

APPENDIX A: CHEMICAL NOMENCLATURE

Chemical elements are substances which contain atoms that have the same atomic number (number of protons in the atomic nucleus). Each element is described by an international IUPAC name and corresponding symbol.

The combination of two or more atoms results in the formation of *compounds*. Their chemical formulae are always composed of symbols of the elements which the compound contains and indices which indicate the number of corresponding atoms of a given element. E.g. H_2SO_4 (sulphuric acid) is a compound that contains 2 hydrogen atoms, 1 atom of sulphur and 4 oxygen atoms in its molecule.

If an element or a group of elements bears an electric charge we call them *ions*. The charge of an ion is represented by a superscript just after the chemical formula. Positively charged ions (Na^+ , Ca^{2+} , Fe^{2+} , Fe^{3+} , NH_4^+) are called *cations* and negatively charged ions (Cl^- , CN^- , S^{2-} , SO_3^{2-}) are *anions*.

The nomenclature of inorganic compounds is based on the oxidation states of elements. The *oxidation state* is an indicator of the degree of oxidation of an atom in a chemical compound. The formal oxidation state is the hypothetical charge that an atom would have if all bonds to atoms of different elements were 100% ionic. Oxidation states can be positive, negative, or zero. It should be remembered that the oxidation state of an atom does not represent the "real" charge on that atom: this is particularly true for high oxidation states, where the ionisation energy required to produce a multiple positive ion is far greater than the energies available in chemical reactions. Oxidation states are typically represented by oxidation numbers in the form of Roman numerals, which are placed either as a right superscript to the element symbol, e.g. Fe^{III} , or in parentheses after the name of the element, e.g. iron(III): in the latter case, there is no space between the element name and the oxidation number. The sum of oxidation states of all atoms in an electroneutral molecule is equal to zero. Similarly, the oxidation state of free elements is also zero (He^0 , Na^0 , O_2^0 , H_2^0).

An overview of common oxidation states in selected elements:

Element	Oxidation state		Element	Oxidation state	
	<i>negative</i>	<i>positive</i>		<i>negative</i>	<i>positive</i>
H	-I	I	Li, Na, K, Cs, Ag	-	I
Al	-	III	Mg, Ca, Sr, Ba, Zn	-	II
Cr	-	III, VI	Cu, Hg	-	I, II
O	-II	-	Fe, Co	-	II, III
C	-IV	II, IV	Sn, Pb	-	II, IV
Si	-IV	IV	Mn	-	II, III, IV, VI, VII
N	-III	I, II, III, IV, V	P, As, Sb	-III	III, V
S	-II	IV, VI	Cl, Br, I	-I	I, III, V, VII
F	-I	-			

Some compounds may contain several particles of the same type. The number of such particles is expressed by a numerical prefix. The list of common prefixes is shown in the following table. The prefix *mono-* is only used in some special cases (e.g. carbon monoxide) and is usually omitted.

Prefix	Number	Prefix	Number
<i>hemi-</i>	1/2	<i>hepta-</i>	7
<i>mono-</i>	1	<i>okta-</i>	8
<i>di-</i>	2	<i>nona-</i>	9
<i>tri-</i>	3	<i>deca-</i>	10
<i>tetra-</i>	4	<i>undeca-</i>	11
<i>penta-</i>	5	<i>dodeca-</i>	12
<i>hexa-</i>	6	<i>trideca-</i>	13

Nomenclature of cations

When an element only forms one monatomic cation, the ion is named by taking the unchanged name of the element:

E.g. Na^+ *sodium cation*
 Al^{3+} *aluminum cation*
 Ca^{2+} *calcium cation*

When an element forms more cations with different oxidation states, each ion is named so that it is differentiated from the others. There are two ways to do this – the Stock system and the ous-ic system.

Stock System

The oxidation state of the element is indicated by means of a Roman numeral in parentheses after the name of the element.

Ous-ic System

This is an older system, but still permitted by IUPAC and often used. When the element forms two different cations, the lower oxidation state is indicated by the suffix *-ous*, and the higher oxidation state by the suffix *-ic*, following the root of the Latin name of the element.

