Compounds : Names and Formulas

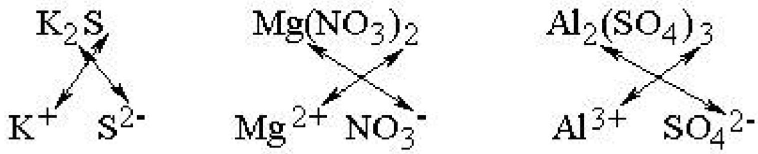
Categories of Compounds

A compound is a chemical combination of elements. It has a constant composition and a unique set of properties. Its composition is represented by its formula, which lists the symbols of the elements it contains, with each symbol followed by a subscript that tells how many atoms of that element are contained in the simplest unit of the compound. Some compounds exist as molecules. These molecular compounds usually contain only nonmetals. Table given below lists several molecular compounds, their common names, and their melting points.

Common name	Formula	Melting point, °C
acetone	C_3H_6O	-95
ammonia	NH_3	-77
cane sugar	$C_{12}H_{22}O_{11}$	185
chloroform	$CHCl_3$	-63
ethyl alcohol	C_2H_5OH	-117
hydrazine	N_2H_4	1.4
phosgene	Cl_2CO	-118
water	H_2O	0

The formula of an ionic compound is neutral. The ratio of the cations and anions it contains is such that there is no excess charge. Thus, the combination of a sodium ion, Na+, with a sulfate ion, SO42-, to form sodium sulfate must be in a 2:1 ratio so that the resulting compound is neutral, Na2SO4. The combination of an aluminum ion, Al3+, with a chloride ion, Cl-, to form aluminum chloride must be in a 1:3 ratio, giving the formula AlCl3, which is neutral. The combination of an ammonium ion, NH4+, with a phosphate ion, PO43-, to form ammonium phosphate must be in a 3:1 ratio, giving the neutral formula (NH4)3PO4. Notice in this last formula that the ammonium ion is enclosed in parentheses and followed by the subscript 3. This notation means that the whole ion is taken three times. When a polyatomic ion is taken more than once in a formula, it is enclosed in parentheses and the number of ions contained in the formula is indicated by a subscript following the parentheses. Monatomic ions and polyatomic ions taken only once (for example, the sulfate ion in sodium sulfate) are not enclosed in parentheses.

Notice two things about the examples shown below: In both magnesium nitrate and aluminum sulfate, the polyatomic ion was enclosed in parentheses because it was taken more than once; the monatomic ion was not enclosed in parentheses regardless of its subscript. (2) If the charge on the two ions differs in magnitude, the number of times the cation is taken equals the magnitude of the charge on the anion. Similarly, the number of times the anion is taken equals the magnitude of the charge on the cation. For example,



Naming Compounds

Each compound has a name. Ideally, this name should indicate the composition of the compound and perhaps something of its properties. Such names are called systematic names and are based on a set of rules drawn up by IUPAC. Although all compounds have systematic names, many also have trivial, or common, names.

Oxidation Numbers

Many of the rules by which names are assigned are based on the concept of oxidation numbers. The oxidation number of an element represents the positive or negative character (nature) of an atom of that element in a particular bonding situation. Oxidation numbers are assigned according to the following rules:

1. The oxidation number of an uncombined element is 0. In the equation

Zn + 2 HCl --> H2 + ZnCl2

the oxidation number of zinc (Zn) as an uncombined atom is 0, and the oxidation number of hydrogen in H2 is 0.

2. The oxidation number of a monatomic ion is the charge on that ion. In ZnCl2, the oxidation number of chlorine as Cl- is -1 and that of zinc as Zn2+ is +2. In Ag2S, the oxidation number of silver as Ag+ is +1 and that of sulfur as S2- is -2.

3. Hydrogen in a compound usually has the oxidation number +1. An exception to this rule occurs when hydrogen is bonded to a metal.

4. Oxygen in a compound usually has the oxidation number -2. Peroxides are an exception to this rule: In hydrogen peroxide, H2O2, for example, the oxidation number of oxygen is -1.

5. The sum of the oxidation numbers of the atoms in a compound is 0. For example, in the compound ZnCl2, the oxidation number of the zinc ion is +2 and that of each chloride ion is -1. The sum of these oxidation numbers (+2 for zinc and -2 for the two chloride ions) is 0.

