BASIC IDEAS IN CHEMISTRY

by Michael Clark

Success in studying Chemistry depends upon the familiarity of students with a few basic ideas, conventions, and methods upon which later studies are built.

This small book presents these basic ideas, conventions and methods. When a student has achieved mastery of them, further studies can be pursued with greater confidence. Without mastery of them, students are likely to find higher levels of study in Chemistry difficult.

Three basic areas are developed:

1. use of chemical symbols and formulae, (with a simple introduction to bonding)
2. writing chemical equations,
3. calculations involving moles (solids, gases, and solutions).

There is no reference to laboratory activities in this book. This is not to suggest, however, that laboratory experience with chemical substances and their reactions is not a vital part of learning Chemistry.

While theoretical rigour is a desirable objective in Chemistry courses, it is not always appropriate for beginning courses. In some of the pages that follow, theoretical rigour has been sacrificed to the need for simplicity. A more rigorous treatment of some of these topics can be developed after a student has mastered the essential basics.

BASIC IDEAS IN CHEMISTRY is not intended to stand alone as a text in its own right, but rather to provide a supplement to other text-books, to which students must return for more detailed and theoretical development of the topics covered in this book.

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CHEMICAL SYMBOLS AND FORMULAE

ELEMENTS AND SYMBOLS

All chemical substances are made up of atoms. Substances made of only one kind of atom are called *elements*. There are about ninety different chemical elements that occur naturally on Earth. Of these, some are very rare. About twenty-five to thirty elements are regarded as "common" or "well-known".

Each chemical element is known by its *SYMBOL*, comprised of one or two letters. The symbols of common elements should be memorised thoroughly, and less common ones might also be learnt as they come to attention.

The following list of symbols and the elements they represent should be memorised. They are listed by *atomic number*, (which is the number of protons present in the nucleus of an atom of the element: see page 11):

1. H = hydrogen	16. S = sulfur	30. Zn = zinc
6. C = carbon	17. Cl = chlorine	35. Br = bromine
7. N = nitrogen	19. K = potassium	47. Ag = silver
8. O = oxygen	20. Ca = calcium	50. Sn = tin
11. Na = sodium	22. Ti = titanium	53. I = iodine
12. Mg = magnesium	24. Cr = chromium	56. Ba = barium
13. Al = aluminium	25. Mn = manganese	79. Au = gold
14. Si = silicon	26. Fe = iron	80. Hg = mercury
15. P = phosphorus	29. Cu = copper	82. Pb = lead

A chemical symbol represents the name of the element. It is used also to represent one atom of the element.

COMPOUNDS AND FORMULAE

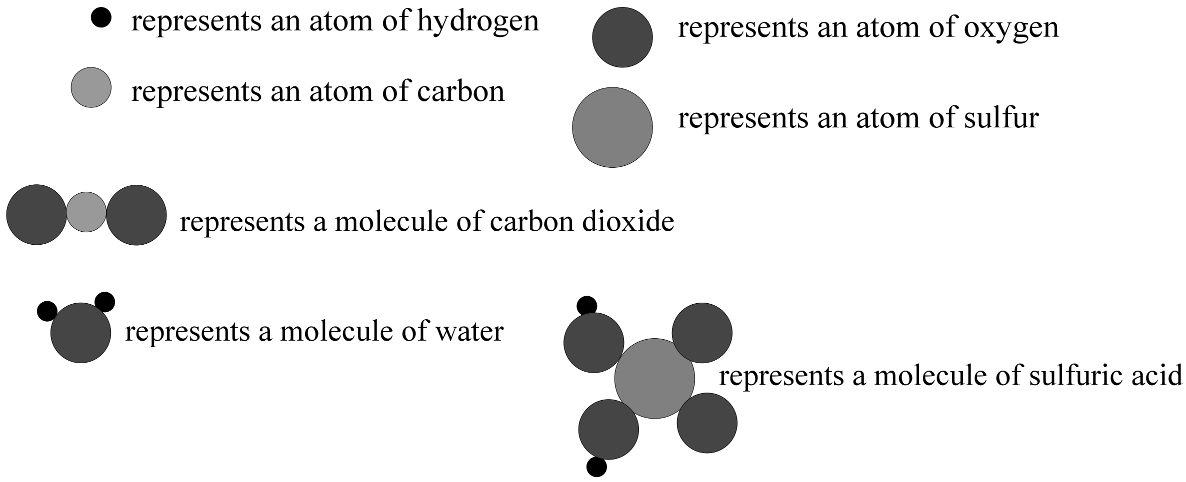
Atoms of elements can join together. Sometimes two identical atoms join together, but more often different kinds of atoms form *compounds*. A compound is made of at least two different elements.

