration
Potassium	2 8 8 1	2 8 8	lose 1 electron
Magnesium		2 8	
Boron		2	
Fluorine			
Phosphorous			
Chlorine			
Calcium			
Sulfur			
Carbon		2 8	

Electron dot diagrams

A simple way to show the outermost electron energy level is to draw an '**electron dot diagram**'.

Rules for electron dot diagrams

1. Maximum number of 8 electrons in the outermost energy level.
2. Electrons are represented by a dot (or a cross).
3. Electrons are placed in 4 regions (orbitals) around the symbol for the element. A maximum of 2 electrons in each orbital.

Example 2.6: Draw the electron dot diagrams for Ar , Al , Cl , C and P.

The electron dot diagram for an element is easy to work out – the number of electrons to draw equals the group number from the periodic table. These diagrams only show the electrons in the outermost level.

Electron dot diagram for Nitrogen

Nitrogen is from group 5 of the periodic table, and hence has 5 electrons in its outer energy level.

Two electrons occupy one orbital (maximum allowed) while the other 3 electrons are in partially filled orbitals.

CHECKPOINT!

Question 2.7 - Draw the electron dot diagrams for each of the following elements

a) Li

b) Ca

c) B

d) Kr

e) Cs

f) Mg

g) Rb

h) Si

i) F

j) Ra

k) I

l) Rn

Review Questions

Set 2 – Electrons

1. Draw electron energy level diagrams for each of the following atoms.

a) $^{9}_{4}Be$ **b)** $^{12}_{6}C$ **c)** $^{32}_{16}S$ **d)** $^{3}_{2}He$

e) $^{1}_{1}H$ **f)** $^{20}_{10}Ne$

2. Write the electron configuration for each of the following atoms.

a) $^{7}_{3}Li$ **b)** $^{10}_{5}B$ **c)** $^{23}_{11}Na$ **d)** $^{19}_{9}F$

e) $^{36}_{17}Cl$ **f)** $^{40}_{20}Ca$

3. Give the number of electrons in the outermost energy level of each of the following atoms (periodic table will help).

a) $^{40}_{19}K$ **b)** $^{28}_{14}Si$ **c)** $^{14}_{7}N$ **d)** $^{84}_{36}Kr$

e) $^{133}_{55}Cs$ **f)** $^{131}_{54}Xe$

4. Say what change would happen for each atom below to get the same electron configuration as the nearest noble gas.

a) $^{6}_{3}Li$ **b)** $^{19}_{9}F$ **c)** $^{28}_{14}Si$ **d)** $^{9}_{4}Be$

e) $^{16}_{8}O$ **f)** $^{127}_{53}I$

5. Draw the electron dot diagram for each of the following elements.

a) Potassium **b)** Nitrogen

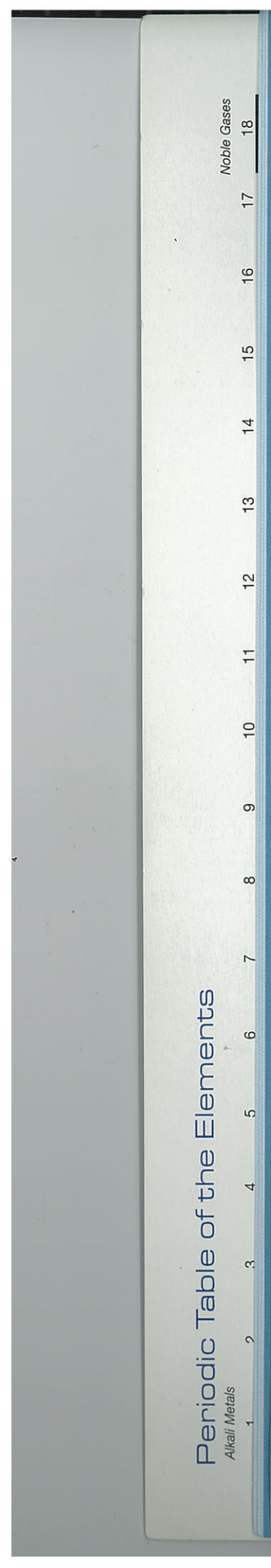
c) Strontium **d)** Aluminium

e) Helium **f)** Hydrogen

g) Oxygen **h)** Bromine

For the experts

6. Water is a very common and important compound. How do hydrogen and oxygen atoms combine to give all atoms involved the same electron configuration as their nearest noble gas?



3. Bonding

A bond is a force that holds atoms together.

The three main types of bonds are IONIC, COVALENT and METALLIC.

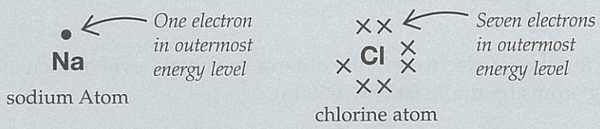
Elements react with each other to become more stable and to have less energy. Reactions involve the interaction between the outermost electrons of the elements involved. When the outermost electrons of atoms interact and cause atoms to join together a new **CHEMICAL BOND** is formed.

