How Elements Form Compounds

Textbook Reference: 5.6 – 5.8, pages 188 – 194

Review of Section 5.5

In the modern Periodic Table the elements are arranged in order of increasing _________ _________.

The elements are arranged in groups and periods.

The **vertical columns** on the periodic table are called _______________, and sometimes also called ________________ ___________________.

Elements in the same __________________ have similar chemical properties, because they have the __________ number of ______________ in the outermost shell/orbit.

The electrons in the outermost shell are called __________________ ______________.

The Roman numeral of the group, i.e. the group number equals the number of _______________ ______________.

The chemical reactivity of an element is determined by the number of __________ __________.

The **horizontal rows** on the periodic table are known as ________________.

Each period represents an ______________ __________ or an ________________ in the Bohr model and an energy level in the Quantum model of the atom.

All atoms want to become chemically / structurally stable.

An atom achieves this stability when it has a complete or a filled "outer shell," i.e. it has **8** valence electrons, this is sometimes called an ___________.

The Noble Gases (i.e. Group ___________) have eight valence electrons, and are therefore chemically unreactive or__________.

(In 1962,Neil Bartlett, of the University of British Columbia produced the first noble gas compound containing xenon, platinum and fluorine, however since then a number of other noble gas compounds have also been prepared.)

The atoms of all other elements can only achieve this stability by:

1. losing electrons: Groups IA, IIA, IIIA to become positively charged ions called ______________ ,

2. by gaining electrons: Groups VA, VIA, VIIA to become negatively charged ions called _________,

3. by sharing electrons: Groups IVA.

Hydrogen can either gain, lose or share electron to fill its shell, to attain the stability of the Noble Gas helium.

Isoelectronic is the term used to describe atoms and ions that have the same number of electrons, (i.e. have the same energy level population).

Name 3 species that are isoelectronic with: (i) Na^{+1} _____ _____ _____

(ii) Cl^{-1} _____ _____ _____

5.6 Bonding Between Metals and Non-metals: Ionic Bonding

The electrons in the outermost energy level of an atom are the ones which participate in chemical bonding. These electrons are called _____________ ______________.

The number of valence electrons possessed by an atom determines the number of other atoms with which that atom can combine.

Thus sodium, $_{11}Na$, atomic number 11, has an electronic arrangement of ____ ____ ____, thus sodium has ___________ valence electron.

Chlorine, $_{17}Cl$, has an atomic number of 17, thus has an electronic arrangement of ____ ____ _____, thus chlorine has __________ valence electrons.

To illustrate the Bonding between Sodium and Chlorine

The sodium atom has an energy level population of 2.8.1 and could become isoelectronic, (i.e. have the same energy level population) as the noble gas neon, (2.8) by losing its valence electron to a chlorine atom:

Ionization energy	+	Na ·	⟶	Na^{+1}	+	e^{-1}
		2.8.1		2.8		
		$11p^{+1}$		$11p^{+1}$		
		$11\ e^{-1}$		$10\ e^{-1}$		
		sodium atom		sodium ion, Na^{+1}		
				(Electron configuration of the noble gas: neon)		

The chlorine atom has an energy level population of 2.8.7 and could become isoelectronic (i.e._______ __________ ___ __________ _____) as the noble gas argon, (2.8.8) by gaining one electron from the sodium atom:

e^{-1}	+	:Cl. (7 dots)	⟶	:Cl: (8 dots)	+	Electron affinity
		2.8.7		2.8.8		
		$17\ p^{+1}$		$17\ p^{+1}$		
		$17\ e^{-1}$		$18\ e^{-1}$		
		Chlorine atom		chloride ion, Cl^{-1}		
				(Electron configuration of the noble gas: argon)		

Now, both the sodium ion and the chloride ion have a stable octet of eight electrons in their outer shell and will show no further tendency to undergo chemical reaction.

The positive sodium ion, Na^{+1} and the negative chloride ion, Cl^{-1} produced attract one another, because they have opposite charges, and an **IONIC BOND** is formed.
The positively charged sodium ions and the negatively charged chloride ions are held together by **<u>'electrostatic force of attraction'</u>**.
An ionic compound contains positive and negative ions in a ratio that make it electrically neutral.

