Nomenclature of inorganic compounds

Noble gases are the only elements with a stable electronic configuration. All other elements have electronic configuration that is more or less unstable.

To attain the electronic configuration of the closest noble gas, the element produces compounds. Only valence electrons are involved in compound formation.

An element can produce a compound by:
1. Forming an ion → Ionic compound
2. Sharing electrons with other elements → Covalent compound

There are ~11 million chemical compounds. Some of the arbitrary (common) names you may recognize (water = hydrogen oxide $\text{H}_2\text{O}$, laughing gas = dinitrogen monoxide $\text{N}_2\text{O}$, quicksilver = mercury Hg). One cannot memorize arbitrary names of all of them. Chemical nomenclature is the system of names for compounds.

Systematization of names was devised by IUPAC (International Union of Pure and Applied Chemistry) in 1921 and is constantly updated.

**Elements:**

- Chemical formula of an element is its symbol.
- Exceptions: A number of **non-metals** cannot exist as single atoms. They form **polyatomic molecules**.
- Chemical formula of element hydrogen is not H, but $\text{H}_2$.
- Same is true for $\text{N}_2$, $\text{O}_2$, $\text{F}_2$, $\text{Cl}_2$, $\text{Br}_2$, $\text{I}_2$, $\text{S}_8$ and $\text{P}_4$. 

**Chemical formulae**

- $\text{S}_8$
- $\text{O}_2$
**Ions, Charge and Periodic Table**

<table>
<thead>
<tr>
<th>IA</th>
<th>IIA</th>
<th>IIB</th>
<th>IIIA</th>
<th>IV</th>
<th>VA</th>
<th>VIA</th>
<th>VIIA</th>
<th>VIIIIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>H+</td>
<td>2</td>
<td>Na+</td>
<td>Mg2+</td>
<td>K+</td>
<td>Ca2+</td>
<td>Cr2+</td>
<td>Fe2+</td>
<td>Fe3+</td>
</tr>
<tr>
<td>Li+</td>
<td>Be2+</td>
<td>Cr3+</td>
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</tbody>
</table>

**Ions:**

Charged particles produced by adding or removing electrons from neutral atoms are called cations and anions.

- K → K⁺ + e⁻
- Mg → Mg²⁺ + 2e⁻
- Al → Al³⁺ + 3e⁻
- F + e⁻ → F⁻
- O + 2e⁻ → O²⁻
- N + 3e⁻ → N³⁻

Metal-non-metal chemical reaction usually results in electron exchange. **Metal** gives away its electron(s) and becomes positively charged **cation**. **Nonmetal** accepts electron(s) and becomes negatively charged **anion**. **Ionic compound** is a result of attraction between oppositely charged ions.
Electronegativity and the Covalent Bond

When non-metals react among themselves, the resulting compound is a molecular compound. Each reacting atom delivers its valence electrons to a pool of electrons, and the resulting compound is made by sharing these electrons among all atoms in the compound. Each shared electron pair produces a **covalent bond** between two atoms.

Electrons are rarely shared equally between atoms. **Electronegativity** (EN) is numerical rating of an atom’s ability to attract to itself the shared electrons in a covalent bond. Generally, electronegativity of metals is low, and that of nonmetals is high.

The difference in electronegativity determines the nature of the bond.

- \( \Delta EN = 0 \), covalent;
- \( \Delta EN = 1.0 \), polar covalent (23% ionic);
- \( \Delta EN = 1.9 \), polar covalent (60% ionic);
- \( \Delta EN > 1.9 \), ionic.

A **bond** is produced as a result of electron sharing between atoms. There is no sharing of electrons in pure ionic compounds, thus there are no bonds.

Naming of the atoms in a compound follows the order of increasing electronegativity.
Naming Chemical Compounds

Millions of compounds are known. Systematic names are given by the chemical formula.

**Binary compounds** (made of two elements):

1. **metal + nonmetal**: ionic, and
2. **nonmetal + nonmetal**: covalent.

**Ionic**: Metal (or less electronegative atom) named first, keeps its name unchanged. Indicate the charge of transition metal using Roman numerals in parenthesis. **Nonmetal** ion keeps the stem, adds suffix –ide.

