Formulas and Nomenclature

Formulas

First of all, the formulas are the symbols for compounds and molecules. There are three different types of formulas, which are,

- **Empirical formula**
- **Molecular formula**
- **Structural formula**

Empirical formula represents the simplest unit of the molecular formula and gives the relative number of different kinds of atoms in a compound. **Molecular Formula,** on the other hand, represents the way the molecule exists in nature and gives the actual number of atoms of each kind. **Structural formula** the detail information of bonding the way the atoms are bonded to one another.

Let examine here more details about empirical and molecular formulas using the following example. The molecular formula for the hydrogen peroxide is H_2O_2 and its empirical formula is HO. Since the empirical formula is derived from the molecular formula, the way to get it is simply divide subscripts with some common factor to come with smallest possible whole numbers. In this example, the subscripts of H_2O_2 are divided by 2 to give HO. Note that the ratio of atoms in HO (H: O :: 1:1) is the same as in H_2O_2 (H:O::2:2 or 1:1). In general,

- The ratio of atoms in empirical formula is the same as in molecular formula.

Examine the following table.

Molecular formula	**Empirical formula**	**Ratio of atoms**
C_2H_2	CH	C:H::1:1
C_6H_6	CH	C:H::1:1
$C_6H_{12}O_6$	CH_2O	C:H:O::1:2:1
N_2H_4	NH_2	N:H::1:2
P_4O_{10}	P_2O_5	P:O::2:5

For many molecules, the empirical formula is the same as molecular formula. For example, water (H_2O), ammonia (NH_3), carbon dioxide (CO_2), and (HNO_3) have the same empirical as well as molecular formula.

From these examples, it is evident that the molecular formula is the integral multiple of the empirical formula:

Molecular formula = n x Empirical formula

H_2O_2 = 2 x HO , n=2
P_4O_{10} = 2 x P_2O5, n=2
H_2O = 1 x H_2O, n =1

Example

Deduce the empirical formula from the following molecular formula.

(a) Hg_2Cl_2, (b) HCl, (c) C_8H_{16}, (d) $Na_2S_2O_4$, (e) Al_2Cl_2

Answer

(a) There are 2 Hg atoms and 2 Cl atoms. Dividing the subscripts by 2 yields the empirical formula HgCl (Hg:Cl :: 1:1).

(b) This molecule is already in the lowest number ratio. Therefore, the empirical formula is the same as molecular formula, i.e. HCl (H:Cl::1:1).

(c) There are 8 C atoms and 16 H atoms, and dividing the subscripts gives the empirical formula CH_2 (C:H::1:2).

(d) This molecule contains 2 Na atoms, 2 S atoms, and 4 O atoms. Thus, there is a common factor, i.e., 2. Dividing the subscripts by 2 gives the empirical formula $NaSO_2$ (Na:S;O::1:1:2).

(e) There are 2 Al atoms and 2 Cl atoms with common factor of 2. Dividing the subscripts by the common factor generates the empirical formula AlCl (Al:Cl::1:1).

Nomenclature

Nomenclature is the systematic method for naming inorganic compounds. As a matter of fact, nomenclature is not typical to inorganic compounds; it exists in every branch of science and arts. Nomenclature is essential to facilitate the understanding and communication between various scientific communities throughout the world. It simply systematizes the scientific literature. Here you are going to learn how to name the following four different types of inorganic compounds.

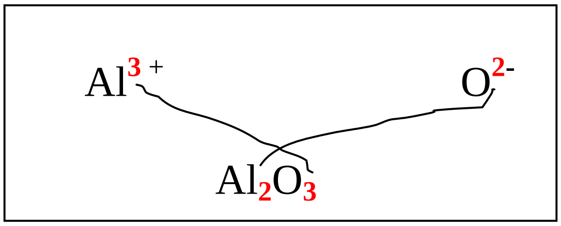
- Ionic compounds
- Molecular compounds
- Acids and Bases
- Hydrates

