Molecules, ions and their compounds.

Antoine Lavoisier
(1743-1794)

TRAITÉ
ÉLÉMENTAIRE
DE CHIMIE,
PRÉSENTÉ DANS UN ORDRE NOUVEAU
ET D'APRÈS LES DÉCOUVERTES MODERNES;
Avec Figures:

Par M. LAVOISIER, de l'Académie des Sciences, de la Société Royale de Médecine, des Sociétés d'Agriculture de Paris & d'Orléans, de la Société Royale de Londres, de l'Inflitut de Bologne, de la Société Helvétique de Bafle, de celles de Philadelphie, Harlem, Manchefter, Padoue, &c.

TOME PREMIER.

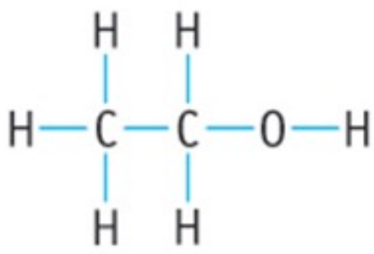
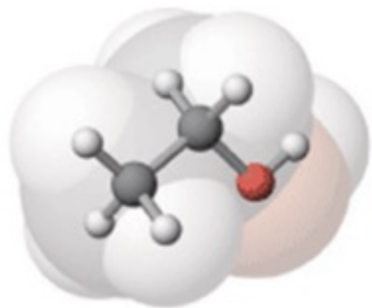
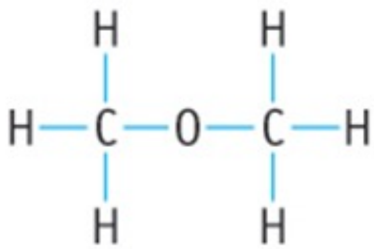
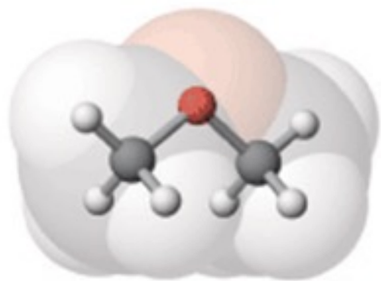
A PARIS,
Chez CUCHET, Libraire, rue & hôtel Serpente.

M. DCC LXXXIX.

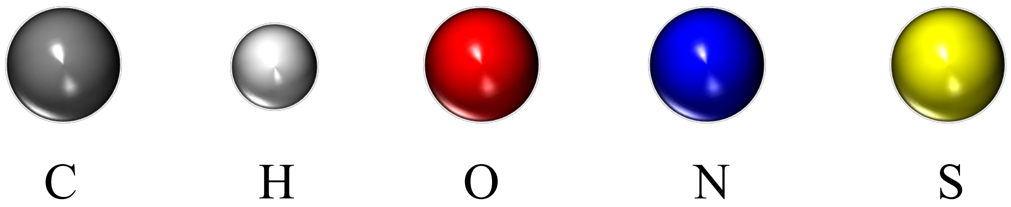
Sous le Privilège de l'Académie des Sciences & de la Société Royale de Médecine.

Chemical formula

There are different ways of representing a chemical formula

Name	Molecular formula	Extended formula	Structural formula	Molecular model
Ethanol	C_2H_6O	CH_3CH_2OH		
Di-methyl ether	C_2H_6O	CH_3OCH_3		

Colour code for atom types in molecular models



Inorganic chemistry compounds

Oxide: compounds containing oxigen

- oxides
- peroxides
- superoxides
- hydroxides (OH^-)

Acids:

- oxides + water (oxoacids)
- elements + hydrogen (hydrides)

Salts: acid + hydroxide

Coordination compound:

Compound in which an element is bound with more atoms than its o.n. would allow.

Oxidation number

1. In free elements (that is, in uncombined state), each atom has an oxidation number of zero. Na, Fe, C, H_2, Cl_2, O_2, etc.

2. In a monoatomic ion, it corresponds to the charge.
ioni Na^+, Ba^{2+}, Fe^{3+}, Br^-, S^{2-} n.o. +1, +2, +3, -1, - 2

3. Hydrogen has always oxidation number +1, with the exception of metal hydrides -1
o.n. H = +1, HCl, H_2O, HNO_3, NH_3, NH_4^+, etc.
o.n. H = -1 NaH, KH, CaH_2

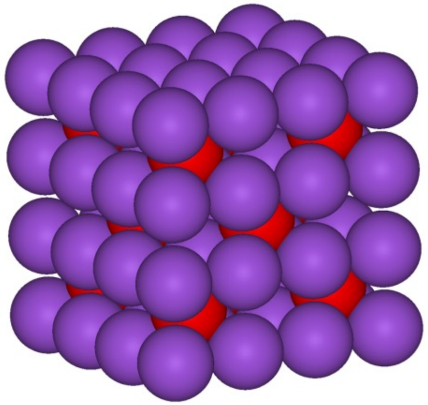
4. Oxygen has oxidation number -2 in most compound, with the exception of peroxides, compounds with F and superoxides.
o.n. O = -2, H_2O, BaO, H_2SO_4, Cl_2O_5, etc.
o.n. O = -1, H_2O_2, Na_2O_2, etc.
o.n. O = +2, OF_2
o.n. = -0.5 NaO_2,

5. The algebraic sum of o.n. in an uncharged compound must be 0
in NaCl, o.n. Na = +1 and o.n. Cl = -1

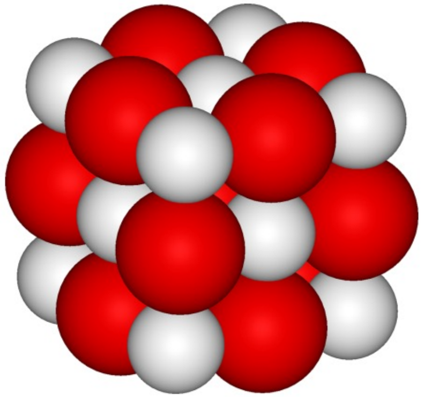
6. The algebraic sum of o.n. in a polyatomic ion must be the charge of the ion. (NH_4^+, SO_4^{2-}, PO_4^{3-}) PO_4^{3-}: o.n. O = -2 and o.n.. P = + 5

Oxides of metals

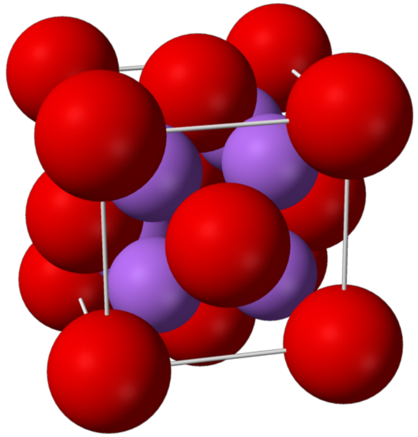
Oxides of elements of Groups I and II are ionic compounds. The metal is a cation and oxygen is in the anionic form O^{2-}.



K_2O



CaO



Na_2O

2 K^+ and 1 O^{2-}

1 Ca^{2+} and 1 O^{2-}

2 Na^+ and 1 O^{2-}

Most oxides of metal are basic. They react with water yielding hydroxides.

$Na_2O + H_2O \rightarrow 2\ NaOH$	Sodium hydroxide
$CaO + H_2O \rightarrow Ca(OH)_2$	Calcium dihydroxide
$FeO + H_2O \rightarrow Fe(OH)_2$	Iron dihydroxide
$Fe_2O_3 + 3\ H_2O \rightarrow 2\ Fe(OH)_3$	Iron trihydroxide
$Al_2O_3 + 3\ H_2O \rightarrow 2\ Al(OH)_3$	Aluminum trihydroxide

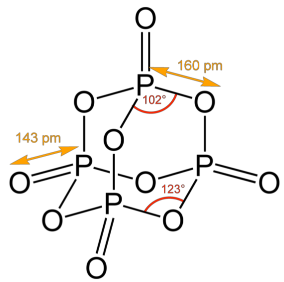
Hydroxides

Ternary complexes formed by H, O and a metal, ionic compounds.
Formula for hydroxides: XOH (metal – hydroxide ions).

Hydroxides have basic properties. Hydroxides from alkali metals (IA group) are strong bases.

hydroxide	name
NaOH	Sodium Hydroxide
KOH	Potassium Hydroxide
$Mg(OH)_2$	Magnesium dihydroxide
$Ca(OH)_2$	Calcium dihydroxide
$Zn(OH)_2$	zinc dihydroxide
$Fe(OH)_2$	Iron dihydroxide (ferrous)
$Al(OH)_3$	Aluminun trihydroxide
$Cr(OH)_3$	Chrome trihydroxide
$Fe(OH)_3$	iron trihydroxide (ferric)

Oxides of nonmetals (anhydrides)

Phosphoric anhydride 

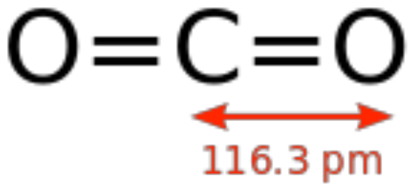
In oxides oxygen always has oxidation number = -2.

Oxides with non metals are also called anhydrides:

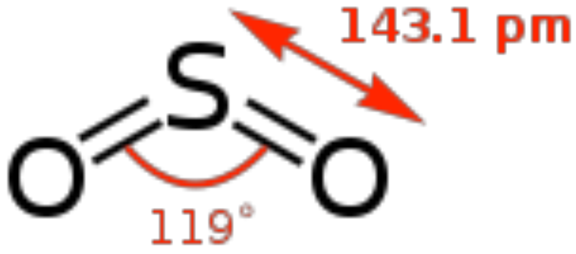
CO_2 (carbon dioxide)
SO_2 (sulpur dioxide)
SO_3 (sulphur trioxide)

IUPAC has suffixes mono-, di-, tri-, tetra-, penta- to indicate the number of O atoms.