MOLECULES

If two or more atoms join together, they form a *molecule*.

A *formula* shows what kinds of atoms, and how many of each, join together when a molecule is formed. A small (subscript) number after a symbol shows the number of atoms of that element that are present in one molecule of the compound. If there is no number, it means that there is one atom of that element.

For example:
CO_2 means that one atom of carbon is joined to two atoms of oxygen.
H_2O means that two atoms of hydrogen are joined to one atom of oxygen.
H_2SO_4 means that two atoms of hydrogen, one atom of sulfur, and four atoms of oxygen are joined in one molecule.



IONIC COMPOUNDS

In some compounds, atoms or groups of atoms have an electrical charge, and are then called *ions*. A group of atoms with an electrical charge is called a *compound ion*. Ions with opposite electric charges attract each other, but do not usually become permanently joined together.

Name of compound	Names of ions in compound	Formulae of ions	Formula of compound	Ratio of positive to negative ions.
Sodium iodide	sodium iodide	Na^+ I^-	NaI	1:1
Silver oxide	silver oxide	Ag^+ O^{2-}	Ag_2O	2:1
Zinc sulfate	zinc sulfate	Zn^{2+} SO_4^{2-}	$ZnSO_4$	1:1
Aluminium phosphate	aluminium phosphate	Al^{3+} PO_4^{3-}	$AlPO_4$	1:1
Lead nitrate	lead nitrate	Pb^{2+} NO_3^-	$Pb(NO_3)_2$	1:2
Iron(III) chloride	iron(III) chloride	Fe^{3+} Cl^-	$FeCl_3$	1:3

The formula of an ionic compound shows how many of each kind of ion are attracted to each other in the compound.

WRITING NAMES AND FORMULAE OF IONIC COMPOUNDS

The first requirement for students needing to master the writing of formulae is to memorise - and memorise thoroughly - the formulae of common ions.

While writing of formulae is being learnt and practised, a list of the common ions and their formulae should be kept close at hand for ready reference. On the following page is a list of ions that students may encounter. Also provided are three sheets of examples of ionic compounds for practising writing formulae.

Basic rules for writing names and formulae are provided here. Explanations of the rules are presented starting on page 11.

1. Clarity and accuracy are of greatest importance. Upper case (capital) letters must be clearly written as capital letters, lower case (small) letters must be written clearly as small letters, subscript numbers (small numbers after a symbol) must be written accurately and clearly.

2. The name of an ionic compound has two parts: the first part is the positive ion, usually a metal, but may also be ammonium, a positive compound ion containing nitrogen and hydrogen. The second part of the name is the negative ion, either the name of a non-metal with the end of its name changed to *-ide*, or the name of a negative compound ion.

EXAMPLES:

Name of compound	**Positive ion**	**Negative ion**
Calcium iodide	calcium, Ca^{2+}	iodide, I^-
Copper phosphate	copper, Cu^{2+}	phosphate, PO_4^{3-}
Aluminium sulfate	aluminium, Al^{3+}	sulfate, SO_4^{2-}
Ammonium chloride	ammonium, NH_4^+	chloride, Cl^-

3. An acid contains hydrogen joined with a negative ion, and has "*acid*" as the second word of its name. The first word is usually the name of the negative ion, with the end of its name changed: *-ate* changes to *-ic, -ite* changes to *-ous*.