Ionic bonds

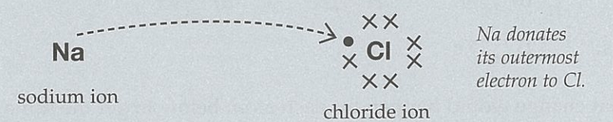
These form when a metal with a nearly empty outer shell (energy level) reacts with a non-metal with a nearly full outer shell.

Example 3.1: Sodium reacts with chlorine to form sodium chloride.

I



II



Both atoms now have full outer shells. But because they have gained or lost electrons they are called ions not atoms.

III Na has lost an electron – it has a +1 charge.
Cl has gained an electron – it has a –1 charge.

IV An ionic bond forms because the oppositely charged atoms (now called ions) attract each other.

i.e. Na^+ ⇢ ⇠ Cl^-

Ions

Ions form when atoms gain or lose electrons.

Positive Ions – form when atoms lose electrons.
The number of electrons the atom loses gives the amount of positive charge.

i.e. Al^{3+} : aluminium ion. It forms when an aluminium atom loses 3 electrons.
Au^+ : gold ion. It forms when a gold atom loses one electron.

Negative Ions – form when atoms gain electrons.

i.e. F^- : fluoride ion. It forms when a fluorine atom gains one electron.
O^{2-} : oxide ion. It forms when an oxygen atom gains two electrons.

Important points about ions

i) Metal ions keep the name of the metal atom.

ii) When non-metal atoms form negative ions, the name changes to end in "ide".

iii) Ions never occur alone in a substance. In any substance containing ions, the total positive charge always equals the total negative charge so that the substance is neutral.

iv) Ions have a charge because the number of electrons no longer equals the number of protons.

v) The charge on an ion is called its valency.

Valency table

The valency of some common ions are shown below. You should memorise these.

Positive ions		Negative ions	
Name	**Symbol**	**Name**	**Symbol**
Hydrogen	H^+	Fluoride	F^-
Sodium	Na^+	Chloride	Cl^-
Potassium	K^+	Bromide	Br^-
Silver	Ag^+	Iodide	I^-
Lithium	Li^+	Hydrogencarbonate	HCO_3^-
Copper (I)	Cu^+	Hydrogensulfate	HSO_4^-
Ammonium	NH_4^+	Hydroxide	OH^-
Magnesium	Mg^{2+}	Ethanoate	CH_3COO^-
Calcium	Ca^{2+}	Nitrate	NO_3^-
Barium	Ba^{2+}	Oxide	O^{2-}
Iron (II)	Fe^{2+}	Sulfide	S^{2-}
Cobalt	Co^{2+}	Sulfate	SO_4^{2-}
Zinc	Zn^{2+}	Sulfite	SO_3^{2-}
Lead (II)	Pb^{2+}	Carbonate	CO_3^{2-}
Tin (II)	Sn^{2+}	Nitride	N^{3-}
Copper (II)	Cu^{2+}	Phosphide	P^{3-}
Aluminium	Al^{3+}	Phosphate	PO_4^{3-}
Chromium (III)	Cr^{3+}		
Iron (III)	Fe^{3+}		
Tin (IV)	Sn^{4+}		
Lead (IV)	Pb^{4+}		

Multiple valencies

Some metals have more than one valency and this is indicated by roman numerals. eg. Iron(II), Iron(III)

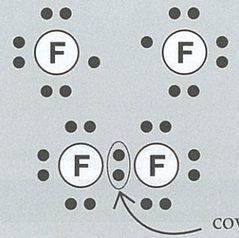
For monovalent elements this is not necessary and hence not shown.

Covalent bonds

These form when two non-metal atoms with nearly full outer shells **share** electrons so that both atoms end up with full outer shells.

Electron dot diagrams are a very good way to show how non-metal atoms form covalent bonds.

Example 3.2: Use electron dot diagrams to show how two fluorine atoms get full outer shells by forming a covalent bond.



Both fluorine atoms have seven electrons in their outermost shell. To get 8 they share a pair of electrons.

Example 2: Draw the electron dot diagrams to show the covalent bonding in:

a) Cl_2 **b)** HCl **c)** OF_2

Metallic bonds

Metal atoms have nearly empty outer shells. To get full outer shells, metal atoms lose these electrons. The metal atoms become positive ions. The valence electrons are distributed throughout the lattice of positive metal ions. They are not held to any one ion but move randomly throughout the lattice. They are often described as forming a **sea of mobile electrons.**