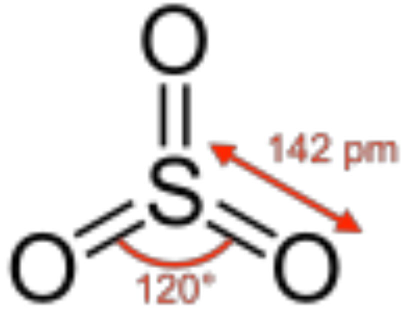
NO: nitrogen monoxide (nitric oxide)
NO_2: nitrogen dioxide
N_2O_3: dinitrogen trioxide

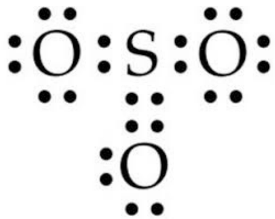


Carbon dioxide
(carbon anhydride)



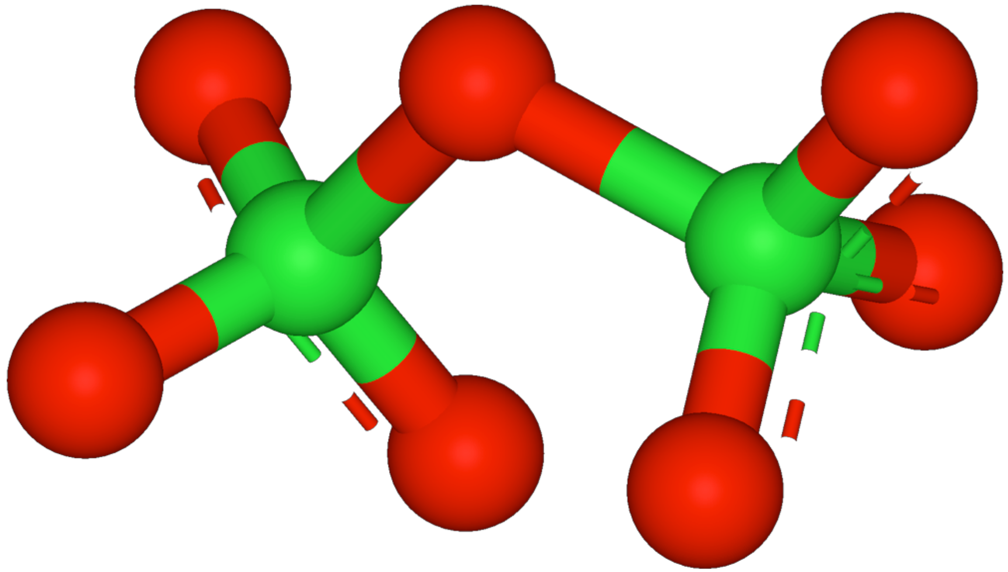
Sulfur dioxide
(sulfurous anhydride o.n.=-4)

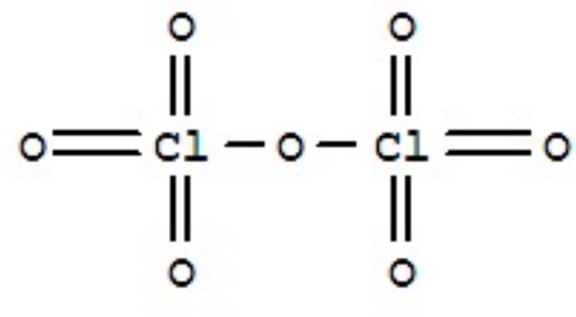




Sulfur trioxide
(sulfuric anhydride o.n.=-6)

NB: suffix -ous = lower oxidation number
suffix -ic = higher oxidation number





Dichlorine heptoxide

Although it is the most stable chlorine oxide, Cl2O7 is a strong oxidizer as well as an explosive that can be set off with flame or mechanical shock, or by contact with iodine. Nevertheless, it is less strongly oxidising than the other chlorine oxides, and does not attack sulfur, phosphorus, or paper when cold. It has the same effects on the human body as elemental chlorine, and requires the same precautions.

Most oxides of nonmetals have acid properties. They react with water yielding oxoacids (or oxyacids).

$N_2O_3 + H_2O \rightarrow 2\ HNO_2$	Nitrous acid
$N_2O_5 + H_2O \rightarrow 2\ HNO_3$	Nitric acid
$SO_2 + H_2O \rightarrow H_2SO_3$	Sulphurous acid
$SO_3 + H_2O \rightarrow H_2SO_4$	Sulphuric acid
$Cl_2O + H_2O \rightarrow 2\ HClO$	Hypochlorous acid
$Cl_2O_3 + H_2O \rightarrow 2\ HClO_2$	Chlorous acid
$Cl_2O_5 + H_2O \rightarrow 2\ HClO_3$	Chloric acid
$Cl_2O_7 + H_2O \rightarrow 2\ HClO_4$	Perchloric acid
$CO_2 + H_2O \rightarrow H_2CO_3$	Carbonic acid
$P_2O_3 + 3\ H_2O \rightarrow 2\ H_3PO_3$	Phosphorous acid
$P_2O_5 + 3\ H_2O \rightarrow 2\ H_3PO_4$	Phosphoric acid

NB: suffix -ous = lower oxidation number
suffix -ic = higher oxidation number

Some common oxides (O_2 Oxidation mumber= –2)

	compound	IUPAC name	Common name (obsolete)	Oxidation number
metals	Na_2O	Disodium oxide	-	+1
	K_2O	Dipotassium oxide	-	+1
	MgO	Magnesium oxide	-	+2
	CaO	Calcium oxide	-	+2
	Al_2O_3	Dialuminum trioxide	-	+3
	FeO	Iron (II) oxide	Ferrous oxide	+2
	Fe_2O_3	Iron (III) oxide	Ferric oxide	+3
non metals	CO	Carbon monoxide		+2
	CO_2	Carbon dioxide	Carbonic ahydride	+4
	N_2O	Dinitrogen oxide	Nitrogen protoxide	+1
	NO	Nitrogen monoxide	-	+2
	N_2O_3	Trinatrogen dioxide		+3
	NO_2	Nitrogen dioxide	-	+4
	N_2O_5	dintrogen pentoxide	Nitric anhydride	+5
	SO_2	Sulphur dioxide	Sulphurous anhydride	+4
	SO_3	Sulphur trioxide	Sulphuric anhydride	+6
	Cl_2O	Dichlorine oxide	Hypochlorous anhydride	+1
	Cl_2O_3	Dichlorine trioxide	Chlorous anhydride	+3
	Cl_2O_5	Dichlorine pentoxide	Chloric anhydride	+5
	Cl_2O_7	Dichlorine heptoxide	Perchloric anhydride	+7

Peroxides

Compounds containing the group: -O - O –
Oxygen has oxidation number = - 1

They can be covalent (hydrogen peroxide, H_2O_2)
or ionic (sodium peroxide, Na_2O_2, calcium peroxide, CaO_2) peroxidic group: O_2^{2-}

Superoxides

Ionic compounds containing the ion: O_2^-
In superoxide, it has oxidation number -1/2

Combination of the metal ion with the superoxid anion (O_2^-),
es. NaO_2, KO_2

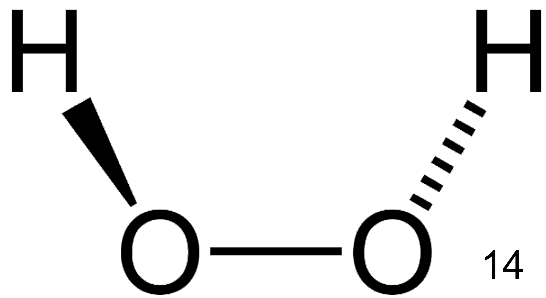
SUPEROXIDE ION

The six outer electrons of each atom of oxygen are highlighted in black; an electron pair is shared; The unpaired electron is shown in the upper left and the extra electron which gives the negative charge is shown in red.

Superoxide is toxic and is used by the immune system as defense against pathogenic microorganisms.

Peroxides are compounds containing this consisting of two oxygen atoms joined by a single bond (O-O).

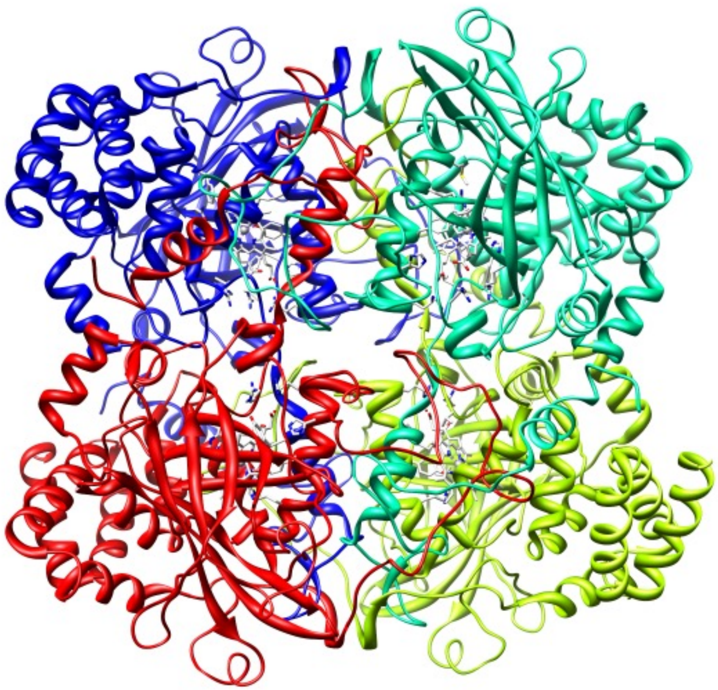
Hydrogen peroxide



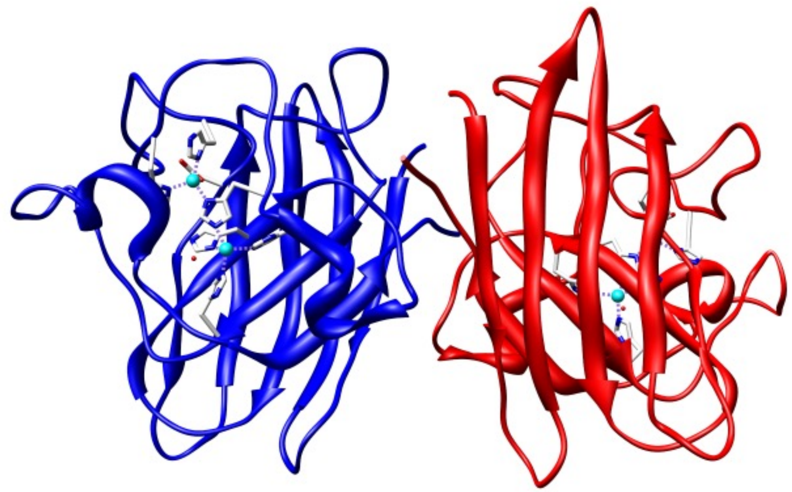
Hydrogen peroxide and superoxide ion are oxidizing agents, toxic for the cell. Two enzymes can transform these compounds into less harmful products.

catalase: $2\ H_2O_2 \rightarrow 2\ H_2O + O_2$

Superoxide dismutase: $2\ O_2^- + 2\ H^+ \rightarrow H_2O_2 + O_2$



Human catalase



Bovine superoxide dismutase.

The peroxisomal disorder acatalasia is due to a deficiency in the function of catalase. Genetic polymorphisms in catalase and its altered expression and activity are associated with oxidative DNA damage and subsequently the individual’s risk of cancer susceptibility

Mice lacking SOD2 die several days after birth, amid massive oxidative stress. Mice lacking SOD1 develop a wide range of pathologies, including hepatocellular carcinoma, an acceleration of age-related muscle mass loss, an earlier incidence of cataracts and a reduced lifespan. Mice lacking SOD3 do not show any obvious defects and exhibit a normal lifespan, though they are more sensitive to hyperoxic injury.