EXAMPLES OF ACIDS:

Name of acid	**Positive ion**	**Negative ion**
Nitric acid	hydrogen, H^+	nitrate, NO_3^-
Carbonic acid	hydrogen, H^+	carbonate, CO_3^{2-}
Sulfurous acid	hydrogen, H^+	sulfite, SO_3^{2-}

But note an important exception: hydrochloric acid, HCl, is hydrogen chloride.

4. Accuracy in reading and clarity in writing names is essential. Names of different ions may differ by only one letter, so any error alters the meaning of a name or formula.

   The names of negative ions end in *-ide*, *-ite*, or *-ate*.

   The ending "-ide" means that the ion contains only one atom (except hydroxide, OH^-, and cyanide, CN^-). The endings "-ite" and "-ate" indicate that the ion is a compound ion, with "-ite" ions containing less oxygen than "-ate" ions. If only one compound ion with oxygen exists for a particular element, the "-ate" ending is used.
   Some compounds have special prefixes, such as "per-", "hypo-", and "thio-". "Per-" means even more oxygen than "-ate", "hypo-" means less oxygen than "-ite". "Thio-" means some sulfur is present instead of oxygen

EXAMPLES

sulfide, S^{2-}		sulfite, SO_3^{2-}	sulfate, SO_4^{2-}	
nitride, N^{3-}		nitrite, NO_2^-	nitrate, NO_3^-	
			carbonate, CO_3^{2-}	
phosphide, P^{3-}		phosphite, PO_3^{3-}	phosphate, PO_4^{3-}	
chloride, Cl-	hypochlorite, ClO^-	chlorite, ClO_2^-	chlorate, ClO_3^-	perchlorate, ClO_4^-

sulfate = SO_4^{2-}; thiosulfate = $S_2O_3^{2-}$ (think of one O from SO_4^{2-} being replaced by S).

5. Formulae are written by the following steps:

EXAMPLES

a) Identify the ions indicated in the name. Common examples are listed on the next page, but **these should be memorised as a matter of high priority!**

Zinc chloride : Zn^{2+} and Cl^-
Ammonium sulfate: NH_4^+ and SO_4^{2-}
Aluminium nitrate: Al^{3+} and NO_3^-
Carbonic acid: H^+ and CO_3^{2-}

b) Check the charge values on the ions. Positive and negative values must balance, so the numbers of positive and negative ions used must be chosen so that positive and negative charges cancel out.

One Zn^{2+} requires two Cl^-
Two NH_4^+ require one SO_4^{2-}
One Al^{3+} requires three NO_3^-
Two H^+ require one CO_3^{2-}

c) Combine the ions into a single formula, leaving out charge values. The number of each kind of ion used in the formula is shown by a subscript (small number at the bottom after the symbol of each ion involved), except that the number 1 is not shown. If there is two or or more of a compound ion, its formula should be enclosed in brackets, with the subscript outside.

$ZnCl_2$

$(NH_4)_2SO_4$

$Al(NO_3)_3$

H_2CO_3

The following are lists of common ions and their formulae. Note that a few metals have more than one possible charge number.

Positive ions are called CATIONS, negative ions are called ANIONS.

"Former names of ions" are not officially used today, but are still frequently encountered in old books and chemical labels, so should be recognised.

SIMPLE IONS

Modern name of ion	**Former name of ion**		**Modern name of ion**	**Former name of ion**		**Name of ion**	
aluminium		Al^{3+}	magnesium		Mg^{2+}	bromide	Br^-
barium		Ba^{2+}	mercury(I)	mercurous	Hg^+	chloride	Cl^-
calcium		Ca^{2+}	mercury(II)	mercuric	Hg^{2+}	fluoride	F^-
chromium(III)	chromic	Cr^{3+}	nickel		Ni^{2+}	iodide	I^-
cobalt(II)	cobaltous	Co^{2+}	potassium		K^+	nitride	N^{3-}
copper(I)	cuprous	Cu^+	silver		Ag^+	oxide	O^{2-}
copper(II)	cupric	Cu^{2+}	sodium		Na^+	phosphide	P^{3-}
iron(II)	ferrous	Fe^{2+}	tin(II)	stannous	Sn^{2+}	sulfide	S^{2-}
iron(III)	ferric	Fe^{3+}	tin(IV)	stannic	Sn^{4+}		
lead(II)	plumbous	Pb^{2+}	zinc		Zn^{2+}		