**Covalent**: Use, prefixes (mono, di, etc) to indicate how many atoms of each element are present in the molecular formula. If there is only one atom of lesser electronegative element, prefix mono– is omitted. **Lesser** electronegative element is named first, keeps its name unchanged. The second element gets suffix –ide.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Formula</th>
<th>Name</th>
<th>Prefix</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>NaCl</td>
<td>Sodium chloride</td>
<td>Mon(o)-1</td>
</tr>
<tr>
<td>MgS</td>
<td>MgS</td>
<td>Magnesium sulfide</td>
<td>Di-2</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>Al₂O₃</td>
<td>Alluminum oxide</td>
<td>Tri-3</td>
</tr>
<tr>
<td>CoCl₃</td>
<td>CoCl₃</td>
<td>Cobalt(III) chloride</td>
<td>Tetr(a)-4</td>
</tr>
<tr>
<td>PCl₃</td>
<td>PCl₃</td>
<td>Phosphorus trichloride</td>
<td>Hexa-6</td>
</tr>
<tr>
<td>P₄O₆</td>
<td>P₄O₆</td>
<td>Tetraphosphorus hexaoxide</td>
<td>Hepta-7</td>
</tr>
<tr>
<td>NO</td>
<td>NO</td>
<td>Nitrogen monoxide</td>
<td>Octa-8</td>
</tr>
<tr>
<td>N₂O₅</td>
<td>N₂O₅</td>
<td>Dinitrogen pentoxide</td>
<td>Nona-9</td>
</tr>
<tr>
<td>N₂O₄</td>
<td>N₂O₄</td>
<td>Dinitrogen tetroxide</td>
<td>Deca-10</td>
</tr>
</tbody>
</table>
Polyatomic ions

Common names are used. **Ammonium** is the only cation. **Oxyanions** are composed of a nonmetal and oxygen atoms.

Most oxyanions exist in series that differ in the number of oxygen atoms. If there are two members in such a series, the ion with **fewer** O atoms gets the **-ite** suffix, the one with **more** O atoms gets the **-ate** ending. Example: NO\(_2^-\) nitrite, NO\(_3^-\) nitrate.

If there are more oxyanions in a series, the prefix **hypo-** is used to denote the ion with **fewest** oxygen atoms; prefix **per-** denotes the oxyanions with the **most** oxygen atoms.

**Naming:** Follow the rules for binary compounds: name metal (ammonium) first, then the polyatomic anion.

A compound must be **uncharged**: the sum of positive charges must be equal to the sum of negative charges.

<table>
<thead>
<tr>
<th>Common multiplier: 6</th>
<th>(\text{Mg}^{2+})</th>
<th>(\text{Mg}^{2+})</th>
<th>(\text{PO}_4^{3-})</th>
<th>(\text{PO}_4^{3-})</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 6</td>
<td>+ 6</td>
<td>- 6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Nomenclature of Acids

A compound that dissociates in water to produce hydrogen ions (H\(^+\)) is an acid.

If the acid does not contain oxygen, it is named by adding prefix hydro- and the suffix -ic acid.

The above names only apply for aqueous solution, i.e. when acid can dissociate. In gaseous phase compounds are named according to the rules for nonacidic compounds.

If the acid contains oxygen(s) it is called oxyacid. The rules follow the polyatomic naming. If the anion name ends in -ate, the acid is named by changing the suffix to -ic.

<table>
<thead>
<tr>
<th>Formula of Ion</th>
<th>Name of ion</th>
<th>Formula of acid</th>
<th>Name of acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{SO}_4^{2-})</td>
<td>sulfate</td>
<td>(\text{H}_2\text{SO}_4)</td>
<td>sulfuric acid</td>
</tr>
<tr>
<td>(\text{NO}_3^-)</td>
<td>nitrate</td>
<td>(\text{HNO}_3)</td>
<td>nitric acid</td>
</tr>
<tr>
<td>(\text{PO}_4^{3-})</td>
<td>phosphate</td>
<td>(\text{H}_3\text{PO}_4)</td>
<td>phosphoric acid</td>
</tr>
<tr>
<td>(\text{CO}_3^{2-})</td>
<td>carbonate</td>
<td>(\text{H}_2\text{CO}_3)</td>
<td>carbonic acid</td>
</tr>
</tbody>
</table>

If the anion name ends in -ite, the acid is named by changing the suffix to -ous.