6. In a polyatomic ion, the net charge on the ion is the sum of the oxidation numbers of the atoms in the ion. We can use this rule to calculate the oxidation number of nitrogen in the nitrate ion, NO3-, by setting up the following equation:

Oxidation number of nitrogen
+3 (oxidation number of oxygen) = -1
Oxidation number of Oxygen = -2
By substituting, we get:
Oxidation number of nitrogen +3(-2) = -1
By rearranging, this equation becomes:
Oxidation number of nitrogen = -1 - 3(-2)
= -1 + 6 = + 5

Binary Compounds

Many chemical compounds are binary; that is, they contain two elements. Binary compounds are of several varieties.

Binary compounds containing a metal and a nonmetal

Binary compounds of a metal and a nonmetal contain a metallic cation and a nonmetallic anion. Recall that the alkali metals form only ions with a +1 charge, the alkaline earth metals form only ions with a +2 charge, and aluminum forms only the ion Al^{3+}. For these ions, the name of the element followed by the term ion is an unambiguous name. For example, the sodium ion can only be Na^+, the calcium ion only Ca^{2+}. According to IUPAC rules, the names of all other metallic cations contain the name of the element followed by its oxidation state (in parentheses) in that ion. This rule prevents ambiguity. The name chromium ion does not say whether the ion is Cr^{2+} or Cr^{3+}; the proper names for these ions are chromium(II) and chromium(III). The anions in binary compounds are named by using the root name of the element, followed by the suffix ide; for example, bromide ion is Br^-, the sulfide ion is S^{2-}, and the oxide ion is O^{2-}. In these examples, the root name of the element is italicized. For binary compounds, the cation is named first and the anion second. Thus,

$NiCl_2$ is nickel(II) chloride

K_2S is potassium sulfide

$CaBr_2$ is calcium bromide

ZnO is zinc(II) oxide

Before leaving this group of compounds, we should mention again the second and less-preferred method of naming cations of the same element in different oxidation states. This older method gives the ending ous to the ion of lower oxidation state and the ending ic to the ion of higher oxidation state. Often this system also uses the Latin root of the name of the element. Thus, in this system, Fe^{2+} is ferrous and Fe^{3+} is ferric; Pb^{2+} is plumbous and Pb^{4+} is plumbic.

binary compound - chemical compound composed of only two elements

common salt, sodium chloride - a white crystalline solid consisting mainly of sodium chloride (NaCl)
Many chemical compounds are binary; that is, they contain two elements. Binary compounds are of several varieties.

Binary compounds containing two nonmetals but not hydrogen

Binary compounds of two nonmetals, neither of which is hydrogen, are molecular rather than ionic. They do not contain cations and anions. Carbon dioxide (CO2) and phosphorus trichloride (PCl3) are examples of such compounds. They are named using prefixes to state how many atoms of an element are in one molecule of the compound.

Number of atoms	**Prefix**	**Number of atoms**	**Prefix**	**Number of atoms**	**Prefix**
1	mono-	5	penta-	9	nona-
2	di-	6	hexa-	10	deca
3	tri-	7	hepta-	11	hendeca-
4	tetra-	8	octa-	12	dodeca-

The name of the second element is modified to the root of its name followed by the ending ide. In both the formula and the name of these compounds, the most nonmetallic element comes first. The prefix mono is often omitted for the first element but never omitted for the second. Thus,

CO is carbon monoxide

SF6 is sulfur hexafluoride

N2O is dinitrogen monoxide

Binary acids

The binary compound formed when a halogen or any element, except oxygen, from Group 6 of the periodic table combines with hydrogen can be named as were the binary nonmetallic compounds discussed in the preceding section. However, when these compounds are dissolved in water, the solution contains hydrogen ions. Because this property identifies an acid , these compounds must also be named as acids. Therefore, these compounds have two sets of names, one for the pure state and one for the compound dissolved in water.Two points should be noted: (1) The acid name has the prefix hydro and the suffix ic. (2) These formulas are always written with hydrogen first. Other nonmetals form compounds with hydrogen, but they are not acids;

their formulas are written with hydrogen last. Methane, CH_4, ammonia, NH_3, and arsine, AsH_3, are examples.

Nomenclature for binary acids

Formula	Name in pure state	Name in water solution
HCl	hydrogen chloride	hydrochloric acid
H_2S	hydrogen sulfide	hydrosulfuric acid
HBr	hydrogen bromide	hydrobromic acid

Pseudo-binary compounds

Binary acids

Several polyatomic ions act so much like monatomic ions that they are classified as such. These ions are called pseudo-binary ions. They include the ammonium ion, NH_4^+, the hydroxide ion, OH^-, the cyanide ion, CN^-, and others. Compounds containing these ions are pseudo-binary compounds.