COMPOUND IONS

Name of compound ion		**Name of compound ion**	
acetate	CH_3COO^-	hypochlorite	ClO^-
carbonate	CO_3^{2-}	nitrate	NO_3^-
chlorate	ClO_3^-	nitrite	NO_2^-
chromate	CrO_4^{2-}	oxalate	$C_2O_4^{2-}$
cyanide	CN^-	permanganate	MnO_4^-
dichromate	$Cr_2O_7^{2-}$	phosphate	PO_4^{3-}
dihydrogenphosphate	$H_2PO_4^-$	sulfate	SO_4^{2-}
hydrogencarbonate (bicarbonate)	HCO_3^-	sulfite	SO_3^{2-}
hydrogensulfate (bisulfate)	HSO_4^-	thiosulfate	$S_2O_3^{2-}$
hydrogenphosphate	HPO_4^{2-}		
hydroxide	OH^-	ammonium	NH_4^+

WRITE FORMULAE FOR EACH IONIC COMPOUND IN THE SPACES PROVIDED.

	potassium	zinc	lead	silver	ammonium
carbonate					
bromide					
hydroxide					
chromate					
iodide					
nitrate					
sulfite					
acetate					
cyanide					
sulfide					
sulfate					
nitrite					
oxide					
chloride					
phosphate					

WRITE FORMULAE FOR EACH IONIC COMPOUND IN THE SPACES PROVIDED.

	Copper(II)	calcium	iron(II)	tin(II)	aluminium
carbonate					
bromide					
hydroxide					
chromate					
iodide					
nitrate					
sulfite					
acetate					
cyanide					
sulfide					
sulfate					
nitrite					
oxide					
chloride					
phosphate					

WRITE FORMULAE FOR EACH IONIC COMPOUND IN THE SPACES PROVIDED.

	sodium	nickel	iron(III)	barium	magnesium
carbonate					
bromide					
hydroxide					
chromate					
iodide					
nitrate					
sulfite					
acetate					
cyanide					
sulfide					
sulfate					
nitrite					
oxide					
chloride					
phosphate					

EXPLANATION OF RULES FOR WRITING FORMULAE

All matter is made of atoms. Atoms are very small: the radius of an atom can be measured in picometres. A picometre (pm) is one million-millionth (10^{-12}) of a metre. The mass of a single atom ranges from about 1.6 x 10^{-24}g for a hydrogen atom to about 4 x 10^{-22}g for an atom of uranium.

PROTONS, NEUTRONS and ELECTRONS

Atoms are made up of three kinds of particles: **neutrons** and **protons** that are located in the nucleus, and **electrons** that revolve around the nucleus in orbits. Protons have a positive electric charge, so the nucleus has a positive charge. This positive charge attracts the electrons, keeping them near the nucleus. Neutrons have no electric charge; they provide part of the mass of the nucleus, and help to hold the protons together (otherwise the repulsion of their positive charges would cause the nucleus to break apart). Protons and neutrons have equal mass. An electron has a negative electric charge. Its mass is slightly more than $\frac{1}{2000}$ of the mass of a proton or neutron.

ATOMIC NUMBER

Atoms of different elements have different numbers of protons in their nuclei. Atoms of the same element always have the same number of nuclear protons. The number of protons in the nucleus of an atom is called its **atomic number**. On page 3 of these notes, some common elements are listed by their atomic numbers. For example, any atom with 11 protons in its nucleus must be sodium. Every sodium atom has 11 protons in its nucleus.