Electronegativity determines the polarization of the chemical bond

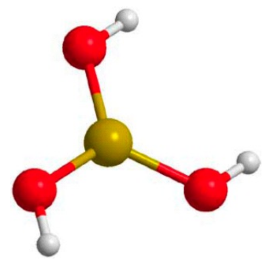
- Metals donate electrons yielding cations
- Nonmetals acquire electrons yielding anions.

1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 –	113 –	114 –	115 –	116 –		

metals | Transition metals | metalloids | Nonmetalls

Elements of group III: B vs Al

H_3BO_3 Boric acid.
Reacts with water:



$$\underset{\displaystyle |\atop OH}{HO\text{-}B\text{-}OH} + H_2O \rightleftharpoons H^+ + \overset{\displaystyle OH\atop |}{\underset{\displaystyle |\atop OH}{HO\text{-}B\text{-}OH^-}}$$

$Al(OH)_3$ Aluminum oxide
Reacts with water:

$$Al(OH)_3 \xrightarrow{H_2O} Al^{3+} + 3\ OH^-$$

The difference in behaviour depends on difference in polarization of the bonds B-O e Al-O

Most oxides of nonmetals have acid properties. They react with water yielding oxoacids (or oxyacids).

$N_2O_3 + H_2O \rightarrow 2\ HNO_2$	Nitrous acid
$N_2O_5 + H_2O \rightarrow 2\ HNO_3$	Nitric acid
$SO_2 + H_2O \rightarrow H_2SO_3$	Sulphurous acid
$SO_3 + H_2O \rightarrow H_2SO_4$	Sulphuric acid
$Cl_2O + H_2O \rightarrow 2\ HClO$	Hypochlorous acid
$Cl_2O_3 + H_2O \rightarrow 2\ HClO_2$	Chlorous acid
$Cl_2O_5 + H_2O \rightarrow 2\ HClO_3$	Chloric acid
$Cl_2O_7 + H_2O \rightarrow 2\ HClO_4$	Perchloric acid
$CO_2 + H_2O \rightarrow H_2CO_3$	Carbonic acid
$P_2O_3 + 3\ H_2O \rightarrow 2\ H_3PO_3$	Phosphorous acid
$P_2O_5 + 3\ H_2O \rightarrow 2\ H_3PO_4$	Phosphoric acid

NB: suffix -ous = lower oxidation number
suffix -ic = higher oxidation number

Oxyacids

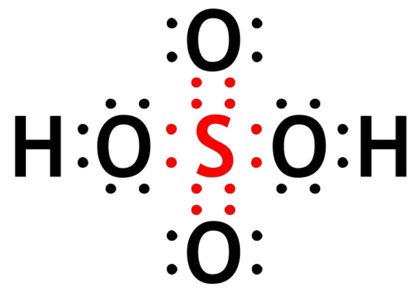
Ternary complexes formed by H, O and a nonmetal, or a metal whose oxide has acidic properties (i.e.: Cr, Mn, V).
Oxoacids have a formula HXO, whereas hydroxides are indicated as XOH.

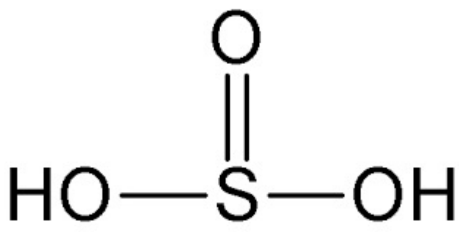
This convention allows to assign the properties of ternary compounds.

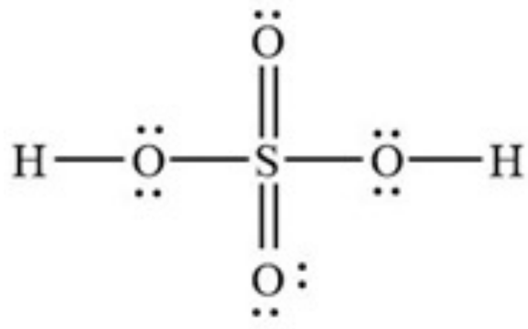
Nomenclature highlights the degree of oxidation:

suffix -ous = smaller oxidation number
suffix -ic = larger oxidation number
e.g.: sulphorous acid (H_2SO_3, o.n. S = +4)
sulphuric acid (H_2SO_4, n.o. S = +6)

Nitrous acid (HNO_2, n.o. N = +3)
Nitric acid (HNO_3, n.o. N = +5)
Sulphurous acid (H_2SO_3, n.o. S = +4)
Sulphuric acid (H_2SO_4, n.o. S = +6)

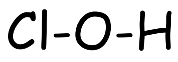




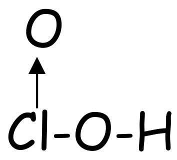


If suffixes do not allow to name all oxoacids prefixes are used:
hypo- and per-

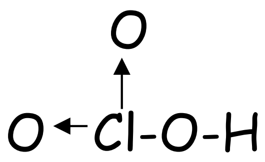
hypochlorous acid (HClO, n.o. +1)
chlorous acid ($HClO_2$, n.o. +3)
chloric acid ($HClO_3$, n.o. +5)
perchloric acid ($HClO_4$, n.o. +7)



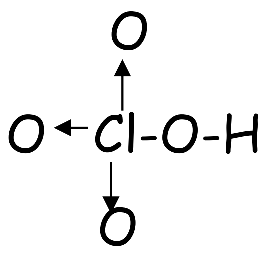
Hypochlorous acid



Chlorous acid



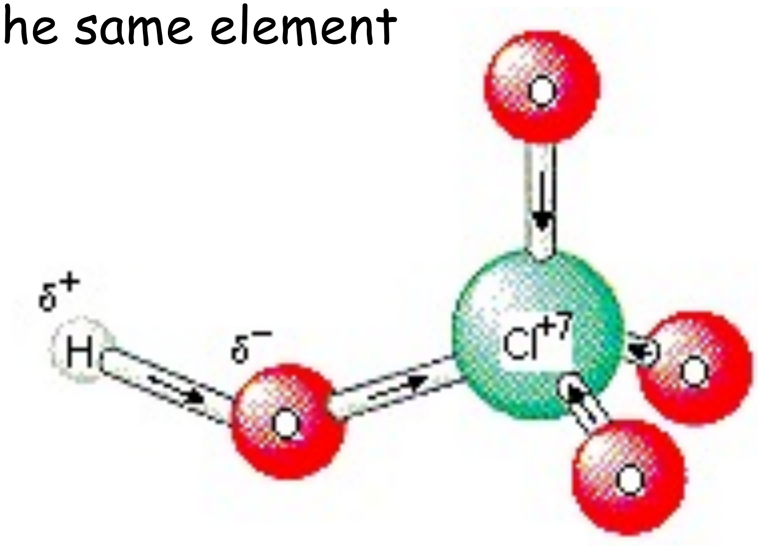
Chloric acid



Perchloric acid

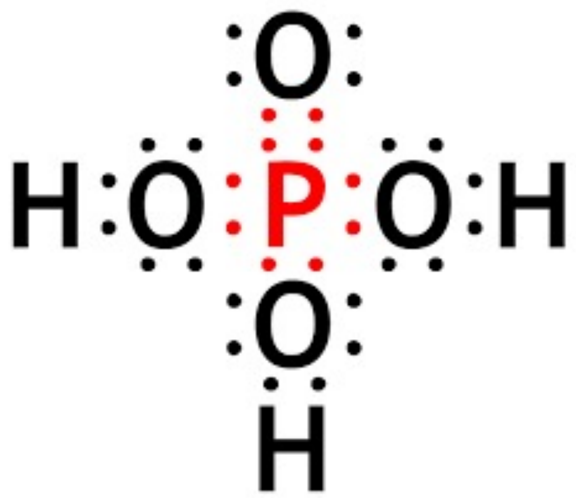
Oxygen atoms are added by means of coordination bond.
The maximum number of oxygen atoms depends the number of pairs available
and the radius of the atom.

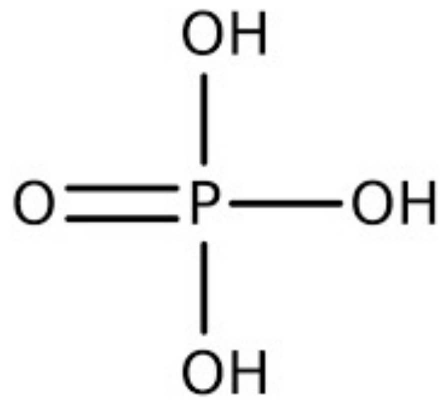
Behaviour of different oxoacids of the same element



Polarization of the O-H bond depends on the attraction of electron exerted by the O atom.

hypochlorous acid ($HClO$, n.o. +1) Very weak
chlorous acid ($HClO_2$, n.o. +3) weak
chloric acid ($HClO_3$, n.o. +5) strong
percloric acid ($HClO_4$, n.o. +7) very strong