Ionic Compounds

Before, you get into the business of naming ionic compounds, it is essential that you understand how the ionic compounds are formed. The ionic compounds are formed by the chemical union of ions, and hence the name ionic compounds. There are two kinds of ions are involved, positive ions (cations) and negative ions (anions). Ions carry the charge, positive (+) or negative (-). However, when the compound is formed by these ions, the charges are neutralized. Therefore, *the compound has no charge, meaning, it is a neutral thing*. Let us illustrate this concept with the following example. Let us that we would like to form a compound from Al^{3+} ion and S^{2-} ion. One Al carries +3 charges and one S carries -2 charges. In order to neutralize the positive charges with negatives charges, we need 2 Al ions (2 x +3 = +6) and 3 S ions (2 x -3 = -6). The sum of the charges is +6 + (-6) = 0. Now we have to write the chemical formula to indicate that there are 2 Al atoms and 3 S atoms, which is written as Al_2S_3. Study the following compounds.

Cation	**Anion**	**Compound**	**Ratio of Ions**	**Total charge**
Na^{+}	Cl^{-}	NaCl	1 : 1	1 x (+1) + 1 x (-1) = 0
Ca^{2+}	O^{2-}	CaO	1 : 1	1 x (+2) + 1 x (-2) = 0
Ba^{2+}	I^{-}	BaI_2	1 : 2	1 x (+2) + 2 x (-1) = 0
K^{+}	S^{-2}	K_2S	2 : 1	2 x (+1) + 1 x (-2) = 0
Al^{+3}	O^{-2}	Al_2O_3	2 : 3	2 x (+3) + 3 x (-2) = 0

There is an easy way to remember this process without going through the labor of counting the charges. This technique is known as “Criss-Cross” method, which is illustrated below:



In essence, what you have to do is *make the positive charge number without the positive sign (+) as the subscript of the negative ion and make the negative charge number without the negative sign (-) as the subscript of the positive ion.* This automatically satisfies the charge neutralization requirement.

Ionic compounds are made up of two kinds of ions, cations (positive ions) and anions (negative ions). Before you learn to name the ionic compounds, you have to learn how to name the ions. Among the ions, there are two kinds of ions; monatomic ions (containing single atom) and polyatomic ions (containing more than one atom that function as a single entity). Most of the cations, except ammonium ion (NH_4^+), are derived from the metals. Here are few examples.

Monatomic ions

Element	**Name**	**Ion**	**Name of cation**
Li	lithium	Li^+	lithium
Ba	barium	Ba^{+2}	barium
Al	aluminum	Al^{3+}	aluminum
Ag	Silver	Ag^+	Silver

Note that name of the metal ion is the same as the name of its element. All the A group elements have fixed charges (also known as oxidation numbers), meaning, they have only one charge. For example, sodium ion is Na^+. There is no other sodium ion. However, in case of B group elements, this is not the case. They do change their charges. In that case their names also include the charges on the ion in Roman numerals. For example, copper (Cu) has two charges, Cu^+ and Cu^{2+}. Hence the names of these ions are copper (I) ion and Cu (II) ion. The following is the list of some common cations.

Copper	Cu^+	Copper (I)
	Cu^{2+}	Copper (II)
Iron	Fe^{2+}	Iron (II)
	Fe^{3+}	Iron (III)

Mercury	Hg_2^{2+}	Mercury (I)
	Hg^{2+}	Mercury (II)
Lead	Pb^{2+}	Lead (II)
	Pb^{4+}	Lead (IV)
Tin	Sn^{2+}	Tin (II)
	Sn_{4+}	Tin (IV)

Anions are named little bit differently than cations. The ending of elemental name is changed to –ide ending:

H → H^-
hydrogen hydride

O → O^{2-}
Oxygen oxide

Cl → Cl^-
chlorine chloride

Now the question is how to remember the charges? If you know the group number, pretty much you can guess the charge on the ion in that group. See the following table that gives the charges in relation to group numbers in the periodic table. Here X is any element in that column.