Calcium sulfite (CaSO\(_3\))   Sulfurous acid (H\(_2\)SO\(_3\))
Writing formula of a compound

- possible existence of an \(-\text{ous} \) acid indicates hydrogen
- contains hydrogen, sulfur, oxygen

\( \text{H}_2\text{SO}_4 \)

Nomenclature of Bases

A compound that dissociates in water to produce hydroxyl ions (OH\(^-\)) is a base.

All bases have the name ending with hydroxide.

- NaOH – sodium hydroxide
- NH\(_4\)OH – ammonium hydroxide
- Mg(OH\(_2\)) – magnesium hydroxide
Learn the names and charges of:
\(\text{SO}_4^{2-}, \text{PO}_4^{3-}, \text{CO}_3^{2-}, \text{NO}_3^{-}\)
anions, the names of their corresponding acids (\(\text{H}_2\text{SO}_4, \text{H}_3\text{PO}_4, \text{H}_2\text{CO}_3, \text{HNO}_3\)), the name and charge of \(\text{OH}^-\) anion and \(\text{NH}_4^+\) cation.

<table>
<thead>
<tr>
<th>Cation</th>
<th>Anions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{K}^+)</td>
<td>(\text{Cl}^-), (\text{SO}_4^{2-}), (\text{O}_2^-), (\text{PO}_4^{3-})</td>
</tr>
<tr>
<td>(\text{H}^+)</td>
<td>(\text{HCl}), (\text{H}_2\text{SO}_4), (\text{H}_2\text{O}), (\text{H}_3\text{PO}_4)</td>
</tr>
<tr>
<td>(\text{Zn}^{2+})</td>
<td>(\text{ZnCl}_2), (\text{ZnSO}_4), (\text{ZnO}), (\text{Zn}_3(\text{PO}_4)_2)</td>
</tr>
<tr>
<td>(\text{Al}^{3+})</td>
<td>(\text{AlCl}_3), (\text{Al}_2(\text{SO}_4)_3), (\text{Al}_2\text{O}_3), (\text{Al}_3\text{PO}_4)</td>
</tr>
</tbody>
</table>

**Practice writing formula of compounds**

If the first atom is nonmetal – covalent compound:
1. Prefixes (mono, di…) give how many atoms of each kind are present. Put prefixes as indices.

   **Dinitrogen pentoxide** \(\text{N}_2\text{O}_5\)

If first atom is metal - ionic compound:
1. Find charges of both ions (from position in periodic table); write cation and anion with charges.
2. The sum of charges must be zero. Find out how many of each ion you must have.
3. Put index next to each ion indicating how many ions of that kind there is in the compound. Erase charges of both ions. Practice with table above.

**Sodium phosphate:**
\[
\text{Na}^+ \quad \text{PO}_4^{3-}
\]
Na in 1\(^{st}\) period – charge +1. a positive & three negative charges. Need three \(\text{Na}^+\) ions to balance a \(\text{PO}_4^{3-}\)

**Iron(III)sulfide**
\[
\text{Fe}^{3+} \quad \text{S}^{2-}
\]
Need two iron ions to balance three \(\text{S}^{2-}\).
Chemical Reactions

In mid 1980s chemists combined $Y_2O_3$, CuO and BaCO$_3$ and obtained a new superconducting ceramic material, YBa$_2$Cu$_3$O$_7$ that conducted electricity without resistance when cooled below liquid nitrogen temperature. Magnetic lines cannot penetrate a superconductor, so a magnet floats above it. Experimental trains based on magnetic levitation (maglev) are in construction.

In a chemical reaction one or more substances (reactants) are converted into new substances (products) with different physical and chemical properties. Only valence e- involved.

Reactants $\rightarrow$ Products

Which reaction is chemical?

$CO_2 + O_2 \rightarrow O_2 + CO_2$

$CO_2 + H_2O \rightarrow H_2CO_3$

Gas molecules travel rapidly at room temperature (hundreds of miles per hour). Energy associated with motion (kinetic energy) is absorbed by colliding molecules.

Energy is required to break a chemical bond.

Balanced equation

Balanced equation must have smallest possible whole numbers as coefficients.
A chemical equation is a **shorthand expression** for a chemical change or reaction. A chemical equation must be balanced. **Coefficients** (whole numbers) are placed in front of substances to balance the equation and to indicate the number of units (atoms, molecules, ions, or moles) of each substance that are reacting.

A chemical equation uses the **chemical symbols** and formulas of the reactants and products and other symbolic terms to represent a chemical reaction.