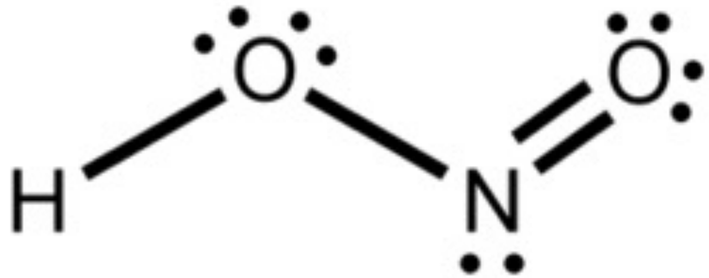


PHOSPHORIC ACID H_3PO_4

NITROUS AND NITRIC ACIDS

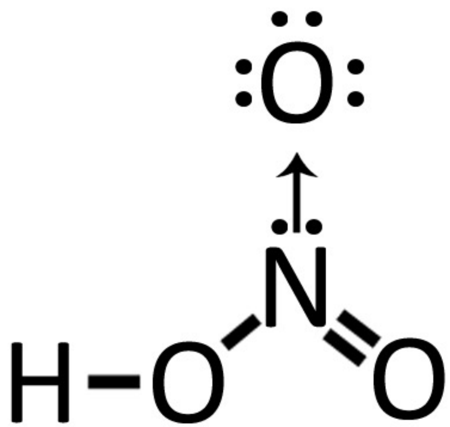
Nitrous acid

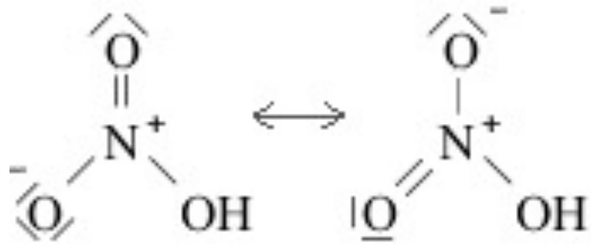
HNO_2



Nitric acid

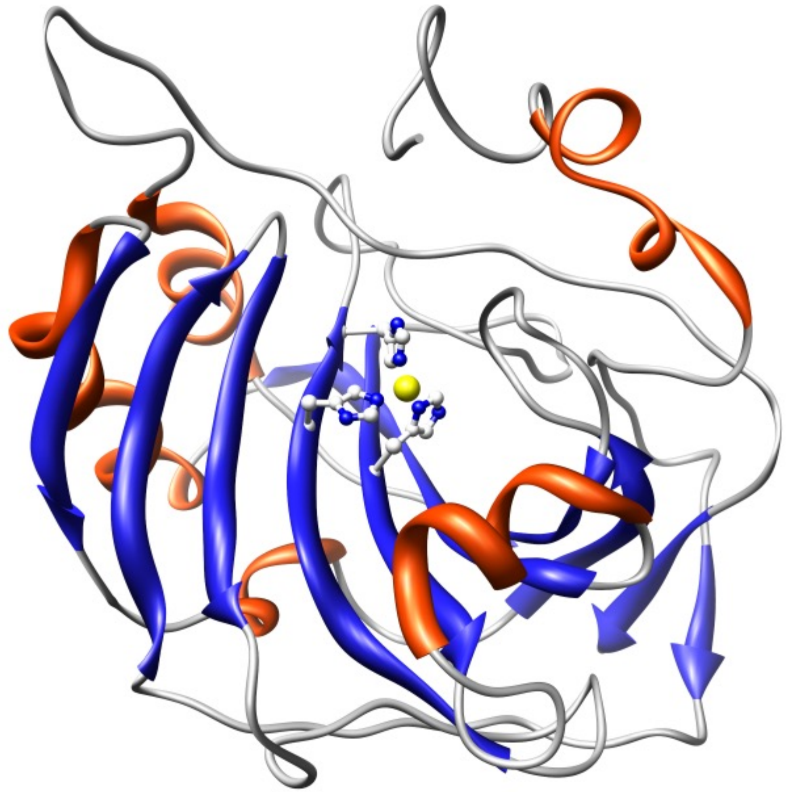
HNO_3





Carbonic anhydrase plays a role in CO_2 transport in blood.

Venous blood: $CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$



Arterial blood: $HCO_3^- + H^+ \rightarrow H_2CO_3 \rightarrow CO_2 + H_2O$

Common oxoacids (oxygen o.n. -2)

Oxoacid	Formula	Anion	Anion Formula
acetic acid	CH_3COOH	acetate	CH_3COO^-
carbonic acid	H_2CO_3	carbonate	CO_3^{2-}
chloric acid	$HClO_3$	chlorate	$ClO_3^=$
chlorous acid	$HClO_2$	chlorite	ClO_2^-
hypochlorous acid	$HClO$	hypochlorite	ClO^-
iodic acid	HIO_3	iodate	IO_3^-
nitric acid	HNO_3	nitrate	NO_3^-
nitrous acid	HNO_2	nitrite	NO_2^-
perchloric acid	$HClO_4$	perchlorate	ClO_4^-
phosphoric acid	H_3PO_4	phosphate	PO_4^{3-}
phosphorous acid	H_3PO_3	phosphite	PO_3^{3-}
sulfuric acid	H_2SO_4	sulfate	SO_4^{2-}
sulfurous acid	H_2SO_3	sulfite	SO_3^{2-}

Hydrides

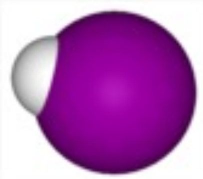
Binary compounds of hydrogen. The ratio with elements from I to VII group are fixed: 1, 2, 3, 4, 3, 2, 1 (LiH, CaH_2, AlH_3, CH_4, NH_3, H_2O, HF)

Metal hydrides: with elements from groups IA and IIA. Hydrogen has o.n. -1. With the exception of LiH e BeH_2, they ara ionic compounds. Hydrogen taks the form of hydride ion (H^-). $H^- + H^+ \rightarrow H_2$; $\Delta H = -1676$ kJ/mol

Covalent hydrides: with elements of groups from IV on (CH_4, methane; SiH_4, silane; NH_3, ammonia; PH_3, phosphane (phosphine).

Hydracids : binary compounds of H with elements from groups VI and VII.
Nomenclature IUPAC Hydrogen + name of the elemnt +suffix -ide)
(prefix hydro- + name of the element + acid):
Es. HF, hydrophluoric acid; HCl, hydrochloric acid; HBr, hydrobromic acid; HI, hydroiodic acid.
Hydrogen sulphide H_2S

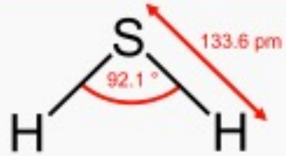
Cations from hydrides take the suffix -onium.
E.g.: PH_4^+, phosphonium; NH_4^+, ammonium; H_3O^+, oxonium (or hydronium).

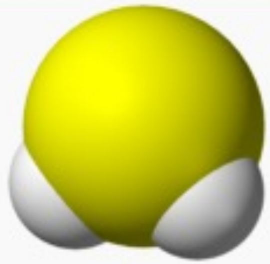
compound	formula	structure	model	d(H–X) / pm (gas phase)	μ / D
hydrogen fluoride	HF	H—F 91.7 pm		91.7	1.86
hydrogen chloride	HCl	H—Cl 127.4 pm		127.4	1.11
hydrogen bromide	HBr	H—Br 141.4 pm		141.4	0.788
hydrogen iodide	HI	H—I 160.9 pm		160.9	0.382

hydrogen halides

Hydrogen oxide (H_2O): water.

Hydrogen sulfide





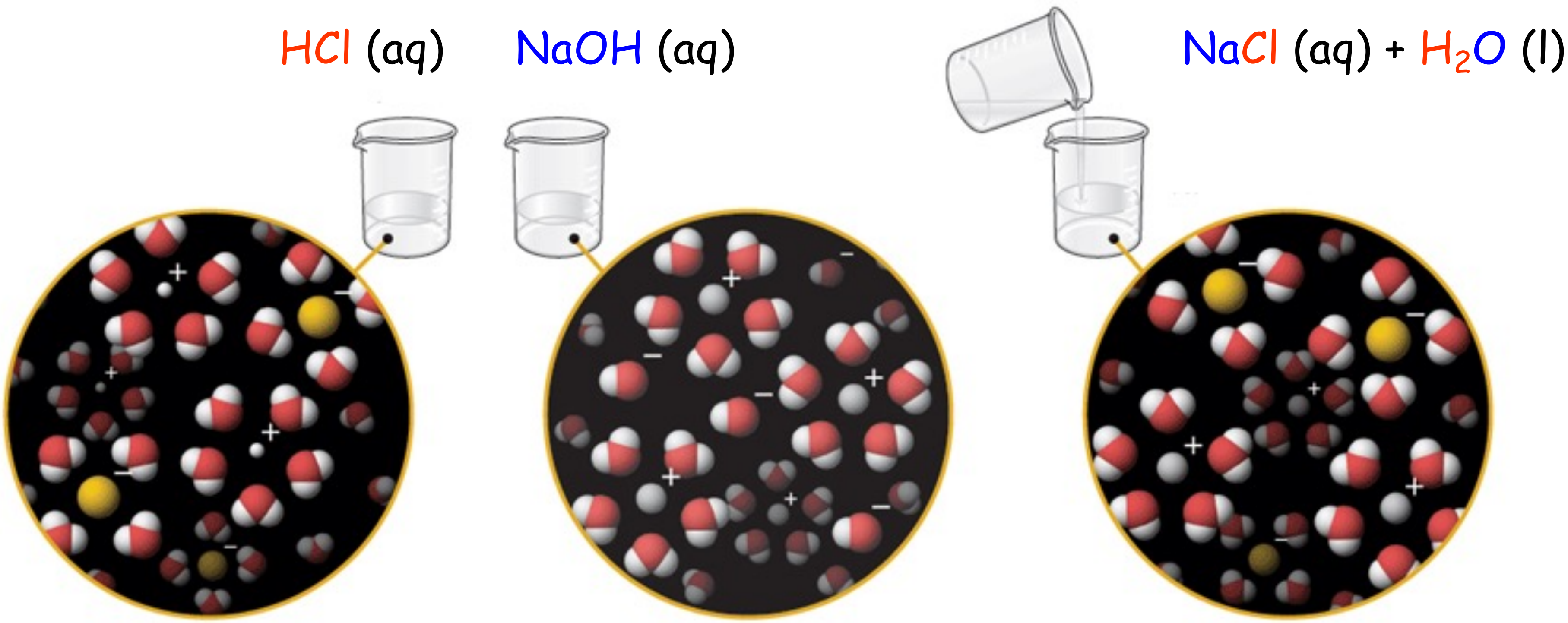
Systematic name [hide]

Hydrogen sulfide[1]

Salts

Ionic compounds arising from the reaction of a base with an acid (neutralization of acids with bases).

$$HCl\ (aq) + NaOH\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l)$$



Nomenclature of salts

The metallic component (positive) is written first, the nonmetallic component (acidic radical, negative) follows.
The name of the salt is formed with: cation name + acidic radical.

type	Acid suffix	Salt suffix	acid	salt
oxoacid	–ous	–ite	HNO_2 Nitrous acid	$NaNO_2$ Sodium nitrite
oxoacid	–ic	–ate	H_2SO_4 Sulphuric acid	$CaSO_4$ Calcium sulphate
hydracid	–ide	–ide	HCl Hydrogen chloride	KCl Potassium chloride

common salts

acid	base	salt	IUPAC name	Traditional name
HCl	NaOH	NaCl	Sodium chloride	Sodium chloride
HF	$Ca(OH)_2$	CaF_2	Calcium difluoride	Calcium fluoride
HBr	$Al(OH)_3$	$AlBr_3$	Aluminum tribromide	Aluminum bromide
H_2S	$Fe(OH)_2$	FeS	Iron (II) sulphide	Ferrous sulphide
H_2S	$Fe(OH)_3$	Fe_2S_3	Iron (III) trisulphide	Ferric sulphide
H_2S	KOH	K_2S	Dipotassium sulphide	Potassium sulphide
H_2CO_3	NaOH	Na_2CO_3	Disodium carbonate	Sodium carbonate
H_2SO_4	KOH	K_2SO_4	Dipotassium sulphate	Potassium sulphate
H_2SO_4	$Fe(OH)_2$	$FeSO_4$	Iron (II) sulphate	Ferrous sulphate
H_2SO_4	$Fe(OH)_3$	$Fe_2(SO_4)_3$	Iron (III) trisulphate	Ferric sulphate
H_3PO_4	$Ca(OH)_2$	$Ca_2(PO_4)_3$	Dicalcium triphosphate	Calcium phosphate
$HMnO_4$	KOH	$KMnO_4$	Potassium manganate(IV)	Potassium permanganate