NEUTRON NUMBERS

The number of neutrons in the nuclei of atoms of any particular element can vary. For example, atomic nuclei of the element hydrogen can have one proton and no neutrons (ordinary hydrogen), or one proton and one neutron (called deuterium, or heavy hydrogen), or one proton and two neutrons (called tritium). These different kinds of atoms of the same element are called **isotopes**.

Not every atom of any particular element will have the same mass, since atoms with more neutrons will have greater mass than those with fewer neutrons.

ELECTRON MOVEMENTS AND NUMBERS

Electrons move around the nucleus in "orbits". The movement of electrons around the nucleus is likened sometimes, for simplicity, to the movement of planets around the Sun, and in the diagrams that follow, they will be represented like that.

Electrons really move in much less regular paths; each electron tending to move freely anywhere within a defined region surrounding the nucleus. The region where each electron can move is called a **shell**, or **energy level**. In these notes, the term *shell* will be used. The rules about the numbers of electrons that can move within each shell are explained below.

ELECTRON NUMBERS and CHEMICAL REACTIONS

In an atom of a pure element, the number of electrons in orbit around the nucleus equals the number of protons in the nucleus. When atoms are involved in chemical reactions, and form compounds, the numbers of electrons in orbit change, as electrons move from atoms of one element to atoms of another element. **In a compound, the number of protons in the nucleus does not equal the number of electrons in orbit around the nucleus.**

Most (but not all) chemical reactions between compounds also involve the shifting of electrons from one atom to another.

RULES ABOUT SHELLS AND NUMBERS OF ELECTRONS IN THEM

Shells can be thought of like layers of space around a nucleus. The one closest to the nucleus is called the first shell, the second one from the nucleus is the second shell, and so on.

Electrons tend to fill a shell closer to the nucleus before starting to fill one further out. There are, however, some rules that must be observed by electrons in shells: there is a maximum number of electrons allowed in each shell, and as each shell is filled, electrons must start to fill the next one, further out from the nucleus.

Maximum number of electrons allowed in each shell:

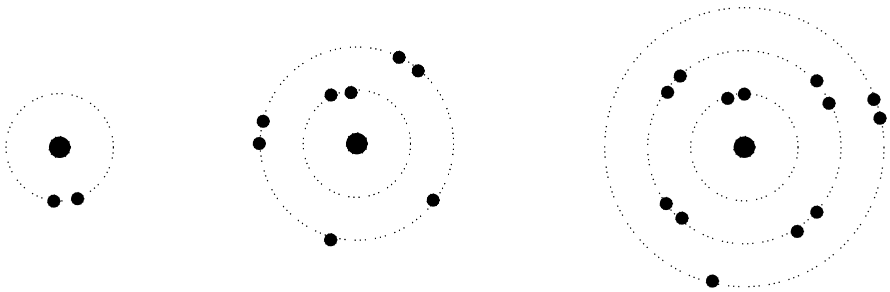
SHELL NUMBER	MAXIMUM NUMBER OF ELECTRONS ALLOWED	MAXIMUM NUMBER OF ELECTRONS ALLOWED IF IT IS THE OUTSIDE SHELL
1	2	2
2	8	8
3	18	8
4	32	8
5	50	8

OCTET RULE

Atoms combining to form compounds tend to swap and share electrons between themselves so that every atom has eight electrons in its outside shell (or two electrons if the outside shell is the first shell).

There are some exceptions to the Octet Rule, but they will not be considered here.

DIAGRAMS on the next four pages show the arrangement of electrons in atoms, and how electrons are rearranged when compounds are formed. It is emphasised that these are very simplified diagrams, showing electrons as if they were moving in simple orbits, like planets around the Sun, instead of freely within the region of a shell.