- Symbol $+$ means plus.
- Symbol $\rightarrow$ means *yields*.
- Symbol $\uparrow$ means gas formation.
- Symbol $\downarrow$ means precipitate.
- Symbol $h\nu$ means light.
- Symbol $\Delta$ means heat.

**Conditions** required to carry out the reaction may be placed above or below the arrow.

The **physical state** of a substance is indicated by symbols such as (s) for solid, (l) for liquid, (g) for gas and (aq) for aqueous solution.
Types of Reactions

Chemists try to classify a reaction by understanding what it is doing.

\[ \text{Ca}^{2+}(aq) + \text{CO}_3^{2-}(aq) \rightarrow \text{CaCO}_3(s) \]

Remember that \textit{aq, s, l, g} indicate physical state.

The reaction is used to soften ‘hard’ water (i.e. water containing \text{Ca}^{2+} ions). There are other reactions serving the same purpose.

**Single-displacement reactions**

One element replaces another element in a compound.

A displaces B.

\[ 2 \text{Al}(s) + \text{Fe}_2\text{O}_3(s) \rightarrow \text{Al}_2\text{O}_3(s) + 2 \text{Fe}(l) \]

\[ \text{Mg}(s) + 2 \text{HCl}(aq) \rightarrow \text{MgCl}_2(aq) + \text{H}_2(g) \]

\[ \text{A} + \text{BC} \rightarrow \text{AC} + \text{B} \]

**Double-displacement reactions**

Two compounds exchange partners.

\[ \text{PCl}_3(l) + 3 \text{AgF}(s) \rightarrow \text{PF}_3(g) + 3 \text{AgCl}(s) \]

\[ \text{AB} + \text{CD} \rightarrow \text{AD} + \text{CB} \]

**Decomposition reaction**

One compound breaks into two or more simpler substances.

\[ 2 \text{HgO}(s) \xrightarrow{\text{Heat}} 2 \text{Hg}(l) + \text{O}_2(g) \]

\[ \text{AB} \rightarrow \text{A} + \text{B} \]

**Combination reaction**

Two or more simple compounds combine to give one or more complex substances.

\[ \text{H}_2(g) + \text{I}_2(g) \rightarrow 2 \text{HI}(g) \]

\[ 2 \text{Na}(s) + \text{Cl}_2(g) \rightarrow 2 \text{NaCl}(s) \]

\[ \text{A} + \text{B} \rightarrow \text{AB} \]
Single displacement reactions
Occur if the reactant in elemental form is more reactive than the one in the compound.

Metal Activity Series
2 \( \text{Al}(s) + \text{Fe}_2\text{O}_3(s) \rightarrow \text{Al}_2\text{O}_3(s) + 2 \text{Fe}(l) \)

\( \text{Mg}(s) + \text{PbS}(s) \rightarrow \text{MgS}(s) + \text{Pb}(s) \)

\( \text{Ag}(s) + \text{CuCl}_2(s) \rightarrow \text{no reaction} \)

Halogen Activity Series
\( \text{Cl}_2(\text{g}) + \text{CaBr}_2(s) \rightarrow \text{CaCl}_2(\text{aq}) + \text{Br}_2(\text{aq}) \)

\( \text{I}_2(\text{g}) + \text{CaBr}_2(s) \rightarrow \text{no reaction} \)

Double displacement reactions
Accompany the following processes:
- release of heat
- formation of water
- formation of a precipitate
- release of gas bubbles

Reaction goes only when one of the products leaves aqueous solution

\[ \text{AB} + \text{CD} \rightarrow \text{AD} + \text{CB} \]
Double Displacement Reactions (cont.d)

1. Acid / base neutralization, or acid + metal oxide, produces **water and heat**

\[
\text{HCl}(aq) + \text{NaOH}(aq) \rightarrow \text{NaCl}(aq) + \text{H}_2\text{O}(l)
\]

\[
2\text{HNO}_3(aq) + \text{CuO}(s) \rightarrow \text{Cu(NO}_3)_2(aq) + \text{H}_2\text{O}(l)
\]

2. Formation of insoluble **precipitate**

\[
\text{AgNO}_3(aq) + \text{NaCl}(aq) \rightarrow \text{AgCl}(s) + \text{NaNO}_3(aq)
\]

3. Formation of a **gas**  
   **Indirect gas formation**

\[
\text{NH}_4\text{Cl}(aq) + \text{NaOH}(aq) \rightarrow \text{NaCl}(aq) + \text{NH}_4\text{OH}(aq)
\]

\[
\text{NH}_4\text{OH}(aq) \rightarrow \text{NH}_3(g) \uparrow + \text{H}_2\text{O}(l)
\]

Heat in Chemical Reactions

Energy changes accompany chemical reactions. Energy is either **released** to, or **absorbed** from surroundings.