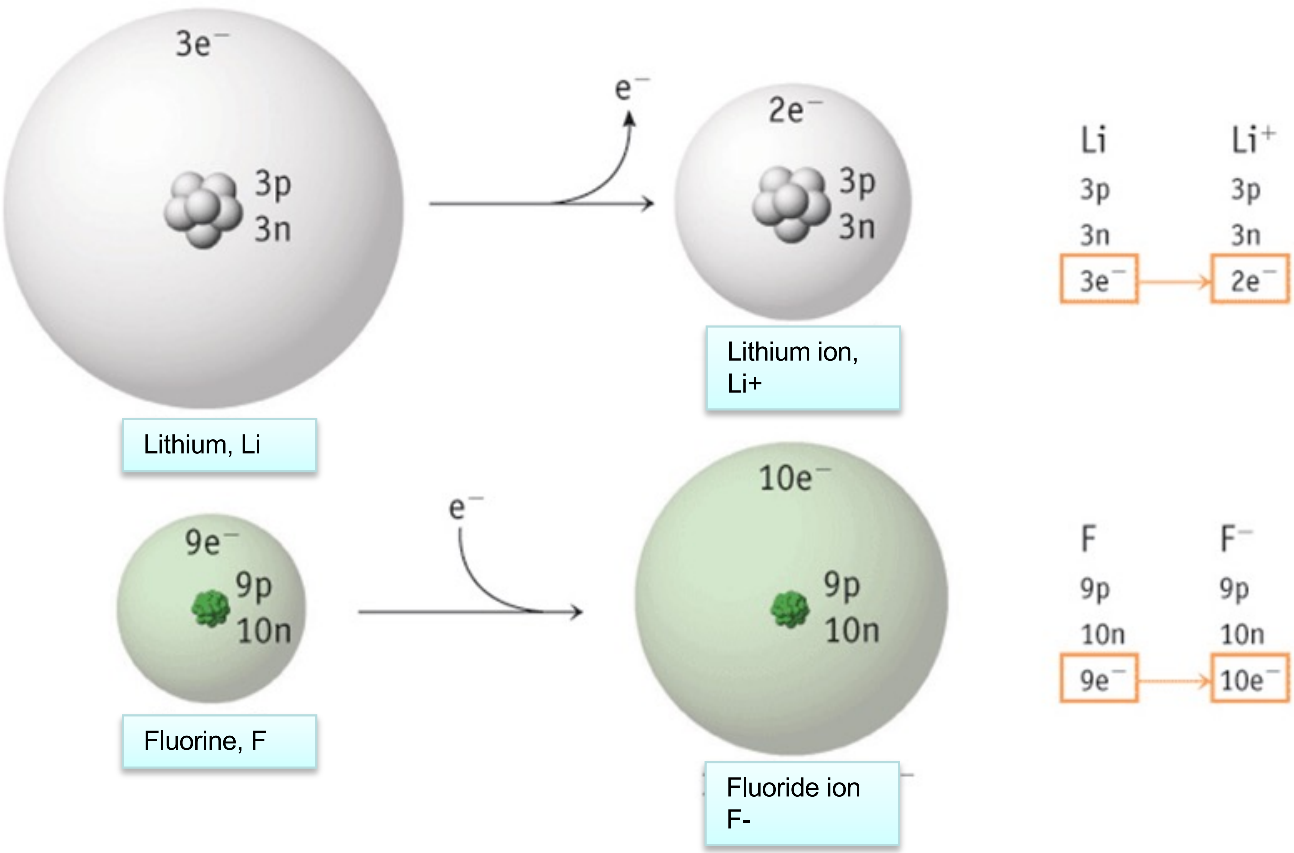
Ionic compounds

Ionic compounds consist of ions, atoms or groups of atoms that have positive or negative charges.

Common name	name	formula	Ions
salt	Sodium chloride	$NaCl$	Na^{+}, Cl^{-}
lime	Calcium oxide	CaO	Ca^{2+}, O^{2-}
limestone	Calcium carbonate	$CaCO_3$	Ca^{2+}, CO_3^{2-}
fluorite	Calcium fluoride	CaF_2	Ca^{2+}, F^{-}
gypsum	Calcium sulphate dihydrate	$CaSO_4 \cdot 2 H_2O$	Ca^{2+}, SO_4^{2-}
hematite	Iron oxide (III)	Fe_2O_3	Fe^{3+}, O^{2-}
orpiment	Arsenic sulfide	As_2S_3	As^{3+}, S^{2-}

The atoms of many elements can give away or acquire electrons during a chemical reaction. To be able to predict the outcome of a chemical reaction, one needs to know if an element acquires or gives up electrons, and if so, how many.

When an atom gives away one or more electrons (transferred to another atom in a reaction), a positively charged ion called cation is formed. When an atom acquires an electron, a negatively charged ion called anion is formed.



Can we predict if an atom of an element will preferentially form a cation or an anion?

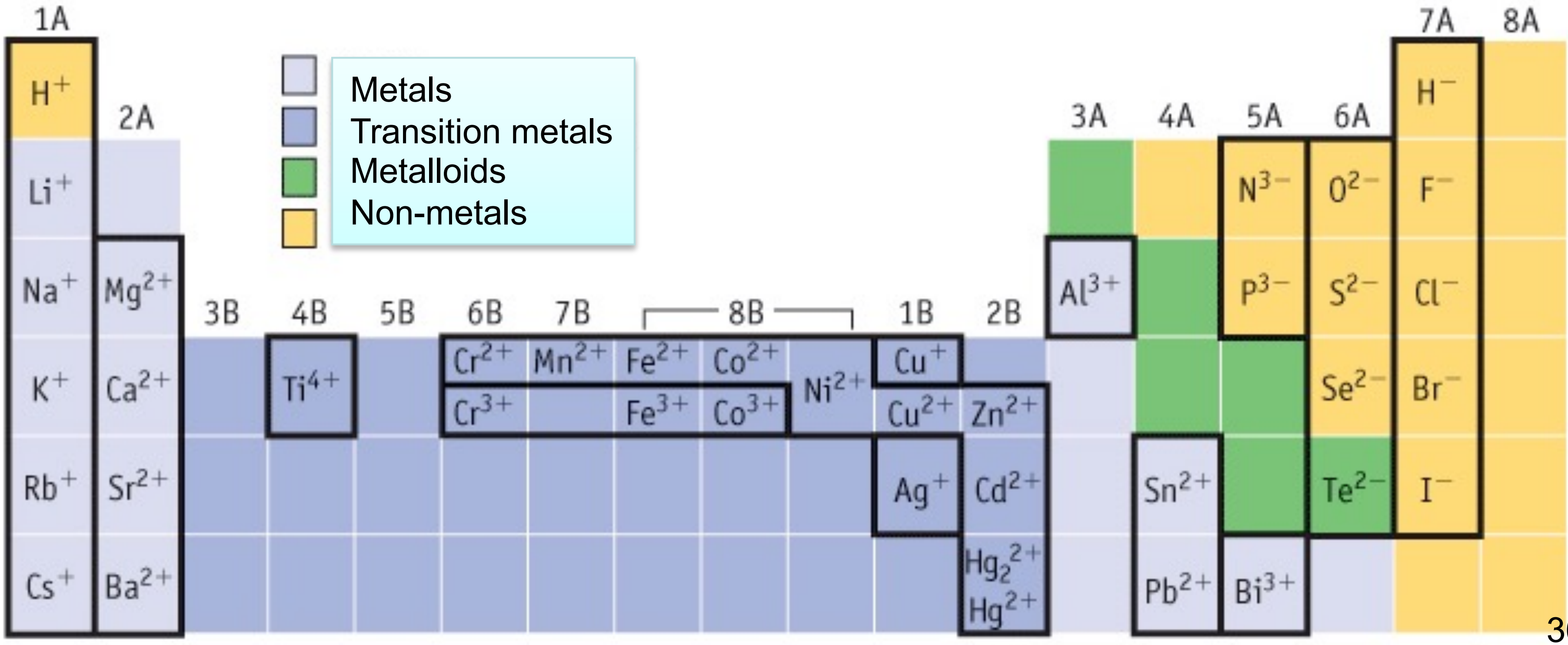
- Metals generally give up their electrons giving rise to cations.
- Non-metals frequently acquire electrons giving rise to anions.

1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 –	113 –	114 –	115 –	116 –		

metals | Transition metals | metalloids | Non-metals

Mono-atomic ions

From elements which have lost or acquired electrons.
1A-3A form positive ions with charge equal to the number of the group.
There are no rules for transition metals.
Non-metals often form ions with negative charge equal to: 8- group number.



group	element	electrons	cation
metals			
1A	Na (11 protons, 11 electrons)	–1	Na^{+} (11 protons, 10 electrons)
2A	Ca (20 protons, 20 electrons)	–2	Ca^{2+} (20 protons, 18 electrons)
3A	Al (13 protons, 13 electrons)	–3	Al^{3+} (13 protons, 10 electrons)
Transition metals			
7B	Mn (25 protons, 25 electrons)	–2	Mn^{2+} (25 protons, 23 electrons)
8B	Fe (26 protons, 26 electrons)	–2	Fe^{2+} (26 protons, 24 electrons)
8B	Fe (26 protons, 26 electrons)	–3	Fe^{3+} (26 protons, 23 electrons)
Non-metals			
5A	N (7 protons, 7 electrons)	+3	N^{3-} (7 protons, 10 electrons)
6A	S (16 protons, 16 electrons)	+2	S^{2-} (16 protons, 18 electrons)
7A	Br (35 protons, 35 electrons)	+1	Br^{-} (35 protons, 36 electrons)

Notation for positive ions (cations).

With few exceptions (such as NH_4^+, ammonium) positive ions arise from metals. They are named according to these rules.

1) For a positive mono-atomic ion, use the name of the metal followed by the word "cation". E.g.. Ag^+ is called "Silver cation".

