Chapter 2 – Atomic Structure and Nomenclature

Section 3 - Nomenclature

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Introduction

Nomenclature is the fundamental of any chemistry education. You have already learned about element names and their symbols. Now we will combine these elements to form compounds.

Compounds are formed when elements combine (form bonds) in different ratios. How are those ratios determined? Can any two elements form a compound? This and many more questions will be answered in this section.

We will learn the following nomenclature:

- Ionic compounds nomenclature: two types for ionic – one for main group metals and one for transition metals.
- Covalent compounds nomenclature.
- Naming using polyatomic ions (cations and anions).
- Nomenclature of acids and bases.
- Nomenclature of hydrates.
- Names of some common compounds.

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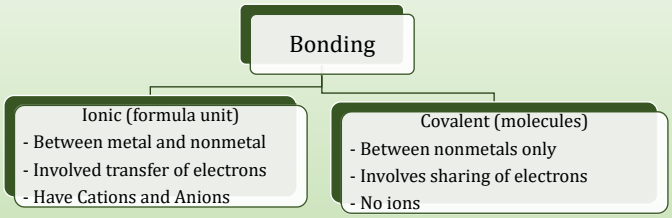
Types of Bonding

- There are two main types of bonding between elements, ionic and covalent.



- Covalent compounds are called molecules.
- Ionic compounds are referred to as having a formula unit because in the solid state ionic compounds have a specific number of ions associated with each other in crystal structure.
- Metals do not form bond with other metals. They can only mix to form a mixture called **alloy**.
- There are seven **diatomic gases**/molecules whose names are the same as the element names: H_2, O_2, N_2, F_2, Cl_2, Br_2 and I_2.

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Ionic Compounds – Main Group

Formed from combination of metals and nonmetals.

- Metals give electrons to form cations.
- Nonmetals gain electrons to form anions.
- Electrons transfer occurs from metals to nonmetals.
- Final compound/unit is electrically neutral.

Metals give e^-	**Cation formed E.g.**	**Non Metals gain e^-**	**Anion formed E.g.**
Group I 1e^- given	Li^+, Na^+	Group V 3e^- gained	N^{3-}, P^{3-}
Group II 2e^- given	Mg^{2+}, Ca^{2+}	Group VI 2e^- gained	O^{2-}, S^{2-}
Group III 3e^- given	Al^{3+}	Group VII 1e^- gained	Cl^-, Br^-

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Naming Ionic Compounds – Main Group

- **Naming cations**
  - The name of the element, usually metal, does not change. Name the element and add the word "ion".
    Example: Na^+, sodium ion, Ca^{2+} ion.
- **Naming Anions**
  - Name of the element, usually nonmetal, is changed by ending the name with "-ide".
    Example: Cl^-(chloride), O^{2-} (oxide).
- **Naming ionic compounds**: Metal is named as is and nonmetal is ending with ***–ide***. E.g. NaCl is sodium chloride, CaO is calcium oxide.
  - Note: The name does not indicate the ratio of the elements. This is because there is only one combination possible for main group elements.
- There are two exceptions –
  Pb in Group IV has two ions Pb^{2+} and Pb^{4+}; and
  Tl in Group III has two ions Tl^+ and Tl^{3+}

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Naming Ionic Compounds – Main Group continued

Compound formed is electrically neutral so the sum of the charges on the cation(s) and anion(s) in each formula unit must be zero.

If there is only 1 atom, that 1 is not written e.g., in NaCl it is understood that Na is 1 atom and Cl is 1 atom.

Solved Problem: naming ionic compounds
Name the following compounds.
CaF_2
K_2O

CaF_2 – calcium fluoride
K_2O – potassium oxide
Note: you cannot tell how many fluorine atoms or potassium atoms in the names above because these are main group metals which have specific charges that do not change. They can form compounds in ONE set ratio.

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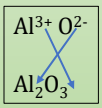
Forming Ionic Compounds – Main Group continued

Form Compounds: Form compounds between the following elements.