	1A	**2A**	**3A**	**4A**	**5A**	**6A**	**7A**	**8A**
	X^+	X^{2+}	X^{3+}	X^{4-}	X^{3-}	X^{2-}	X^-	No charges
example	Na^+	Ba^{2+}	Al^{3+}	C^{4-}	N^{3-}	O^{2-}	Cl^-	

Polyatomic ions

Polyatomic ion is defined as *the group of atoms function together as a single unit.* Among the polyatomic cations and anions, there is only one polyatomic cation, i.e., NH_4^+ (ammonium ion). But, there many polyatomic anions that you need to remember. There is no other way to remember except memorize. Some common ones are:

Chlorate	ClO_3^-
Chromate	CrO_4^-
Cyanide	CN^-
Dichromate	$Cr_2O_7^{2-}$
Hydroxide	OH^-

Nitrate	NO_3^-
Nitrite	NO_2^-
Permanganate	MNO_4^-
Phosphate	PO_4^{3-}
Phosphite	PO_3^{3-}
Sulfate	SO_4^{2-}
Sulfite	SO_3^{2-}
Thiocyanate	SCN^-

Equipped with ionic names, we are now ready to name the compounds. There are two kinds of compounds, binary compounds and ternary and higher compounds. **Binary compounds** are the compounds formed by just two elements. In binary compound, the first element is a metal and the second element is a nonmetal. *The name consists of name of the metal ion followed by the name of the nonmetal ion.*

Name of the metal ion + Name of the nonmetal ion

For example, NaCl consists of two ions; sodium ion (Na^+) and chloride ion (Cl^-). Therefore, the name is sodium chloride. Similarly, KI is named as potassium iodide, Al_2O_3 is named as aluminum oxide, CuCl named as copper (I) chloride and $CuCl_2$ is named as copper (II) chloride.

In naming **ternary and higher order compounds**, you have to know the name of the polyatomic ions. Naming convention is *exactly the same as the binary compounds except the name of the nonmetal ion is substituted with the name of the polyatomic ion.*

Name of the metal ion + Name of the polyatomic ion

For example, NaOH consists of sodium metal ion (Na^+) and the hydroxide OH^-) polyatomic ion. The name of this compound becomes sodium hydroxide. Similarly, the name of $BaSO_4$ is barium sulfate, the name of KCN is potassium cyanide, the name of $Fe(OH)_2$ is iron(II) hydroxide, and the name of the $Fe(OH)_3$ is iron(III) hydroxide.

There are three steps you should follow while naming an ionic compound:

1. **Identify the positive ion and determine whether it is a fixed charged metal ion or a variable charged metal ion.**
2. **Identify the negative ion and decide whether it is a single ion or a polyatomic ion.**
3. **Name the compound based on the above two identifications.**

Example

Name the following compounds: (a) AgCl, (b) NaH, (c) Ca $(OH)_2$, (d) Hg_2Cl_2, and (e) $HgCl_2$.

Answer

(a) The name of the metal ion is silver (Ag^+) and the name of the nonmetal ion is chloride (Cl^-), and hence the name is **silver chloride.**

(b) The name of the metal ion is sodium (Na^+) and name of the nonmetal ion is hydride (H^-), and hence the name is **sodium hydride**.

(c) This compound contains a polyatomic ion. The name of the metal ion is calcium (Ca^{2+}) and that of polyatomic ion is hydroxide. Therefore, the name is **calcium hydroxide.**

(d) The metal ion Hg has a 1+ charge and the name is mercury (I). The name of the nonmetal ion is chloride. Therefore, the name is **mercury (I) chloride**.

(e) The metal ion has 2+ charges (Hg^{2+}) and the name is mercury (II). The name of the nonmetal ion is chloride. Hence, the name is **mercury (II) chloride.**

So far, you have learned how to name the compound if the chemical formula is given. You should also be able to do other way around, i.e., write the proper chemical formula if the name is given. As you recall, the compound name contains the name of the metal ion followed by the name of the nonmetal ion. Followings are some simple steps:

- **Write the symbol and the proper charges for the metal ion.**
- **Write the symbol and the charges for the negative ion.**
- **Neutralize the positive charges with negative charges by writing appropriate number of ions as subscripts using "criss-cross" method.**

Example

Write the chemical formulas for the following compounds: (a) magnesium bromide, (b) tin (IV) oxide, (c) iron (II) phosphate, (d) silver sulfide, and (e) aluminum hydroxide.