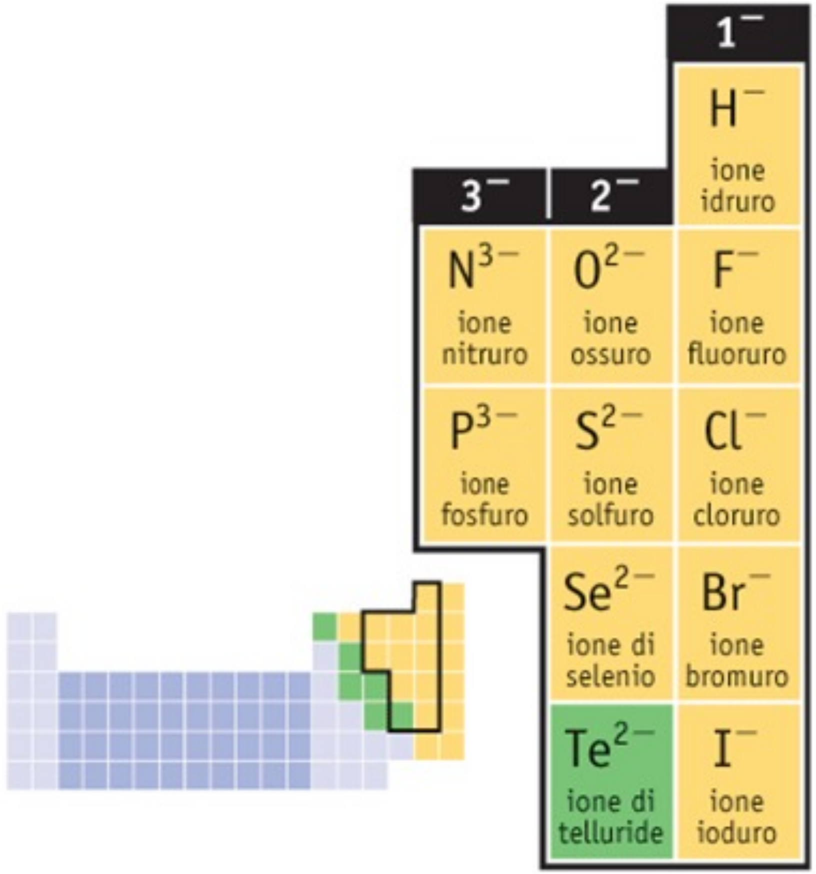
2) Cations that can have on more than one positive charge are labeled with Roman numerals in parentheses. E.g.: Co^{1+} is Copper (I) and Cu^{2+} is Copper(II) ("copper one cation" and "copper two cation").

1) An older, notation is to append -*ous* or -*ic* to the root of the Latin name to name ions with a lesser or greater charge: Cu^{2+} = Cupric and Cu^{1+} = Cuprous.

Notation for negative ions (anions).

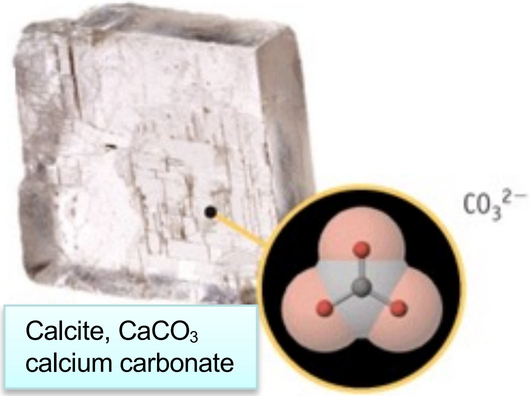
Two types of anions: monoatomic and polyatomic
The name of a monoatomic negative ione is formed by adding the **-ide** ending to the name of the non-metal element. E.g. Cl^- is called chloride anion.

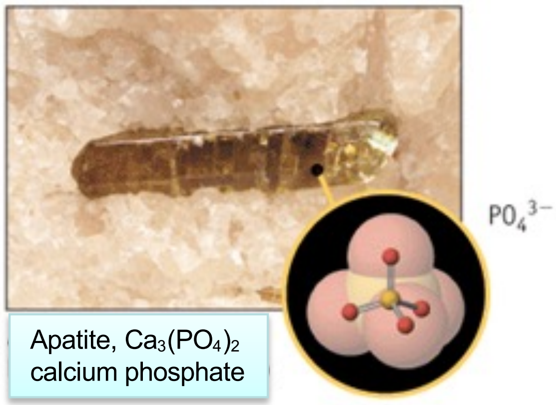
H^- Hydride
F^- Fluoride
O^{2-} Oxide
S^{2-} Sulfide
N^{3-} Nitride
P^{3-} Phosphide



Molecular ions (polyatomic)

Made up by more than one atom, electrically charged.





E.g.: the carbonate ion, CO_3^{2-}, is formed by 1 atom of C and 3 atoms of O. It has 2 negative charges since it contains two extra e^-.

Ionic compounds have net charge=0

Ruby is made up by ions Al^{3+} and oxide ions O^{2-}. To achieve null charge 2 Al^{3+} ions [total charge = 2 x (3+) = 6+] are combined with 3 O^{2-} ions [total charge = 3 x (2-) = 6+] to yield Al_2O_3.

Polyatomic ions that contain oxygen are called oxyanions.

- Oxyanions are named with *-ite* or *-ate*, for a lesser or greater quantity of oxygen.

NO_3^- is called nitrate and NO_2^- is called nitrite
SO_4^{2-} is called sulphate e SO_3^{2-} is called sulphite

- If four oxyanions are possible, the prefixes *hypo-* and *per-* are used:

ClO_4^- is called perchlorate e ClO_3^- is called chlorate
ClO_2^- is called chlorite e ClO^- is called hypochlorite

- The modern systematic specifically names the hydrogen atom.

HPO_4^{2-} is hydrogen phosphate e $H_2PO_4^{1-}$ is dihydrogen phosphate
HCO_3^- is called hydrogen carbonate (bicarbonate) e HSO_4^{2-} is hydrogen sulphate.

Formula and names of some common polyatomic anions

Formula	Name	Formula	Name
Group 4A		Group 7A	
CN^-	Cyanide ion	ClO^-	Hypochlorite ion
$CH_3CO_2^-$	Acetate ion	ClO_2^-	Chlorite ion
CO_3^{2-}	Carbonate ion	ClO_3^-	Chlorate ion
HCO_3^-	Hydrogen carbonate (bicarbonate)	ClO_4^-	Perchlorate ion
Group 5A		Transition metals	
NO_2^-	Nitrite ion	CrO_4^-	Chromate ion
NO_3^-	Nitrate ion	$Cr_2O_7^{2-}$	Dichromate ion
PO_4^{3-}	Phosphate ion	MnO_4^-	Permanganate ion
HPO_4^{2-}	Hydrogen phosphate ion		
$H_2PO_4^-$	Di-hydrogen phosphate		
Group 6A			
OH^-	Hydroxide ion		
SO_3^{2-}	Sulphite ion		
SO_4^{2-}	Sulphate ion		
HSO_4^-	Hydrogen sulphate ion		

Inorganic compounds

ACIDS

1. Hydrogen halides

HF	hydrogen fluoride (hydrofluoric acid)	strong	caustic
HCl	hydrogen chloride (hydrochloric acid)	strong	digestive fluid
HBr	hydrogen bromide (hydrobromic acid)	strong	caustic
HI	hydrogen iodide (hydroiodic acid)	strong	caustic

2. Oxyacids

HClO	hypochlorous acid	weak	oxidant
$HClO_2$	chlorous acid	weak	oxidant
$HClO_3$	chloric acid	strong	oxidant
$HClO_4$	perchloric acid	strong	oxidant/caustic
HNO_2	Nitrous acid	weak	atmosphere/ozone depletion
HNO_3	nitric acid	strong	caustic
H_2SO_4	sulfuric acid	strong	caustic
H_2SO_3	sulphorous acid	strong	caustic
H_3PO_4	phosphoric acid	weak	buffer in blood
H_3BO_3	boric acid	weak	antiseptic
H_2CO_3	carbonic acid	weak	buffer in blood
$HMnO_4$	Permanganic acid		oxidizing salts
HCN	hydrogen cyanide (cyanidric acid)weak	poison	

Inorganic compounds

BASES (hydroxides)

NaOH	sodium hydroxide	strong	caustic
KOH	potassium hydroxide	strong	caustic
$Ca(OH)_2$	calcium hydroxide	strong	caustic
$Mg(OH)_2$	magnesium (di)hydroxide	strong	caustic
$Al(OH)_3$	aluminun (tri hydroxide	strong	caustic
$NH_3.H_2O$	ammonia	weak	surface cleaning
NH_4OH	ammonium hydrodide		

OXIDES

CO	carbon monoxide	lethal gas
Na_2O	(di)sodium oxide	yields hydroxide in water
K_2O	(di)sodium oxide	yields hydroxide in water
CaO	calcium oxide	yields hydroxide in water
MgO	magnesium oxide	yields hydroxide in water
Al_2O_3	(di)aluminum (tri)oxide	yields hydroxide in water

OXIDES (anhydrides that in water yield oxyacids)

CO_2	carbon dioxide	present in air, cell resp. product
NO	nitrogen oxide	messenger, vasodilation, toxic
NO_2	nitrogen dioxide	$2\ NO_2 + H_2O \rightarrow HNO_2 + HNO_3$
		Exhaustion gas (+ H_20 acid rain)
SO_2	sulfur dioxide	$SO_2 + H_2O \rightarrow H_2SO_3$
SO_3	sulfur trioxide	$SO_3 + H_2O \rightarrow H_2SO_4$

Inorganic compounds

SALT

Non-hydrolizing salts (neutral)

NaCl	sodium chloride	body fluids, cells
KCl	potassium chloride	ubiquitario
KBr	potassium bromide	sedative
KI	potassium iodide	supply for tyroid
$CaCl_2$	calcium chloride	ion supply
$MgSO_4$	magnesium sulfate	low solubility/ laxative
KNO_3	potassium nitrate	fertilizer/agriculture
$NaNO_3$	sodium nitrate	fertilizer/agriculture
$CuSO_4$	copper sulfate	antimicrobial/agriculture
$AgNO_3$	silver nitrate	local antiseptic
$KMnO_4$	potassium permanganate	antiseptic/oxidizing
$HgCl_2$	mercury choride	toxic
$BaSO_4$	barium sulfate	low solubility/ x-ray diagnistics

SALT (Acidic hydrolysis)

NH_4Cl	ammonium chloride	urine
$CH_3COO(NH_4)$	ammonium acetate	lab reagent
$(NH_4)_2SO_4$	ammonium sulphate	lab reagent

SALT

(basic hydrolysis)

CH_3COONa	sodium acetate	in buffers
CH_3COOK	potassium acetate	in buffers
$CaCO_3$	calcium carbonate	antiacid
$Ca_3(PO_4)_2$	calcium phosphate	bone matrix
Na_3PO_4	sodium phosphate	industry
Na_2HPO_4	disodium hydrogen phosphate	buffer in plasma
NaH_2PO_4	mono-sodium hydrogen phosphate	“
$NaHCO_3$	sodium hydrogencarbonate	*(bicarbonate) blood*

Coordination complex

Compound in which an atom or ion is bound to other chemical species with a number larger than its oxidation number.