ELEMENT:	helium	oxygen	aluminium
PROTONS IN NUCLEUS	2	8	13
ELECTRON SHELLS	2	2, 6	2, 8, 3

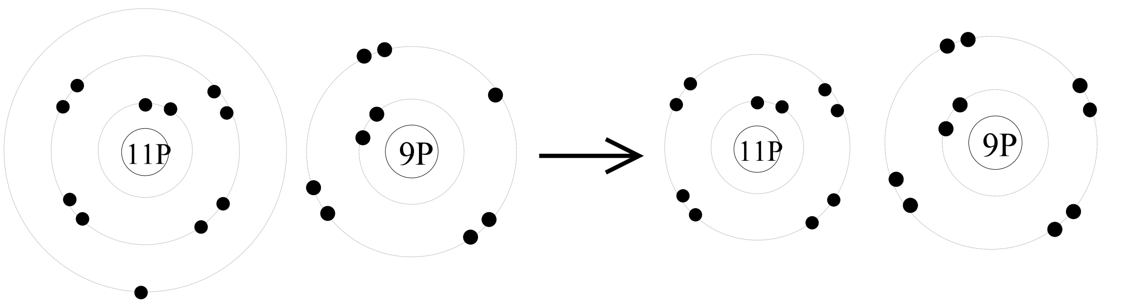
◌ represents path of electron movement in shell

• • represent electrons

● represents nucleus

When atoms combine, electrons are rearranged so that each atom has eight electrons in its outermost shell (or two electrons if the outermost shell is the first). This can happen in two main ways: electrons move completely from one atom to another, or electrons are shared between pairs of atoms.

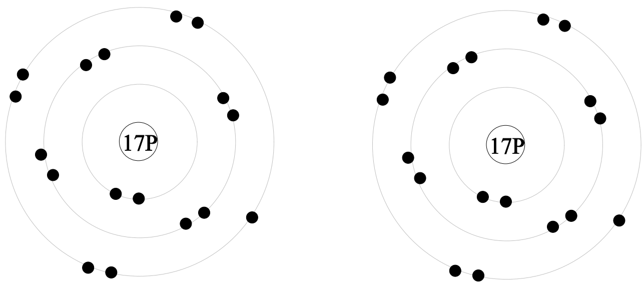
1. ELECTRONS MOVE COMPLETELY FROM ONE ATOM TO ANOTHER.



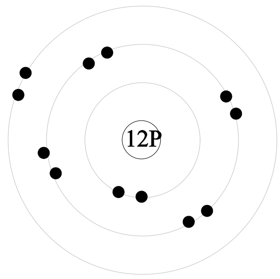
Sodium atom has one electron more than it needs to form a full outer shell of eight.	Fluorine atom has one electron fewer than it needs to form a full outer shell of eight.	Sodium ion has lost one electron to leave an outer shell of eight electrons.	Fluoride ion has gained one electron to achieve an outer shell of eight electrons.
Na	F	Na^+	F^-

The sodium ion still has 11 protons (this cannot change because it is sodium) but now has only ten electrons. Overall it has a positive charge of one, so is symbolised Na^+.

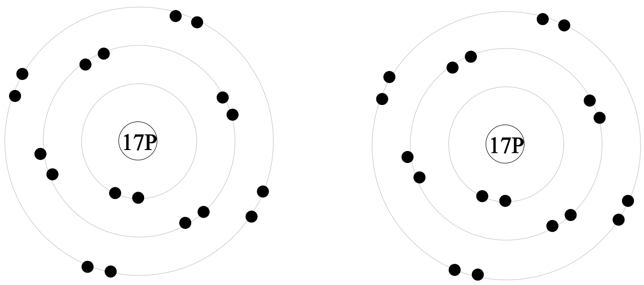
The fluoride ion still has 9 protons (this cannot change because it is fluorine) but now has ten electrons. Overall it has a negative charge of one, so is symbolised F^-.



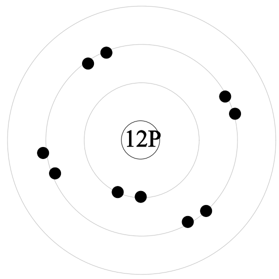
Two chlorine atoms



Magnesium atom



Two chloride ions



Magnesium ion

Each magnesium atom has two outer shell electrons. When a magnesium atom combines with chlorine, it loses its two outer electrons, and is left as a magnesium ion with eight electrons in its outer shell. With 12 protons (because it is still magnesium) and ten electrons, the ion has two positive electric charges. Its formula is Mg^{2+}.