If we add these two processes together we get:

Na . + :Cl. ⟶ Na^{+1} [:Cl:]$^{-1}$ (Overall release of energy: Lattice Energy)

The **formula:** NaCl implies that the ratio of cation to anion is 1+ : 1–
NaCl would be named as: sodium chloride (metal _non-metal– ide)

When metals react with non-metals they form ionic compounds.
Metal atoms and non-metal atoms are converted to their respective ions:

$$\textbf{I.E} + \textbf{Metal atoms} \xrightarrow{\textbf{Lose electrons}} \textbf{positive ions, cations}$$

$$\textbf{Non-metals} \xrightarrow{\textbf{Gain electrons}} \textbf{negative ions, anions} + \textbf{E.A}$$

$$\textbf{cations} + \textbf{anions} \longrightarrow \textbf{Ionic Compound} + \textbf{Lattice Energy}$$

An ionic bond is the electrostatic attraction between oppositely charged ions. This attraction forms a giant crystal lattice structure, held by bonds created by the balance of electrical attraction and repulsion.

All crystal lattices are arranged so that the attractive forces between the opposite charges are maximized and the repulsive forces between ions of the same charge are minimized.

When an ionic bond is formed by electron transfer between a metal and a non-metal, all of the electrons __________ by the metal must be ______________ by the non-metal.

When ionic bonds are formed, enough electrons must be transferred so that each ion produced is ___________________ with a noble gas,

The **alkali metals of Group IA** of the periodic table achieve a stable octet in the outer shell by _________ one electron to form a unit ______________ __________ ion, M^{+1}, (where M represents any Group IA metal); called a ____________.

The **halogens in Group VIIA** of the periodic table achieve a stable octet in the outer shell by __________ one electron to form a unit ________________ ______________ ion, X^{-1}, (where X represents any Group VIIA non-metal), called an ___________.

To name an Ionic Binary Compound

A binary compound is a compound containing only two elements.
1. The **metal** is named **first** always.
2. The non-metal's name is changed by adding the **suffix — IDE** to the name.
(Note: no prefixes are used to illustrate the number of each element present.)

Anion	Suffix used for naming
F^{-1}	fluoride
Cl^{-1}	chloride
Br^{-1}	bromide
I^{-1}	iodide
O^{-2}	oxide
S^{-2}	sulphide
N^{-3}	nitride
P^{-3}	phosphide
H^{-1}	hydride

<u>Answer the following:</u>

1. (a) why does each lithium ion require one fluoride ion in the compound LiF?

b) Show the bonding when LiF is formed

c) name LiF

2.(a) Why does each rubidium ion require one bromide ion in the compound: RbBr.

(b) Name RbBr

<u>To illustrate the bonding between magnesium and oxygen</u>

A Group IIA metal, (aka: ___________ __________ metals), such as magnesium, $_{12}Mg$, has _________ valence electrons, electronic configuration: ____ ____ _____.

Magnesium can become isoelectronic with the noble gas ____________, if it _______ ____________ valence electrons. (The energy required to lose electrons is called: ___________ ___________ .)

Oxygen atoms are in Group VIA, oxygen atoms, $_8O$ have the electronic configuration of ___ ___ ____. Oxygen atoms have __________ valence electrons.

Oxygen atoms would have to __________ _______ electrons to become isoelectronic with the noble gas __________. (The gain of electrons results in the loss of energy called: _________ __________.)

Hence, the ionic bonding between magnesium and oxygen could be represented as:

Hence, one magnesium atom could transfer ________ electrons to a single oxygen atom, and the ionic compound, **named** ______________ ________________, with the **formula** ___________ would form. The bonding of Mg with O results in the loss of energy: _______ _______, hence a very stable ionic compound is formed.

Thus, **Group IIA** metals, (the alkaline- earth metals) have **two valence electrons** in their outer shell, and to achieve a stable octet of outer electrons they must **lose two electrons** to produce a dipositive ion, M^{+2}, where M represents any Group IIA metal.

<u>To illustrate the bonding between magnesium and chlorine</u>

Each magnesium atom transfers two valence electrons, each chlorine atom needs to gain one electron, thus __________ chlorine atoms will be required to accept the two electrons from the magnesium atom.

Each chlorine atom will accept _________ electron from the magnesium atom and will be isoelectronic with the noble gas ______________.
Two ___________________ ions will be formed, and both will be attracted to the magnesium ion:

The formula of the compound will be ____________, and the name of the compound will be ______________ ________________.

Now, try to answer the following questions as true or false, if the answer is false, correct the statement:

A. When calcium combines with fluorine:

1. Each calcium atom gives up two electrons
2. Each fluorine atom receives two electrons
3. The product is an ionic bond
4. The product has on overall positive charge
5. The product contains an equal number of calcium ions and fluoride ions
6. The formula of the product is CaF
7. The name of the product is calcium difluoride.