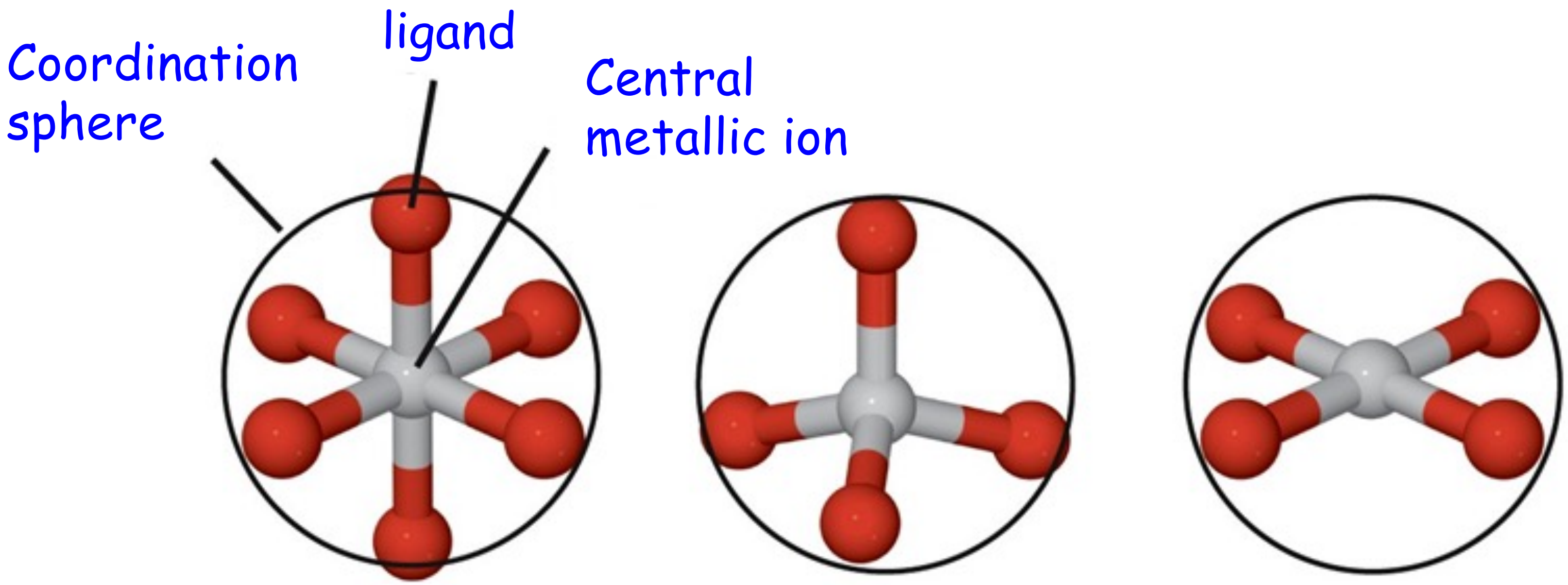
Typically the central atom is a transition metal cation, the ion or molecules that surround it are called ligands.

The set of ligand forms the coordination sphere of the complex and the number of ligands is called the coordination number (ranging from 1 to 16.

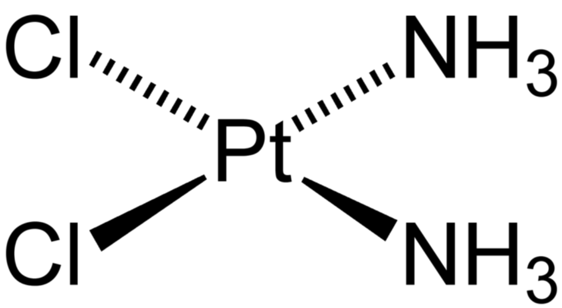
The bond in the coordination complexes arises from empty d orbital of the central atoms and lone pairs from s and p orbitals of the ligands.

The resulting bonds have transition energies that fall in the visibile region of the spectrum, therfore they have characteristic colours (heme and chlorophyll).

E.g. a metal in aqueous solution (coordinated by water or other ligands).



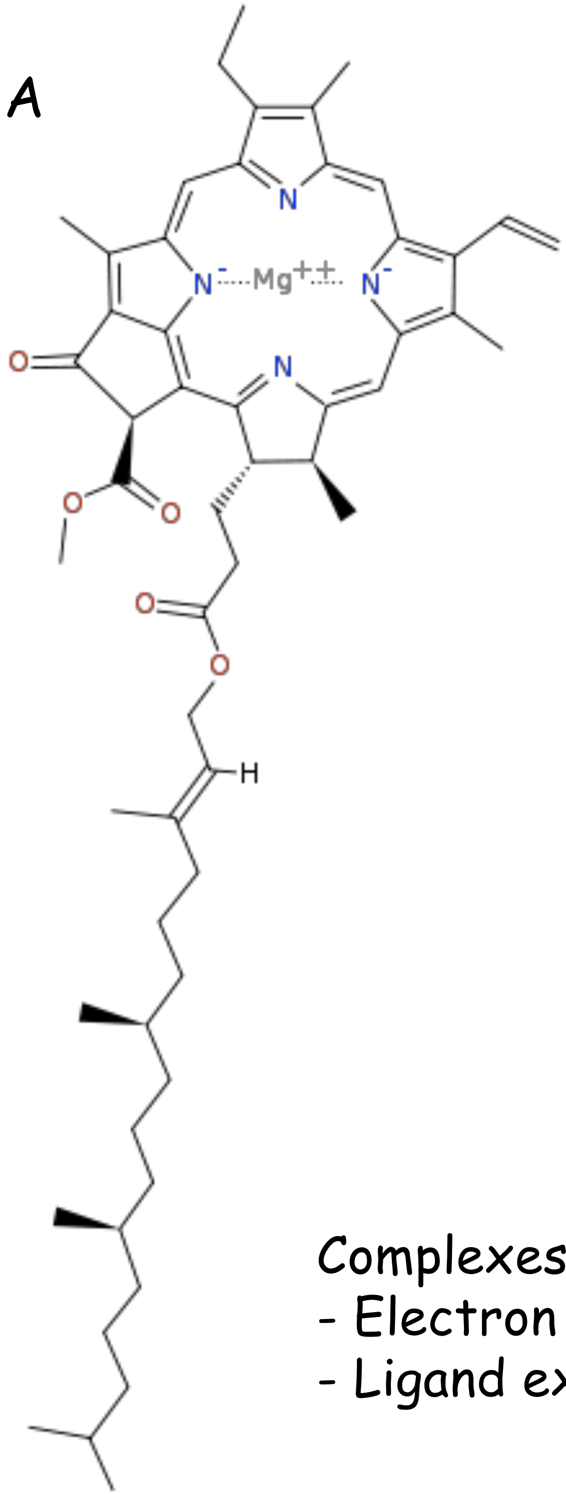
octahedral tetrahedric Square planar



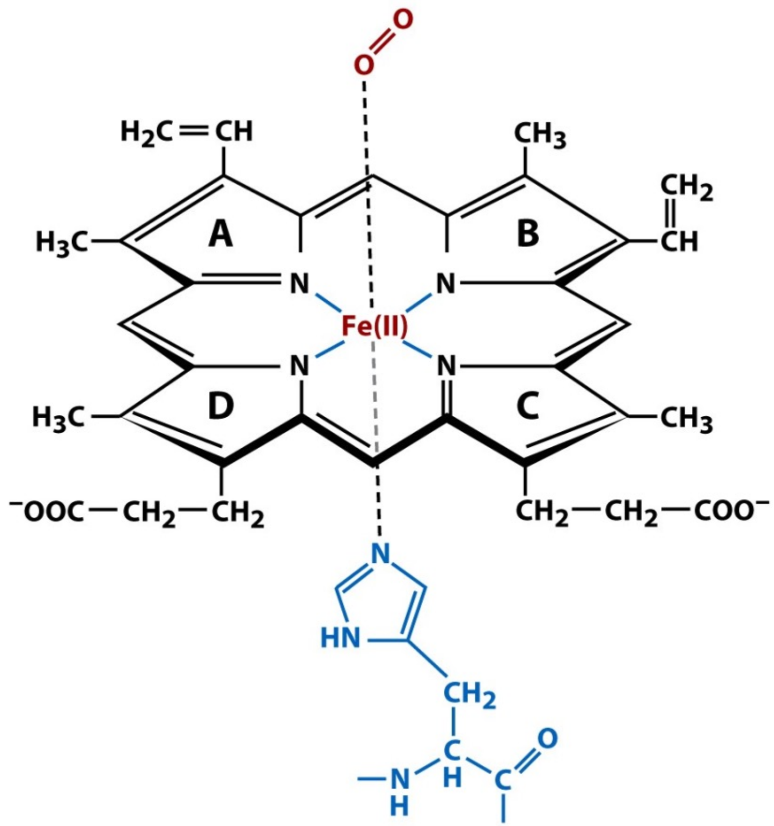
Cisplatinum(I), a drug used in chemiotherapy.

It reacts *in vivo*, binding to and causing crosslinking of DNA, triggering apoptosis (programmed cell death).

Chlorophyll A



Heme in hemoglobin and myoglobin

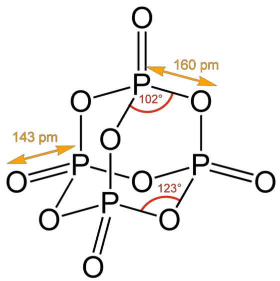


Complexes show a variety of possible reactivities:
- Electron transfers
- Ligand exchange

Meta-, ortho- e pyro- acids

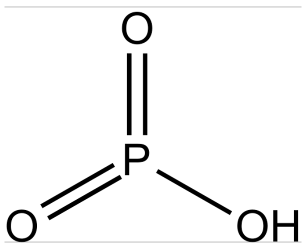
This (obsolete) nomenclature is still used to distinguish the degree of hydration of an oxoacid.