Element Name		Oxidation State	Formula of Cation	Name	
English	Latin			ous-ic s.	Stock s.
copper	cuprum	+I	Cu^+	cuprous ion	copper(I) ion
		+II	Cu^{2+}	cupric ion	copper(II) ion
tin	stannum	+II	Sn^{2+}	stannous ion	tin(II) ion
		+IV	Sn^{4+}	stannic ion	tin(IV) ion
iron	ferrum	+II	Fe^{2+}	ferrous ion	iron(II) ion
		+III	Fe^{3+}	ferric ion	iron(III) ion
arsenic	arsenium	+III	As^{3+}	arsenous ion	arsenic(III) ion
		+V	As^{5+}	arsenic ion	arsenic(V) ion
lead	plumbum	+II	Pb^{2+}	plumbous ion	lead(II) ion
		+IV	Pb^{4+}	plumbic ion	lead(IV) ion

A special type of complex cation is the ammonium ion (NH_4^+), which is formed by the addition of hydrogen cation (H^+) to a neutral molecule of ammonia. It has the formal oxidation state +I, $(NH_4)^I$.

Oxides

Naming oxides

Oxides are binary compounds with oxygen where the oxidation state of oxygen is O^{-II} . Oxides of metals are named as if they were salts. The name is composed of the cation name and the word **oxide**.

E.g.	Na_2O	<i>sodium oxide</i>
	CaO	<i>calcium oxide</i>
	SnO	<i>tin(II) oxide or stannous oxide</i>
	SnO_2	<i>tin(IV) oxide or stannic oxide</i>
	Cu_2O	<i>copper(I) oxide or cuprous oxide</i>
	CuO	<i>copper(II) oxide or cupric oxide</i>

Oxides of non-metals are named by stating the name of the element first, followed by the word **oxide**. Numeral prefixes are used where necessary:

E.g.	SO_2	<i>sulphur dioxide</i>
	SO_3	<i>sulphur trioxide</i>
	NO	<i>nitrogen oxide or nitrogen monoxide</i>
	N_2O_5	<i>dinitrogen pentoxide</i>
	Cl_2O	<i>dichlorine oxide</i>
	Cl_2O_5	<i>dichlorine pentoxide</i>
	Cl_2O_7	<i>dichlorine heptoxide</i>
	P_2O_3	<i>diphosphorus trioxide</i>
	P_2O_5	<i>diphosphorus pentoxide</i>

Some elements form only one type of oxide. In these cases, the use of numerical prefixes is not necessary:

E.g.	Al_2O_3	<i>aluminum oxide</i>
	SiO_2	<i>silicon oxide</i>

Deriving formulas

To derive a formula for an oxide, write the symbols of the elements together with indices according to the numerical prefix that indicates the number of specified atoms in the molecule.

E.g.	<i>dinitrogen oxide</i>	N_2O
	<i>carbon dioxide</i>	CO_2

In the case of metal oxides, where the numerical prefixes are not usually used, we have to obey the rule of electroneutrality.

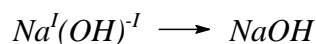
E.g.	<i>boron oxide</i>	$B_2^{III}O_3^{-II} \longrightarrow B_2O_3$
------	--------------------	---



Hydroxides

Hydroxides are compounds which have an OH^- group in their molecules. Since the oxidation state of oxygen is $-II$ and the oxidation state of hydrogen is I , the formal oxidation state of the hydroxide group is $-I$, $(\text{OH})^{-I}$. In the nomenclature of hydroxides the metal ion is named first, followed by the word **hydroxide**. If the oxidation state of the metal is $> I$, we have to put the OH group into brackets.