Writing Formulas for Ionic Compounds Using the Cross-Over Rule: M^{+a} X^{-b}

Chemists obviously do not draw a Lewis diagram each time they want the chemical formula of the compound that contains a metal and a non-metal.

Chemists look for a shortcut.

The shortcut uses valences and is sometimes referred to as the "**Crossover Rule**".

1. Write sown the symbols of the elements (metal first)
2. Record the valence number for each element (as a superscript above the symbol of each element)
3. Crossover the valence numbers
4. Find the highest common factor to the two valences
5. Divide the valence numbers by the highest factor
6. Write the numbers as subscripts in the formula (do not write any "1" in the formula)

Examples:

1. Al^{+3} N^{-3} $\longrightarrow$ Al_3N_3 $\longrightarrow$ AlN aluminium nitride

2. Ba^{+2} O^{-2} $\longrightarrow$ Ba_2O_2 $\longrightarrow$ BaO Barium oxide

B. Now use the cross-over rule to predict the name and formula of the compound formed when:

	FORMULA	NAME
1. Magnesium reacts with sulphur	____________	__________
2. When barium reacts with bromine	____________	__________
3. When lithium reacts with nitrogen	____________	__________
4. When sodium reacts with sulphur	____________	__________
5. When potassium reacts with phosphorus	____________	__________
6. When aluminium reacts with oxygen	____________	__________
7. When gallium reacts with sulphur	____________	__________
8. Sodium reacts with carbon	____________	__________
9. When aluminium reacts with nitrogen	____________	__________
10. When strontium reacts with iodine	____________	__________

C. Give the chemical name for each of the following

1. Li_2S

2. CaO

3. Al_2S_3

4. K_3P

5. K_4C

6. BaI_2

D. Give the correct formula for each of the following:

1. Potassium sulphide
2. Barium nitride
3. Lithium iodide
4. Aluminium nitride
5. Magnesium bromide
6. radium chloride
7. Strontium phosphide
8. beryllium sulphide
9. Cesium fluoride
10. Rubidium sulphide
11. Francium oxide
12. Gallium sulphide

Can you see why metals react with non-metals but not with other metals.

Metals are keen to give up electrons when they react and non-metals are keen to gain these electrons.

Two metals cannot react with each other because they both want to lose electrons.

The two metals cannot come to any arrangement which satisfies both of them.

Now DO: Binary Compounds Drill Sheet I **(See PAGE of the Notes)**

<u>Names and Formulas for Atoms with Variable oxidation states (valencies)</u>

The atoms of some metals form more than one stable ion,

e.g. iron forms: Fe^{+2} and Fe^{+3},

tin forms: Sn^{+2} and Sn^{+4}.

copper forms: Cu^{+1} and Cu^{+2}

In such cases a **Roman numeral in parentheses**, (i.e. round brackets), is added immediately after the name of the element to indicate the oxidation number of the element.

Roman Numerals:	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

This system of nomenclature is called the **Stock** system, (after the German chemist Alfred Stock, who first proposed it).

STOCK SYSTEM: The compounds are named as all other ionic compounds, except that a Roman Numeral is added in round brackets to indicate the oxidation state of the metal.

Example:
$CuCl$ is copper (I) chloride, the oxidation state of copper is +1, whereas
$CuCl_2$ is copper (II) chloride, since the oxidation state of copper is +2.

Example:
$NiBr_2$ Nickel (II) bromide $NiBr_3$ Nickel (III) bromide

Example:
FeO: Fe_2O_3

Note: Roman numerals are not used if the positive ion has only one possible oxidation number, for example, ions of elements in Group IA, Group IIA and Group IIIA.

An older method of naming such ions, referred to as the **Classical** method, in which the metals can have variable oxidation states uses the Latin name of the metal.
For the **lower oxidation number**, the suffix **— *O*US** was added to the suffix of the name of the element.
For the ion of **higher oxidation number**, the suffix **— *ic*** was added.

Symbol	Name	Latin Name	Oxidation State	Classic Name
Cu	copper	cuprum	+1, +2	cuprous, cpric
Sn	tin	stannum	+2, +4	stannous, stannic
Au	gold	aurum	+1, +3	aurous, auric
Pb	lead	plumbum	+2, +4	
Sb	antimony	stibium		
Fe	iron	ferrum	+2, +3	
Hg	mercury	hydrargyrum	+1, +3	
As	arsenic	arsenic	+3, +5	

This system has two distinct disadvantages:

1. A given suffix does not consistently represent the same oxidation number, e.g. – ic stands for +3 in ferric but +4 in stannic ion.
2. The system has the disadvantage that it does not work at all for ions which may have more than two oxidation numbers, e.g. chromium can have oxidation numbers of +2, +3, and +6.