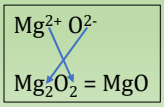
- We will learn the cris- cross method given below to easily form compounds.
- Don't use charges (+ or -) for the subscripts in the final formula
- Bring atom ratio to the LOWEST divisible ratio, see example of Mg and O below.

- Na and N: Sodium is +1 and nitrogen is -3. We need 3 Na to give three electrons because N needs 3 electrons in order to make a neutral compound between Na and N. Or we can do the cris-cross method on the right.

- Al and O: Aluminum is +3 from the periodic table and oxygen is -2 . We need 2 Al and 3 O for a total transfer of 6 electrons to form a neutral compound.



- Mg and O – Mg is +2, O is -2, the ratio of elements is 1:1 to give a neutral compound – MgO. Make sure to bring to lowest ratio in the final formula.



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Naming Ionic Compounds – Transition Metals

- Transition metals form cations but have multiple valencies, meaning they can give different charges. E.g. Iron, Fe, can give 2 or 3 electrons, which will form Fe^{2+} and Fe^{3+} ions respectively. This means iron oxide can be FeO or Fe_2O_3. To clear that confusion transition metals, have some different rules for naming.
- Naming the transition metal cations: Name of metal is followed by a Roman numeral to indicate the charge on the cation (the number of electrons the metal is giving).
  - Fe^{2+} is iron (II) ion and Fe^{3+} is iron (III) ion.
- The name of the anion remains the same, ending with "ide".
- Hence FeO is named as iron (II) oxide. Which means that the charge of Fe is 2+ because oxygen is always 2- (*from our previous information of the charges on the periodic table groups*).

Example: Form the compounds between the following ions.

Fe^{3+} and O^{2-} → Fe_2O_3 — Iron (III) oxide

Mn^{4+} and S^{2-} → Mn_2S_4 = MnS_2 — Manganese (IV) sulfide

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Solved Problem: Naming transition metal compounds
Name the following compounds:
$TiCl_2$, Cu_2O, Mn_2O_5

$TiCl_2$ – chlorine is -1 from the PT as it is in group VII, and because there are 2 chlorides, total charge on chloride is -2; Ti must be +2 to be electrically neutral.
Name: Titanium (II) chloride.

Cu_2O – oxygen is -2 from the PT as it is in group VI; and because there is only one oxide, copper must have a total charge of +2. Since there are 2 copper ions, divide the charge equally between them, +2/2 = +1.
Name: copper (I) oxide.

Mn_2O_5 – oxygen is -2 from the PT as it is in group VI, and because there are 5 oxygens, total charge on oxygen is +10; there are 2 Mn atoms, so divide the +10 on the two Mn atoms equally, +10/2 = +5.
Name: manganese (V) oxide.

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More on Ions

- Main group elements give and take standarde number of electrons.
- Transition metals can give different number of electrons hence there is no point in memorizing the charges; it is better to look at the formula or name to calculate the charge (valency) on the metal.
- The table below gives the cations and anions you need from PT.

IA	IIA											IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H +1, -1																	2 He
3 Li +1	4 Be +2											5 B +3	6 C +4 +2 -4	7 N -3	8 O -2	9 F -1	10 Ne
11 Na +1	12 Mg +2	IIIB	IVB	VB	VIB	VIIB		VIIIB		IB	IIB	13 Al +3	14 Si +4 -4	15 P -3	16 S -2	17 Cl -1	18 Ar
19 K +1	20 Ca +2	21 Sc +3	22 Ti +4 +3 +2	23 V +5 +4 +3 +2	24 Cr +3 +2	25 Mn +7 +6 +4 +3 +2	26 Fe +3 +2	27 Co +3 +2	28 Ni +2 +3	29 Cu +2 +1	30 Zn +2	31 Ga +3	32 Ge +4 -4	33 As	34 Se -2	35 Br -1	36 Kr
37 Rb +1	38 Sr +2	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag +1	48 Cd +2	49 In +3	50 Sn +4 +2	51 Sb	52 Te -2	53 I -1	54 Xe
55 Cs +1	56 Ba +2	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au +3 +1	80 Hg +2 +1	81 Tl +3 +1	82 Pb +4 +2	83 Bi +5 +3	84 Po	85 At -1	86 Rn

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Polyatomic Ions

- These are ions (cations and anions) formed from multiple combinations of nonmetals.
- Only one polyatomic ion is a cation.
- Most polyatomic ions are anions meaning they have excess electrons. (*Where are these excess electrons coming from?* From the metals they combine with).