The properties of the ammonium ion are much like those of the alkali-metal ions. Compounds containing the hydroxide ion are bases. A general definition of a base is that its aqueous solution contains more hydroxide than hydrogen ions.

The cyanide ion behaves very much like a halogen ion. Many compounds containing the cyanide ion are extremely toxic.

Ternary Compounds

Ternary compounds are those compounds containing three elements. Ionic ternary compounds are formed by the combination of a monatomic cation with a polyatomic (containing several atoms) anion, as in sodium nitrate, $NaNO_3$. A polyatomic anion is derived from a ternary acid.

Ternary acids and their anions

When a ternary compound contains hydrogen and a polyatomic anion (for example, HNO_3), its name in the pure state is hydrogen followed by the name of the anion. Pure HNO_3 has the name hydrogen nitrate. When this compound is dissolved in water, it is an acid and is named as such. HNO_3 in water solution is named nitric acid. Table 6.6 lists the formulas of some of these compounds, the names they carry when in water solution, the oxidation number of the nonmetal other than oxygen that they contain, and the name and formula of their anions. The rules for naming these compounds as acids follow the table. Be sure to study the table as you read the rules and notice the pattern shown in the names and formulas.

The rules for naming ternary acids are as follows:

1. The name of the most common oxyacid for a particular nonmetal is the root of the element's name plus the suffix ic. It has no prefix. The name of the anion of this acid is the root of the element's name plus the suffix ate. The oxidation number of the nonmetal in this acid is high but not necessarily the highest possible. These acids are sometimes referred to as ic-ate acids. Of the oxyacids in Table 7.6, nitric, sulfuric, phosphoric, and chloric are in the category of "most common." In the table, the formulas marked with an asterisk are the most common acids for a particular nonmetal.

2. The name of the acid in which the nonmetal has the next lower oxidation number is the element's root plus the suffix ous. The name of its anion is the root plus ite. These acids may be called ous-ite acids. Of the acids in Table 6.6, nitrous, sulfurous, and chlorous fall into this group. Their formulas can be predicted if you have learned the formulas in the first group. The anion of an ous-ite acid contains one fewer oxygen atom than that of the ic-ate acid.

3. As with the halogens, if there is an oxyacid in which the nonmetal has an even lower oxidation number, that acid is named using the prefix-suffix hypo-ous, and its anion using hypo-ite. Of the acids in Table 6.6, only hypochlorous is in this category. Its formula can be predicted if you know the formula of chloric acid. The anions of these acids contain two fewer oxygen atoms than the anions of the ic-ate acids.

4. Again as with the halogens, if there is an oxyacid in which the nonmetal has a higher oxidation number than in the most common acid, that acid is named per-ic acid and its anion per-ate. Of the acids in Table 6.6, only perchloric is in this group. Its formula can be predicted from the formula of chloric acid. The anion will contain one more oxygen atom than the anion of the ic-ate acid.

Ternary acids containing carbon

Many acids contain only carbon, hydrogen, and oxygen. Acetic acid is an example. Its formula can be written as

$HC_2H_3O_2$ or HCH_3CO_2 or CH_3COOH or CH_3CO_2H

Regardless of how it is written, there is only one acidic hydrogen in acetic acid; the other three hydrogens do not separate as hydrogen ions in aqueous solution. Notice how the acidic hydrogen is placed by itself in each of the formulas to signify this difference. Many acids, like acetic acid, contain a group of atoms bonded to a -COOH group. Only the hydrogen of the -COOH group is an acidic hydrogen. For example,

C_6H_5COOH benzoic acid

C_2H_3COOH acrylic acid

These acids are called carboxylic acids.

In naming the anions of these acids, the ic of the acid is replaced by ate. Thus,

acetic acid $HC_2H_3O_2$, yields acetate ion, $C_2H_3O_2^-$
benzioc acid C_6H_5COOH, yields benzoate ion, $C_2H_5COO^-$
acrylic acid C_2H_3COOH, yields acrylate ion, $C_2H_3COO^-$

Salts containing more than one cation

Occasionally you will encounter a salt containing more than one cation. If both cations are metals, they are named in the order in which they are written according to the rules already given. If one of the cations is hydrogen, the salt can be named either by calling the cation hydrogen or by adding bi as a prefix to the name of the anion. Thus, NaHCO3 can be named sodium hydrogen carbonate or sodium bicarbonate. Salts with more than one cation, one of which is hydrogen, are sometimes called acid salts.