E.g. sodium hydroxide



calcium hydroxide



aluminum hydroxide



Binary acids

Binary acids are compounds of hydrogen with non-metal. The oxidation state of hydrogen in acids is always $+I$. These acids are actually aqueous solutions of gaseous binary compounds that have the same formula. The most common binary acids are summarised in the following table:

Formula	Name of Pure Compound	Name of Aqueous Solution
HF	hydrogen fluoride	hydrofluoric acid
HCl	hydrogen chloride	hydrochloric acid
HBr	hydrogen bromide	hydrobromic acid
HI	hydrogen iodide	hydroiodic acid
H ₂ S	hydrogen sulphide sulphane	hydrosulphuric acid

Oxoacids

Oxoacids are ternary compounds that can be generally formed by the reaction of non-metal oxides with water. Oxoacids are always formed of hydrogen H^{I} , oxygen $\text{O}^{-\text{II}}$, and a central atom that can have various oxidation states. Such acids are named according to the rules of ous-ic system. When the central atom forms only **one** acid, the suffix *-ic* is used:

E.g. H_2CO_3 carbonic acid

H_2SiO_3 silicic acid

In the case that the central atom forms **two** oxoacids with different oxidation states, the suffixes *-ous* for the lower and *-ic* for the higher oxidation states are used.

Formula	Oxidation state	Systematic name
HNO ₂	+III	nitrous acid
HNO ₃	+V	nitric acid
H ₂ SO ₃	+IV	sulphurous acid
H ₂ SO ₄	+VI	sulphuric acid

Up to four different oxidation states can be differentiated by using the prefix *hypo-* to indicate a state lower than the *-ous* state and the prefix *per-* to indicate a state higher than the *-ic* state.

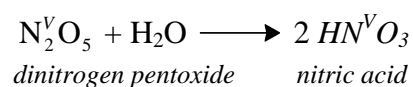
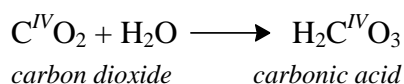
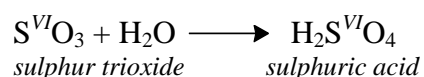
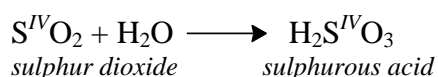
Formula	Oxidation state	Systematic name
HClO	+I	hypochlorous acid
HClO ₂	+III	chlorous acid
HClO ₃	+V	chloric acid
HClO ₄	+VII	perchloric acid

Some acids have more than two hydrogen atoms or more than one central atom in their molecules. These compounds are called polyprotic acids or polyacids, respectively. The number of hydrogen and central atoms is then expressed by numerical prefix.

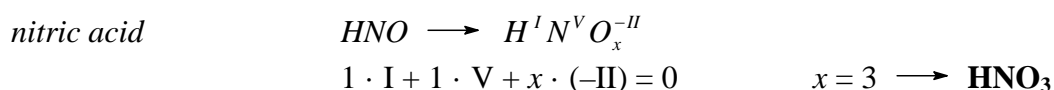
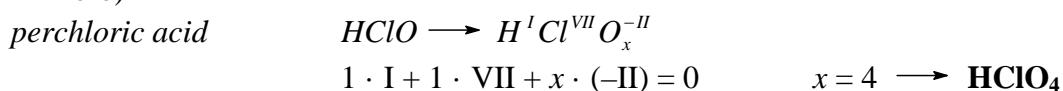
Formula	Oxidation state	Systematic name
H ₃ PO ₄	+V	trihydrogenphosphoric acid
H ₄ SiO ₄	+IV	tetrahydrogensilicic acid
H ₂ S ₂ O ₅	+IV	disulphurous acid
H ₂ S ₂ O ₇	+VI	disulphuric acid
H ₄ P ₂ O ₇	+V	tetrahydrogendiphosphoric acid

Deriving formulas

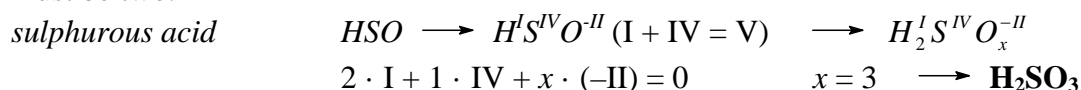
- from corresponding oxides by adding molecule(s) of water and subsequent cancelling of indices



- by applying the rule of electroneutrality (sum of oxidation states must be equal to zero)