Because the classical system is still used by chemists, it is therefore necessary for you to learn it!!!

<u>Now Do the following Assignment</u>

A newly discovered metal, **M**, has an oxide of formula: $\mathbf{M_2O_3}$.

a. What is the oxidation number of **M** ? ____________

b. In which group of the periodic table does **M** belong? ____________

c. Give the formula of the ion formed by **M**. ____________

d. Give the formulae of the chloride and the sulphide of **M**. ________ _________

e. Is **M** a metal or a non-metal? Predict <u>three</u> physical properties for **M**.

1. 2. 3.

f. Would you expect $\mathbf{M_2O_3}$ to be a solid, liquid or gas, justify your answer. __________________

g. Would you expect $\mathbf{M_2O_3}$ to be soluble in water? Justify your answer. __________________

h. **M** also forms a compound of the formula $\mathbf{M_2O_5}$, Hence using both the stock and the classic system, name both $\mathbf{M_2O_3}$ and $\mathbf{M_2O_5}$. (use the name: ottawium to represent M)

Binary Compound Drill Sheet: I

Binary Compounds containing only two types of elements. Always use the suffix "ide". (Except for binary acids, which we will study later.)

1. Write the IUPAC chemical names for the following compounds

a. NaCl

b. K_2O

c. ZnS

d. MgO

e. $BeBr_2$

f. Al_2O_3

g. Ca_2F

h. KBr

i. ZnI_2

j. LiCl

k. Ag_3N

2. Write the chemical formula of the following compounds. (Hint: using the cross-over rule.)

a. Potassium bromide

b. Sodium oxide

c. Calcium chloride

d. Potassium phosphide

e. Lithium iodide

f. Hydrogen sulfide

g. Beryllium nitride

h. Rubidium fluoride

i. Sodium carbide

j. Potassium sulfide

k. Strontium hydride

l. beryllium oxide

m. calcium iodide

n. Boron oxide

o. Gallium bromide

BINARY COMPOUND DRILL SHEET: II

1 **Write the IUPAC chemical name for the following: Stock System: (IUPAC) use a Roman Numeral to represent the oxidation number of the first element (metal) in the compound.**

Cu_2O

Fe_3N_2

NiS

Hg_2Cl_2

SnO_2

PbI_4

CuF

SnH_2

$SnCl_4$

$CoBr_2$

CrF_3

2. Write the "IC" or "OUS" suffix chemical name of the following:

Note: The suffix "IC" is used for the <u>higher</u> oxidation number
The Suffix "OUS" is used for the <u>lower</u> oxidation number.

a. Fe_2S_3

b. NiN

c. $PbCl_2$

d. $HgCl_2$

e. SnS_2

f. PbI_4

g. CuF

h. SnH_2

i. Hg_4C

j. $CoBr_2$

k. CuF_2

Binary Compound Drill Sheet: III

1. Practice: Name each of the following. Where applicable, give both the Stock and the classical "ous - ic" names.

a. ZnS
b. Na_2O
c. FeP
d. $Sb_2 S_3$
e. $FeCl_3$
f. Sb_2O_3
g. $CaCl_2$
h. BaO
i. $CuBr_2$
j. Hg_2O
k. $HgCl_2$
l. Cu_2O
m. $AuBr_3$
n. Sb_2S_3
o. As_2O_3
p. As_2O_5
q. $SnCl_4$
r. SnO
s. MnO
t. MnO_2
u. PbO
v. PbO_2
w. $SbCl_5$
x. $SbCl_5$

2. Write the formulas for the following compounds:

1. Iron (II) chloride ____________
2. Tin (II) iodide ______________
3. Vanadium (II) bromide _____________
4. Ferric sulphide ______________
5. Stannic bromide _____________
6. auric chloride ______________
7. Mercuric chloride _____________
8. Plumbic iodide ______________
9. Ferric phosphide _____________
10. Beryllium fluoride ___________
11. Sodium nitride _____________
12. Calcium oxide ____________
13. Beryllium oxide _____________
14. Calcium nitride ____________
15. Nickel (III) carbide _____________
16. Manganese(IV)oxide _________
17. Vanadium (V) oxide ______________
18. stannous fluoride ____________
19. Cobaltic sulphide _______________
20. Cuprous bromide ____________.