A chlorine atom has seven outer electrons, so needs to gain only one electron to have eight outer-shell electrons. Each magnesium atom that reacts with chlorine can give one electron to each of two chlorine atoms. With an extra electron, the atoms are now called chloride ions. With 17 protons and 18 electrons, the ion has one negative charge. Its formula is Cl^-.

Since one magnesium atom can give electrons to two chlorine atoms, the formula for magnesium chloride is $MgCl_2$.

Refer again to the rules on page 6 for writing formulae.

<u>Exercises:</u> The arrangements of electrons for several elements are listed below.

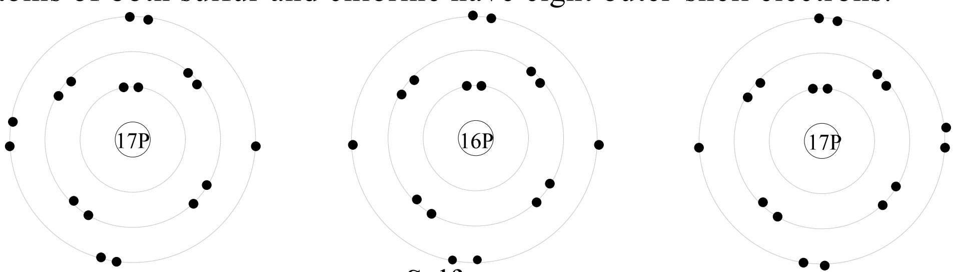
Lithium: 2,1	Nitrogen: 2,5	Oxygen: 2,6
Fluorine: 2,7	Sodium: 2,8,1	Magnesium: 2,8,2
Aluminium: 2,8,3	Sulfur: 2,8,6	Chlorine: 2,8,7
Potassium: 2,8,8,1	Calcium: 2,8,8,2	

Using only the information about electron shells, write formulae for

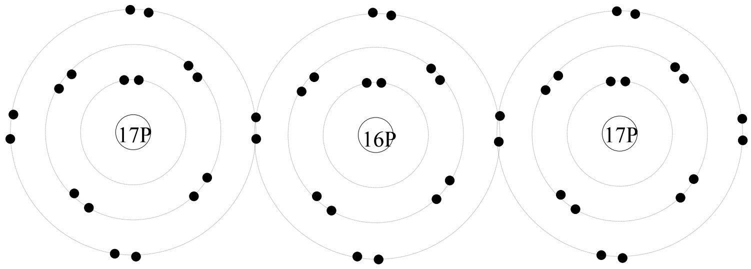
a) calcium oxide	d) potassium sulfide	g) lithium sulfide
b) lithium fluoride	e) aluminium chloride	h) aluminium nitride
c) sodium nitride	f) calcium nitride	i) aluminium oxide

2. **ELEMENTS WITH FOUR OR MORE OUTER-SHELL ELECTRONS COMBINE BY *SHARING* ELECTRONS, RATHER THAN BY TRANSFERRING THEM FROM ONE ATOM TO ANOTHER.**

For example, sulfur (2,8,6) can combine with chlorine (2,8,7) by sharing electrons so that atoms of both sulfur and chlorine have eight outer-shell electrons.



Chlorine atom Sulfur atom Chlorine atom

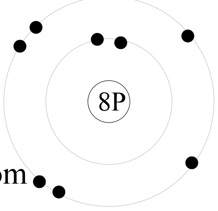


Sulfur dichloride molecule

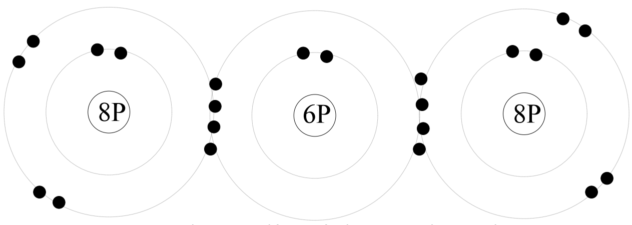
Compounds like magnesium chloride, in which electrons are transferred completely from one atom to another, are called *IONIC COMPOUNDS*. The ions are attracted to each other by the attraction between the positive and negative charges, yet are not actually joined together.