Summary - Bonding types

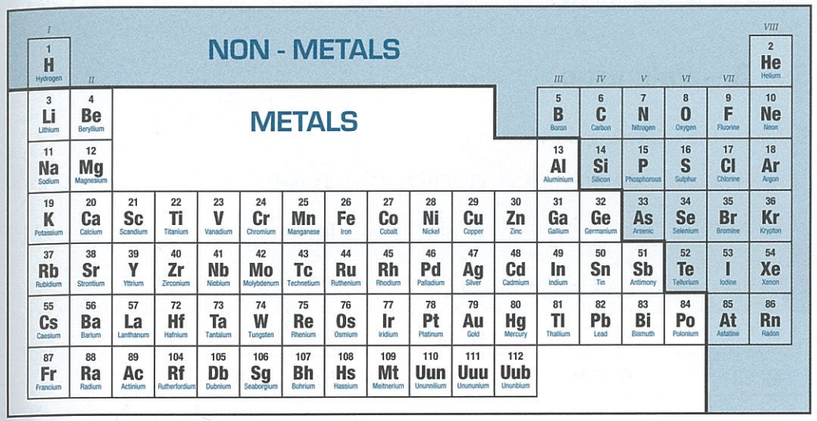
General guide for deciding how to identify the bonding type in an element or compound is as follows:

Substance composed of metals only – **METALLIC BONDING**

Substance composed of metals and non-metals – **IONIC BONDING**

Substance composed of non-metals only – **COVALENT BONDING**

The periodic table is often used to classify elements as metals or non-metals.



CHECKPOINT!

Question 3.1 - Use a periodic table to classify the following elements as metals or non-metals.

a) Na _____ b) Xe _____

c) Fe _____ d) F _____

e) O _____ f) Mg _____

g) H _____ h) Ca _____

Question 3.2 - For each of the following compounds name the type of bonding involved.

a) NaCl _____ b) SO_2 _____

c) Pb _____ d) $PbCl_2$ _____

e) C_3H_8 _____ f) HNO_3 _____

g) $ZnBr_2$ _____ h) N_2O_4 _____

3. Review Questions

Set 3 – Valencies

1. Name the following positive ions.

a) H^+ **b)** Mg^{2+} **c)** Cu^{2+} **d)** Fe^{2+}

e) Al^{3+} **f)** Fe^{3+} **g)** Ba^{2+} **h)** Zn^{2+}

2. Name the following negative ions.

a) O^{2-} **b)** F^- **c)** N^{3-} **d)** S^{2-}

e) Cl^- **f)** C^{4-} **g)** P^{3-} **h)** I^-

3. Write the formula showing the valency of the following ions.

a) silver **b)** copper (I) **c)** fluoride **d)** ammonium

e) sulfate **f)** zinc **g)** barium **h)** phosphate

i) nitrate **j)** nitride **k)** oxide **l)** iron (III)

4. Give the valencies of the positive and negative ions in each of the following compounds.

a) $CuCl_2$ **b)** ZnO **c)** Fe_2S_3 **d)** FeS

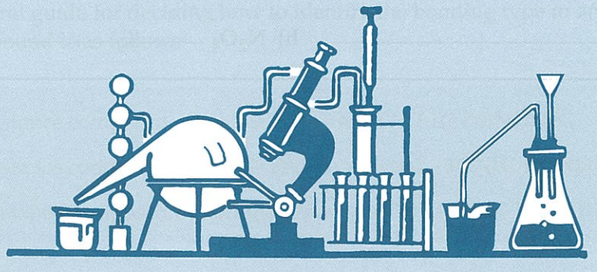
e) Mg_3N_2 **f)** $AlBr_3$

5. Give the valencies of the positive and negative ions in each of the following compounds.

a) $AlPO_4$ **b)** $Zn(NO_3)_2$ **c)** $Fe_2(SO_4)_3$

For the experts

6. Dichromate (Cr_2O_7) is an ion containing oxygen and chromium. If potassium dichromate has the formula $K_2Cr_2O_7$, what is the valency of the dichromate ion?



Set 4 – Bonding

1. Classify the following elements as metals or non-metals.

a) Zn **b)** Se **c)** I **d)** W

e) N **f)** K **g)** Kr **h)** Ti

2. Complete the following table to determine the type of bonding between the atoms (or ions).

Formula	Element type (metals or non-metals)	Bonding type
O_2	non-metals only	covalent
NaCl	metal with non-metal	ionic
Fe		
MgO		
Al_2S_3		
NH_3		
OCl_2		
BaI_2		

3. State the type of bonding that would exist in the following substances.

a) CO_2 **b)** Al **c)** K_2S **d)** Rb_3N

e) HCl **f)** CH_4 **g)** $FeBr_3$ **h)** P_2O_5

4. State the number of electrons that the element has gained or lost in forming the following ions.

a) Fe^{3+} **b)** S^{2-} **c)** F^- **d)** Co^{2+} **e)** Pb^{+4}

f) O^{2-} **g)** Cr^{3+} **h)** N^{3-} **i)** Li^+ **j)** P^{3-}

5. Draw the electron dot diagrams to show how the following non-metal atoms combine to form covalent bonds.

a) PCl_3 **b)** I_2 **c)** I_2CH_2 **d)** CF_4

For the experts

6. Draw the electron dot diagrams for the following.

a) O_2 **b)** C_2H_2 **c)** CO_2 **d)** N_2