Positive Polyatomic Cations

H_3O^+ hydronium ion (*exists only in acidic solutions*)

NH_4^+ ammonium ion (formed from NH_3: ammonia)

Simple Polyatomic Anions

OH^- hydroxide

CN^- cyanide

Polyatomic Ions Containing Oxygen

(*all end in "ate" or "ite"*)

Formula	Name
CO_3^{2-}	Carbonate
HCO_3^-	Hydrogen carbonate
SO_4^{2-}	Sulfate
HSO_4^-	Hydrogen sulfate
SO_3^{2-}	Sulfite
HSO_3^-	Hydrogen sulfite
NO_3^-	Nitrate
NO_2^-	Nitrite
PO_4^{3-}	Phosphate
HPO_4^{2-}	Hydrogen phosphate
$H_2PO_4^-$	Dihydrogen phosphate
$C_2H_3O_2^-$ CH_3COO^-	Acetate

Formula	Name
CrO_4^{2-}	Chromate
$Cr_2O_7^{2-}$	Dichromate
MnO_4^-	Permanganate
SCN^-	Thiocyanate
$S_2O_3^{2-}$	Thiosulfate
ClO^-	Hypochlorite
ClO_2^-	Chlorite
ClO_3^-	Chlorate
ClO_4^-	Perchlorate

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Solved Problem: Forming compounds with polyatomic ions and naming

Form compounds between the following ions and name the compound formed.

Polyatomic ions form compounds with cations or anions as usual. Follow the same rules for main group elements and transition metals for nomenclature.

Na^+ and OH^-

Na_1OH_1 NaOH – sodium hydroxide – 1:1 ratio – no brackets necessary.

K^+ and SO_4^{2-}

$K_2(SO_4)_1$ K_2SO_4 – potassium sulfate (one polyatomic ion does not need brackets.

I am not writing cris-cross arrows here as you should be comfortable with it now.

Ca^{2+} and PO_4^{3-}

$Ca_3(PO_4)_2$ – calcium phosphate

Cr^{2+} and HCO_3

$Cr(HCO_3)_2$ – chromium (II) hydrogen carbonate

NH_4^+ and NO_3^-

NH_4NO_3 – ammonium nitrate

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Naming Covalent Compounds

- Combination of nonmetals gives covalent compounds.
- The first element is named as it is and the second one ends with "ide".
- In many cases of covalent compounds, more than one combination of nonmetals is possible, hence "mono", "di" etc. are used to indicate how many atoms are in the compound.
- **Note:** if the first element is only one then don't indicate as "mono".

Example:

- NO nitrogen monoxide
- NO_2 nitrogen dioxide
- N_2O dinitrogen monoxide
- NO_3 nitrogen trioxide
- N_2O_4 dinitrogen tetraoxide
- P_2S_5 diphosphorous pentasulfide

Number	Prefix
1	mono
2	di
3	tri
4	tetra
5	penta
6	hexa
7	hepta
8	octa
9	nona
10	deca

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Solved Problem: Naming covalent compounds
Name the compounds or compounds for the names given below.

OF_2	Oxygen difluoride
S_4N_4	Tetrasulfur tetranitride
CS_2	Carbon disulfide

Boron trichloride	BCl_3
Nitrogen tribromide	NBr_3
Dinitrogen tetrafluoride	N_2F_4

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Acids and Bases

Acids and bases are a class of compounds on their own. We will learn more about them in later chapters. For now, you need to be able to recognize a compound as acid or base and name them. Below are some of the properties of acids and bases and some examples.