Compounds like sulfur dichloride, SCl_2, in which electrons are shared between atoms, are called *COVALENT COMPOUNDS*. A pair of shared electrons is called a *COVALENT BOND*. The atoms are actually joined together, to form a *MOLECULE*.

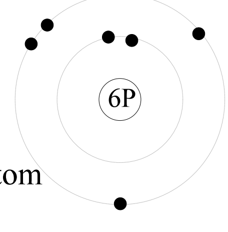
Atoms can share more than one pair of electrons. In carbon dioxide, carbon and oxygen atoms are bound together by two pairs of electrons, or two *covalent bonds*.



Oxygen atom

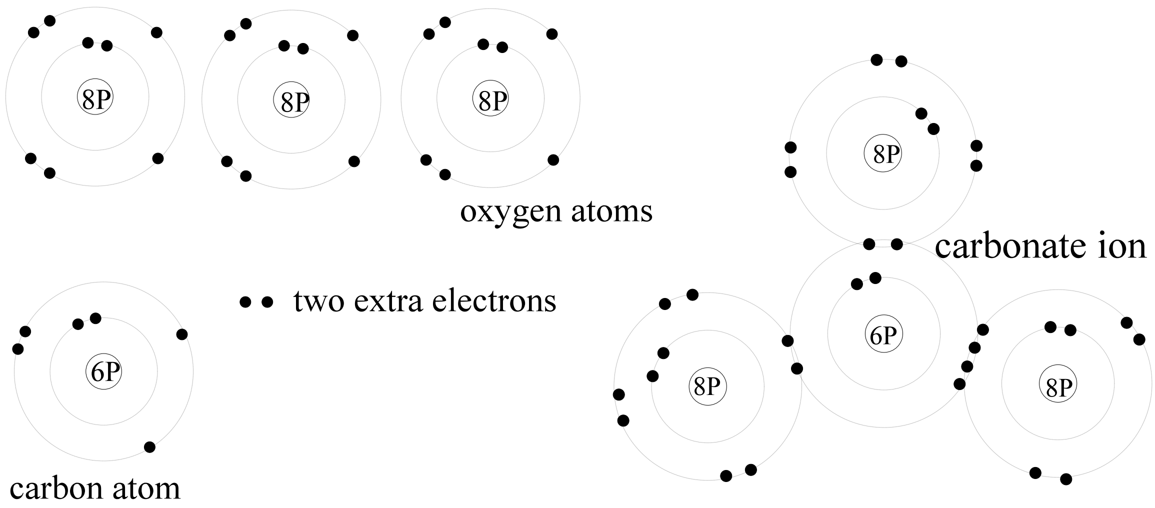


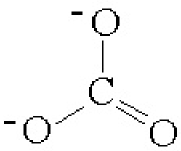
Carbon dioxide molecule



Carbon atom

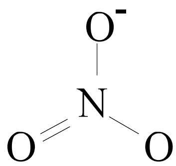
In compound ions such as carbonate, CO_3^{2-}, or nitrate, NO_3^-, the atoms are held together by covalent bonds. The atoms take up one or more extra electrons as they join, so that the compound ion has a negative charge, and can attract to positive ions.





Carbonate ion, CO_3^{2-}

The electron shells for the nitrate ion are shown in the diagram below:



Nitrate ion, NO_3^-

Uncombined oxygen atoms have six outer-shell electrons, while uncombined nitrogen atoms have five outer shell electrons.

One extra electron is taken up by the atoms as they unite, so that the nitrate ion has a negative charge.