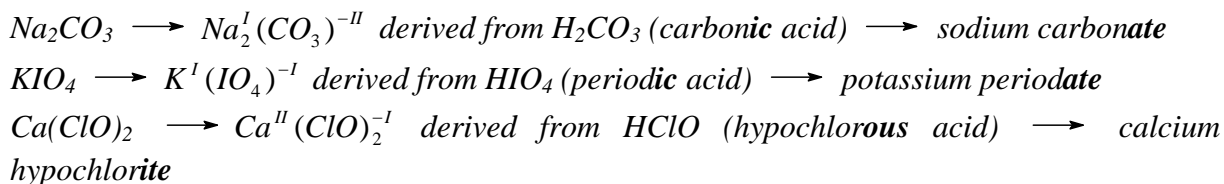


If the sum of positive oxidation numbers is an odd integer the number of hydrogen atoms must be two.

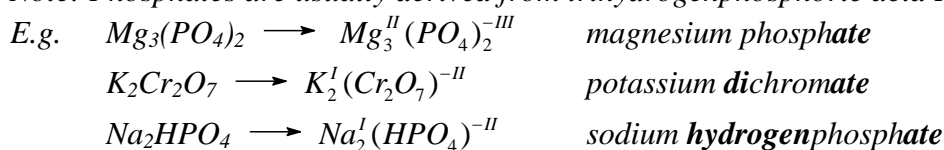


Salts of oxoacids

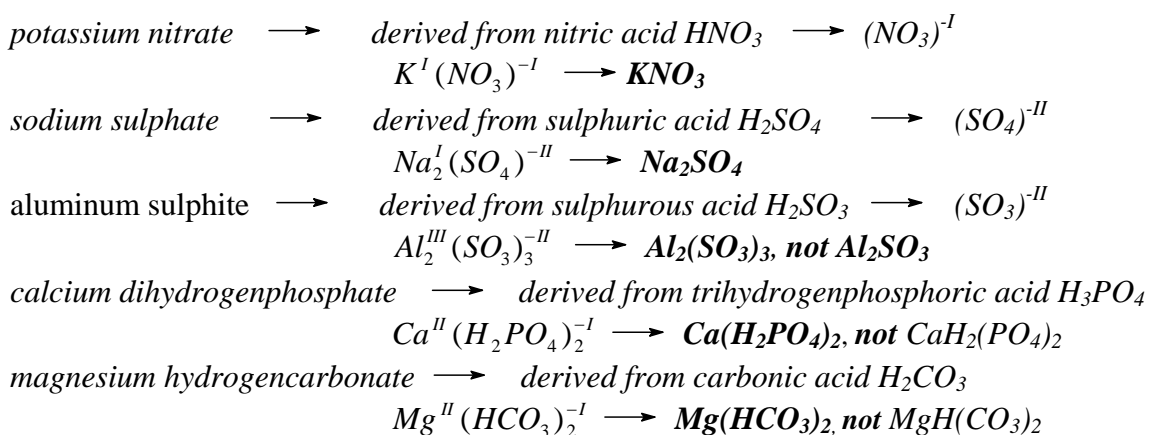
The name of an oxoanion is derived from the name of the corresponding oxoacid. When the name of an acid ends with *-ous* the anion ends with the suffix *-ite* and when the acid ends with *-ic* the corresponding suffix is *-ate*. The system of prefixes for even higher or lower oxidation states is the same as for the naming of acids. The formal oxidation state of an anion can be obtained using the cross rule.



Note: Phosphates are usually derived from trihydrogenphosphoric acid H_3PO_4 .

**Deriving formulas**

To derive the formulas for ternary salts it is necessary to obtain the formula for the corresponding oxoacid. The anion can be obtained by splitting one or more hydrogen atoms from the acid. To obtain the whole formula, put cation first followed by the anionic part together with numerical indices so that the sum of the oxidation numbers is zero. Complex anions that consist of more than one atom must be enclosed in brackets if the numerical index is greater than one.

**Hydrates**

Many inorganic salts and minerals contain weakly bonded molecules of water in their structure. These compounds are called hydrates. The chemical formula is formed from two parts: the formula of a salt and the formula of water, separated by a dot. The number of water molecules is expressed by a capital numeral just before the water formula and is identified in the name by a numerical prefix.