Answer

(a) The chemical formula is $MgBr_2$.
Here magnesium is a metal ion and bromide is a nonmetal ion. The symbol for the magnesium ion is Mg^{2+} because it belongs to 2A group. The symbol for the

bromide is Br^- because it is derived from bromine element and part 7A group. The formula is written using the criss-cross method:

$Mg^{+2} + Br^- \rightarrow MgBr_2$

NOTE: if the charge is 1+ or 1-, there is no need indicate 1 as a subscript it is understood.

(b) The chemical formula is SnO_2.
The symbol for the metal ion with proper charges is Sn^{4+} because it has Roman numeral IV in the parenthesis that indicates it has 4+. The symbol for oxide is O^{-2} because it is derived from oxygen and belongs to 6A group. Thus according to criss-cross method,

$Sn^{4+} + O^{-2} \rightarrow Sn_2O_4 \rightarrow SnO_2$

The formula Sn_2O_4 is not acceptable because it does not contain the simple whole numbered ratio, and hence SnO_2 is the correct one.

(c) The chemical formula is $Fe_3(PO_4)_2$.
The symbol for iron (II) is Fe^{2+} because Roman numeral II indicates 2+ charges. The symbol for the phosphate ion is PO_4^{3-}. Thus the chemical formula after neutralizing charges is,

$Fe^{2+} + PO_4^{3-} \rightarrow Fe_3(PO_4)_2$

NOTE: if more than one polyatomic ion is involved, the polyatomic ion should be enclosed in parenthesis and the number of ions should be written as a subscript. In the above example, there are two phosphate ions and due that $(PO_4)_2$ is written.

(d) The chemical formula is Ag_2S.
The symbol for silver is Ag^+ (this is the only charge on silver) and that of sulfide is S^2 because it is derived from elemental name sulfur and belongs to 6A group. Silver ion and sulfur ion combine in 2:1 ratio to neutralize the charges. Therefore,

$Ag^+ + S^{2-} \rightarrow Ag_2S$

(e) The chemical formula is $Al(OH)_3$.
The symbol for aluminum is Al^{3+} because it belongs to 3A. The symbol for hydroxide is OH^-. They combine in the ratio of 1:3 to neutralize the charges. Thus,

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

Molecular Compounds

Molecular compounds are formed by nonmetals. Unlike ionic compounds, the molecular compounds do not contain ions but contain molecular units. Many molecular compounds are also binary compounds and hence naming binary molecular compounds is similar to naming binary ionic compounds; name of the first element remains the same as the elemental name and the name of the second element is modified using –ide ending. For example,

HF	Hydrogen fluoride	HCl	Hydrogen chloride
HBr	Hydrogen bromide	HI	Hydrogen iodide

Many times, the same two nonmetals combine and produce several different types of compounds. In that case, the Greek prefixes are used to avoid the confusion. The following table gives the Greek prefixes and their meanings.

Prefix	**Meaning**
Mono-	1
Di-	2
Tri-	3
Tetra-	4
Penta-	5
Hexa-	6
Hepta-	7
Octa-	8
Nona-	9
Deca-	10

Carbon and oxygen combine and form two different types of molecular compounds, which are CO and CO_2. We cannot name both as carbon oxides because these two are different molecules with altogether quite distinct physical and chemical properties; CO is poisonous and very toxic and people die with inhale of this molecule, whereas CO_2 is harmless, we exhale this gas and plants do need this gas. Besides, it is plenty in atmosphere. Therefore, they are named using the Greek prefixes as follows.

CO	Carbon monoxide	CO_2	Carbon dioxide

Similarly, consider the following examples.

SO_2	Sulfur dioxide	NO_2	Nitrogen dioxide
SO_3	Sulfur trioxide	N_2O_5	Dinitrogen pentoxide

PCl_3 Phosphorous trichloride
PCl_5 Phosphorous pentachloride

It is customary not use mono- for the first element if there is only atom. For example, CO is not named as monocarbon monoxide. It is simply labeled as carbon monoxide.