Ortho- the acid containing the largest number of water molecules.
Pyro- the acid containing one less water molecule
Metha- the acid containing the fewer number of water molecules

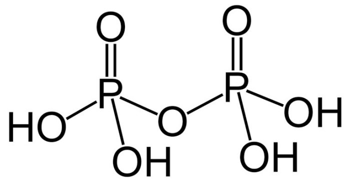


Phosphorous pentoxide

$P_2O_5 + 1H_2O \rightarrow 2HPO_3$
$P_2O_5 + 2H_2O \rightarrow H_4P_2O_7$
$P_2O_5 + 3H_2O \rightarrow 2H_3PO_4$

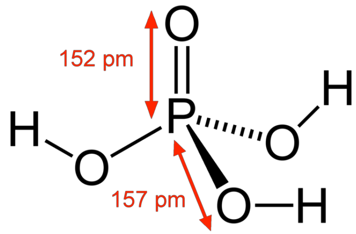


metaphosphoric acid
(HPO_3)



Pyrophosphoric acid
($H_4P_2O_7$)

Phosporic acid



Orthophosphoric acid
(H_3PO_4)

Inorganic compounds nomenclature

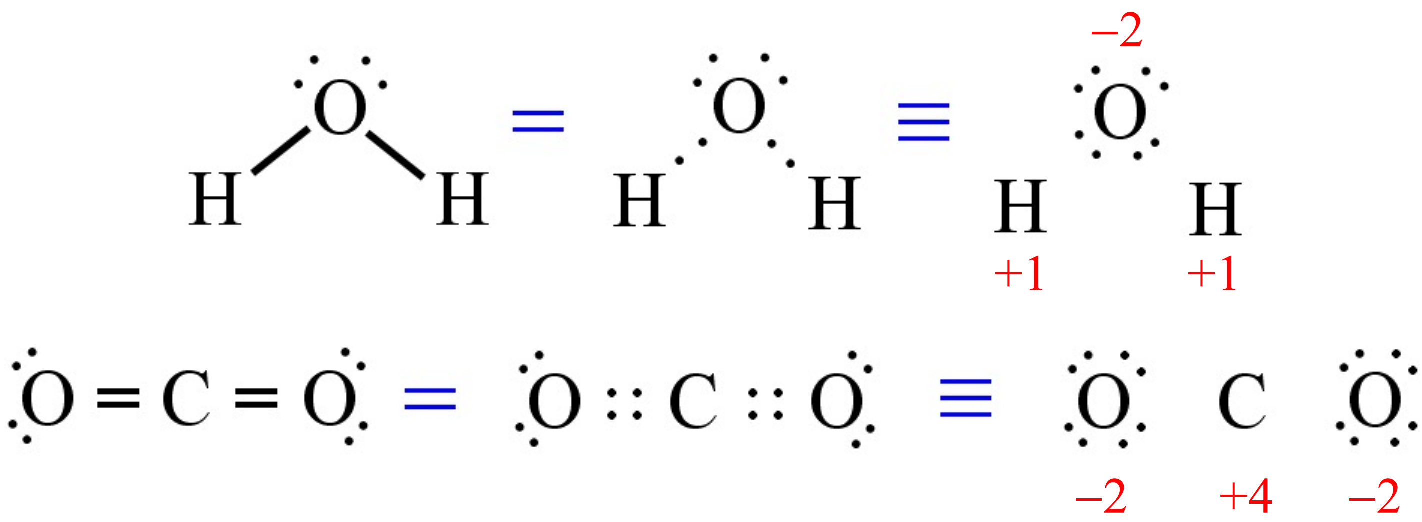
Currently known inorganic compounds are about 6 million and their number increases by about 6000 a week. Such a number of substances need to be organized according to clear, simple and universally shared rules.

The purpose of nomenclature is to provide rules for identifying a compound, *giving* it a unique name and a formula, using as few words as possible

Rules for nomenclature are published by IUPAC (International Union of Pure and Applied Chemistry). http://www.iupac.org/ "Traditional" nomenclature is sometimes still in use.

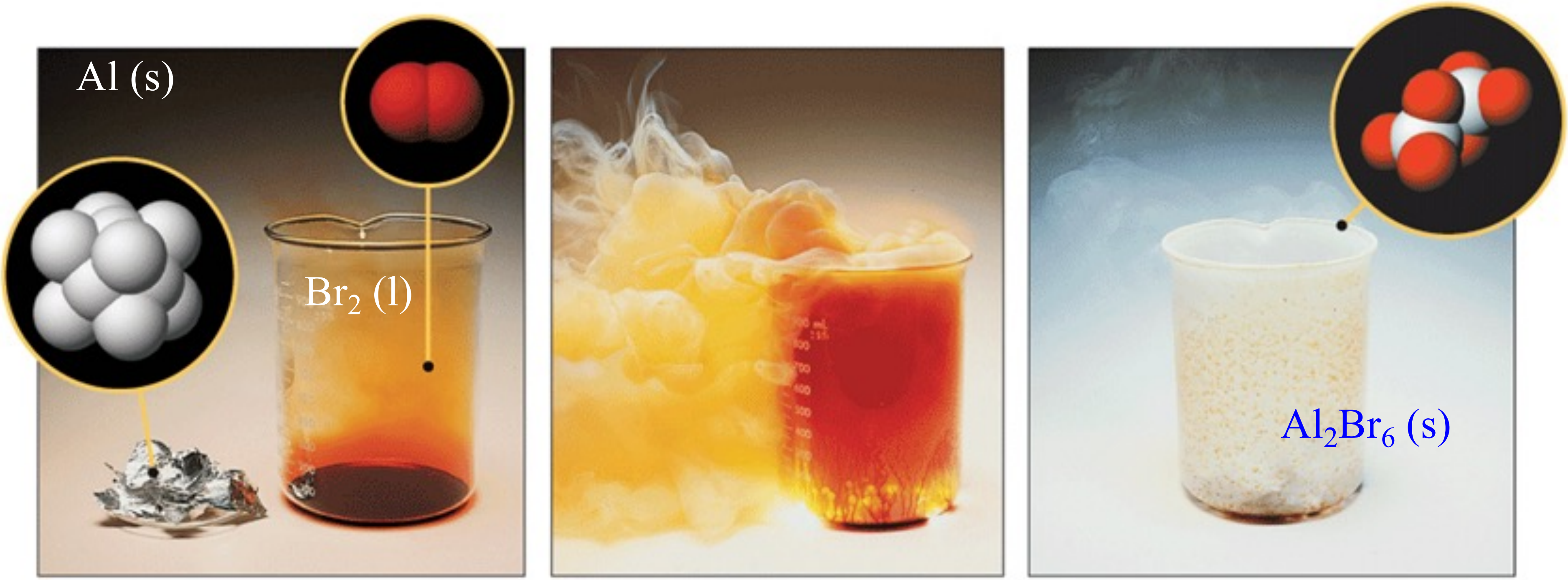
Oxidation number

O.N. is the charge that would be acquired by an element in a compound if bonding electrons were on the more electronegative atom.
The O.N. is deduced from its external electronic configuration in its fundamental state.



The oxidation number is not an actual charge, but it is only formally attributed to the atom.

The oxidation numbers allow to distribute electrons between the atoms of a molecule. Since the distribution of electrons changes during a redox reaction, this method is used to identify a redox reaction, the reducing and oxidizing agents and to balance the chemical equation.



Aluminum and boron react to form aluminum bromide.

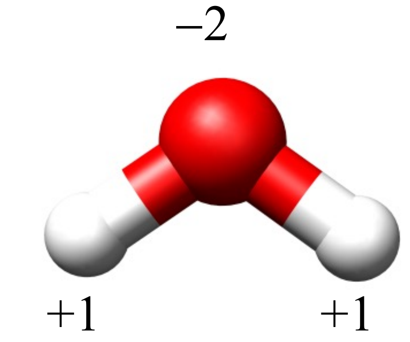
$$2\,Al\,(s) + 3\,Br_2\,(l) \rightarrow Al_2Br_6\,(s)$$

n.o. = 0 n.o. = 0 n.o. Al = +3 e n.o. Br = –1

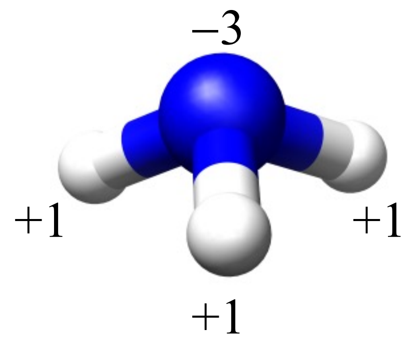
To calculate the oxidation number in a compound:

- 1. Identify the most electronegative atom
- 2. Assign the electrons involved in bonds
- 3. Evaluate the gain and loss of electrons

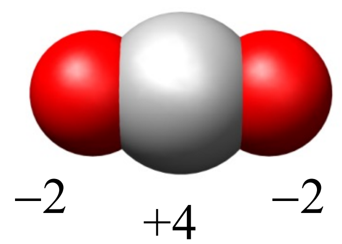
H_2O	Z	electronegativity	Electron configuration	Oxidation number
H	1	2.2	$1s^1$	+1 ($1s^0$)
O	8	3.5	$1s^2 2s^2 2p^4$	–2 ($1s^2 2s^2 2p^6$)



NH_3	Z	electronegativity	Electron configuration	Electron configuration
H	1	2.2	$1s^1$	+1 ($1s^0$)
N	7	3.0	$1s^2 2s^2 2p^3$	–3 ($1s^2 2s^2 2p^6$)



CO_2	Z	electronegativity	Electron configuration	Electron configuration
C	6	2.5	$1s^2 2s^2 2p^2$	+4 ($1s^2$)
O	8	3.5	$1s^2 2s^2 2p^4$	–2 ($1s^2 2s^2 2p^6$)



1. What is the o.n. of sulphur in sulphuric acid?

$$\overset{+1}{H}_2\overset{x?}{S}\overset{-2}{O}_4 \qquad \underset{\text{H atoms}}{2}(\underset{\text{o.n. H}}{+1}) + (\overset{\text{n.o. S}}{x}) + \underset{\text{O atoms}}{4}(\underset{\text{O o.n.}}{-2}) = 0$$

$$x = +6 \quad \overset{+1}{H}_2\overset{+6}{S}\overset{-2}{O}_4$$

2. What is the o.n. in the anion carbonate?

$$\overset{x?}{C}\overset{-2}{O}_3{}^{2-} \qquad (x) + \underset{\text{O atoms}}{3}(\underset{\text{O o. n.}}{-2}) = -2$$

$$x = +4 \quad \overset{+4}{C}\overset{-2}{O}_3{}^{2-}$$

Determine the oxidation number of:

a) Aluminum in aluminum oxide, Al_2O_3
b) Phosphorus in phosphoric acid H_3PO_4
c) Sulphur in sulphate SO_4^{2-}

a) Al_2O_3 bears no charge, O=-2, Al=+3(gruppo 3A):
Net charge $Al_2O_3 = 0$
$2\,(+3) + 3\,(-2) = 0$

b) H_3PO_4 bears no charge. If O has o.n.=–2, and each H atom has o.n.= +1, il P must have o.n.=+5
Net charge $H_3PO_4 = 0$
$3\,(+1) + (+5) + 4\,(-2) = 0$

c) Sulphate ion has a 2- charge SO_4^{2-} O =–2, thetefore S=+6.

Net charge $SO_4^{2-} = 2-$
o.n. S + n.o. O = –2
$(+6) + 4\,(-2) = -2$