Acids	Bases
1. Give protons 2. Corrosive 3. Sour 4. Reacts with metals to give H_2 gas 5. Found in fruit juices **Examples:** Strong acids - Sulfuric acid, nitric acid, hydrochloric acid. Weak acids – phosphoric acid, acetic acid, carbonic acid.	1. Accept protons from acids 2. Caustic 3. Bitter 4. Found in cleaners **Examples:** Strong bases – sodium hydroxide, potassium hydroxide. Weak bases – ammonium hydroxide, sodium carbonate, sodium hydrogen carbonate.

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Naming Acids

There are two kinds of acids – binary and oxo-acids.

Binary acids are formed from the group VII elements, halogens. For this reason they are also called haloacids. They are considered binary acids because there are only two elements in it HX (X stands for halogen).

Oxoacids have oxygen in them and usually formed by addition of protons to polyatomic ions (see then next slide for specific examples).

The table below gives you some examples of all the binary acids and some of the most common oxoacids.

Binary acids (Haloacids) Made from hydrogen halide dissolved in water	
HF	Hydrofluoric acid
HCl	Hydrochloric acid
HBr	Hydrobromic acid
HI	Hydroiodic acid

Oxoacids Made from polyatomic anions.	
HNO_3	Nitric acid
H_2SO_4	Sulfuric acid
H_3PO_4	Phosphoric acid
H_2CO_3	Carbonic acid

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Polyatomic Ions and Their Acids

Formula	Name	H^+ added	Oxoacid	Name
CO_3^{2-}	Carbonate	$+2H^+$	H_2CO_3	Carbonic acid
HCO_3^-	Hydrogen carbonate			
SO_4^{2-}	Sulfate	$+2H^+$	H_2SO_4	Sulfuric acid
HSO_4-	Hydrogen sulfate			
SO_3^{2-}	Sulfite			
HSO_3^-	Hydrogen sulfite			
NO_3^-	Nitrate	$+H^+$	HNO_3	Nitric acid
NO_2-	Nitrite			
PO_4^{3-}	Phosphate	$+3H^+$	H_3PO_4	Phosphoric acid
HPO_4^{2-}	Hydrogen phosphate			
H_2PO_4-	Dihydrogen phosphate			
$C_2H_3O_2^-$ CH_3COO-	Acetate	$+H^+$	$HC_2H_3O_2$ CH_3COOH	Acetic acid

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Naming Bases

Most bases are hydroxides: e.g. sodium hydroxide (NaOH), potassium hydroxide (KOH), aluminum hydroxide ($Al(OH)_3$).

Some other bases are carbonates and hydrogen carbonates (these are weaker bases) e.g.: sodium carbonate (Na_2CO_3), sodium hydrogen carbonate ($NaHCO_3$), sodium sulfite ($NaHSO_3$) etc.

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Naming Hydrates

Hydrates are ionic compounds with water molecules associated with them.

- When the ionic compounds crystallize, water gets trapped in the empty spaces. In some cases, the solids absorb water (hygroscopic).
- This type of water can be removed from the compound by heating the compound.
- Naming is as usual for the ionic compound and then add the water as hydrate with the appropriate prefix of the number of water molecules.

Examples and Names:

$MgSO_4 \cdot 7H_2O$ – Magnesium sulfate heptahydrate

$CuSO_4 \cdot 5H_2O$ - Copper (II) sulfate pentahydrate

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Common Names of Some Compounds

Formula	Common name	IUPAC Name
H_2O	Water	Dihydrogen monoxide
NaCl	Salt	Sodium chloride
CH_4	Methane	methane
CO_2	Dry ice	Carbon dioxide (solid)
NH_3	Ammonia	Trihydrogen nitride
$CaCO_3$	Marble, chalk	Calcium carbonate
$MgSO_4 \bullet 7H_2O$	Epsom salt	Magnesium sulfate heptahydrate
$Mg(OH)_2$	Milk of magnesia	Magnesium hydroxide

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Keywords/Concepts

- Formula unit
- Molecule
- Ionic compounds nomenclature
- Transition metal ions
- Polyatomic ions
- Covalent compounds nomenclature
- Acids and bases
- Hydrates
- Common names