There are few common names still in usage. The following table gives both proper and common names:

Formula	**Common name**	**Proper name**
B_2H_6	Diborane	Diboron hexahydride
CH_4	Methane	Carbon tetrahydride
SiH_4	Silane	Silicon tetrahydride
NH_3	Ammonia	Nitrogen trihydride
PH_3	Phosphine	Phosphorous trihydride
H_2O	Water	Dihydrogen oxide
H_2S	Hydrogen sulfide	Dihydrogen sulfide

Example

Name following molecular compounds: (a) NF_3, (b) Cl_2O_7, (c) CS_2, (d) P_4O_{10}, (e) NO

Answer

(a) Nitrogen trifluoride (b) Dichloro heptoxide (c) Carbon disulfide
(d) Tetraphosphorous decoxide (e) Nitrogen monoxide

Example

Write the chemical formulas for following moleculer compounds: (a) Carbon tetrabromide, (b) Xenon tetrafluoride, (c) Diiodine pentoxide, (d) Carbon tetrachloride, (e) Disulfur dichloride

Answer

(a) CBr_4, (b) XeF_4, (c) I_2O_5, (d) CCl_4, (e) S_2Cl_2

Acids and Bases

Acids

An **acid** is *a molecular compound that liberates hydrogen ion(s) (H^+) when dissolved in water.* The hydrogen ion is also known as **proton**. For example, HCl is molecular compound in the gaseous form and when dissolved in water it separates into H^+ ion and Cl^- ion. Thus, we say that it liberates H^+ ion. To distinguish between the molecular compound in the gaseous form from the molecular compound in dissolved form, we write HCl(g) for the former and HCl(aq) for the later. Here aq means *aqueous* (water) solution.

There are two kinds of acids; (a) simple acids and (b) oxyacids. *The simple acids contain hydrogen as the first element and nonmetal as the second element in the chemical formula.* The name of the simple acid is based on the name of the nonmetal and involves three things:

- The nonmetal name is changed to –ic
- The word "hydro" used as a prefix to indicate that it is a water solution
- The word "acid" is appended

Consider the following examples.

HF(aq)	Hydrofluoric acid	HCl(aq)	Hydrochloric acid
HBr(aq)	Hydrobromic acid	HI(aq)	Hydroiodic acid

Oxyacids contain *hydrogen, nonmetal and oxygen.* The nonmetal and oxygen together make up what is known as a polyatomic anion. The name of the acid depends on the name of the polyatomic anion. And the word "acid" is appended. For example,

HNO_3 Nitric acid (nitric is derived from the nitrate ion (NO_3^-)
HNO_2 Nitrous acid (nitrous is derived from the nitrite ion (NO_2^-)
H_2SO_4 Sulfuric acid (sulfuric is derived from the sulfate ion (SO_4^{2-})
H_2SO_3 Sulfurous acid (sulfurous is derived from the sulfite ion (SO_3^{2-})
H_3PO_4 Phosphoric acid (phosphoric is derived from the phosphate ion ($PO_4^{3-)}$
H_3PO_3 Phosphorous acid (phosphorous is derived from the phosphate ion (PO_3^{3-})

It is important to note that –ous acid contains one less oxygen than –ic acid. In general, if the polyatomic ion name ends with –ate, it become –ic acid and if it ends with –ite, it becomes ous acid.

- **-ate → -ic acid**
- **-ite → -ous acid**

Important

Acids are recognized by the fact that they have hydrogen as the first element in the formula.

Bases

A base is a substance that yields hydroxide ion (OH^-) when dissolved in water. That means the chemical formula contains one or more hydroxide ions. Naming bases is simple and similar to ionic compounds.

$NaOH$	Sodium hydroxide	KOH	Potassium hydroxide
$Ca(OH)_2$	Calcium hydroxide	$Ba(OH)_2$	Barium hydroxide
$Al(OH)_3$	Aluminum hydroxide	NH_4OH	Ammonium hydroxide

Hydrates

***Hydrates** are the compounds that contain specific amount of water.* The amount of water molecules are indicated by the number of moles of water and are separated from the main chemical formula by a dot (.). Naming the hydrates is similar to naming ionic compounds but with one difference; the number of water molecules are indicated with Greek prefix with "hydrate" word appended. For example,

$BaCl_2 . 2H_2O$	Barium chloride dihydrate
$CuSO_4 . 5H_2O$	Copper (II) sulfate pentahydrate
$CaSO_4 . 4H_2O$	Calcium sulfate tetrahydrate
$MgSO_4 . 7H_2O$	Magnesium sulfate heptahydrate