Since the amount of substance is expressed **in moles**, the heat of the reaction is expressed **per mole** of either reactant or product.

\[
\text{H}_2(g) + \text{Cl}_2(g) \rightarrow 2\text{HCl}(g) + 185 \text{ kJ} \quad \text{(exothermic)}
\]

\[
\text{N}_2(g) + \text{O}_2(g) + 185 \text{ kJ} \rightarrow 2\text{NO}(g) \quad \text{(endothermic)}
\]

6\text{CO}_2 + 6\text{H}_2\text{O} + 2519 \text{ kJ} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2

2519 \text{ kJ of energy is absorbed per 1 mole } \text{C}_6\text{H}_{12}\text{O}_6!
A certain amount of energy is always required for a reaction to occur. It is called the energy of activation, $E_a$. The reaction will occur only if the activation energy is supplied. The activation energy can take the form of a spark or a flame.

\[
\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + 890 \text{ kJ}
\]

Although the reaction releases energy, it needs $E_a$ to start.

**Exothermic Reaction:** Combined energy of products is lower than that of reactants. The difference is released.

**Endothermic Reaction:** Combined energy of products is larger than that of reactants. The difference is absorbed.

\[
\text{N}_2(g) + \text{O}_2(g) + 185 \text{ kJ} \rightarrow 2\text{NO}(g)
\]
Always adjust coefficients, i.e. numbers in front of the molecules.

**Practice**

\[ \text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3 \]

Balanced

N: 2  \(\checkmark\) 2
H: 6 \(\checkmark\) 6

Try some more…

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \]

C: 1 \(\checkmark\) 1
H: 4 \(\checkmark\) 4
O: 2 \(\checkmark\) 4

And more…

\[ 2\text{NaOH} + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O} \]

\[ 2\text{HCl} + \text{Ca(OH)}_2 \rightarrow 2\text{HOH} + \text{CaCl}_2 \]

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} \]

\[ 2\text{HCl} + \text{Na}_2\text{CO}_3 \rightarrow 2\text{NaCl} + \text{CO}_2 + \text{H}_2\text{O} \]
A Balanced Equation Shows:

\[ 44.09 \text{ g } + 160.0 \text{ g} = 132.0 \text{ g } + 72.08 \text{ g} \]

Sum of masses must be balanced

\[ 44.09 \text{ g } + 160.0 \text{ g} = 204.1 \text{ g} \]

\[ 132.0 \text{ g } + 72.08 \text{ g} = 204.1 \text{ g} \]
HW, Chapter 6 (p.120):
3. Write formulas for the following cations: potassium, ammonium, copper(I), titanium(IV), nickel(III), cesium, mercury(II), calcium, lead(II), zinc(II), silver(I), hydrogen, tin(II), iron(III).
6. (b-d),f: Write the systematic names for the following: b) laughing gas (N₂O), c) alumina (Al₂O₃), d) table salt (NaCl), f) galena (PbS).
7. Complete the table, filling in each box with the proper formula:

<table>
<thead>
<tr>
<th></th>
<th>Br⁻</th>
<th>O²⁻</th>
<th>NO₃⁻</th>
<th>PO₄³⁻</th>
<th>CO₃²⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>K⁺</td>
<td>KBr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg²⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al³⁺</td>
<td></td>
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</tr>
<tr>
<td>Zn²⁺</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H⁺</td>
<td></td>
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</tr>
</tbody>
</table>

15. Name these compounds by the IUPAC System: CuCl₂, FeCl₂, Fe(NO₃)₂, FeCl₃, SnF₂, VPO₄.
17(a,c,d,f). Write the formula for these acids: a) hydrochloric acid, c) nitric acid, d) carbonic acid, f) phosphoric acid.
31. Write formulas for all possible compounds formed between the calcium ion and the anions (SO₄²⁻, PO₄³⁻, NO₃⁻, CO₃²⁻).

HW, Chapter 8 (p.169):
3. Balance each of the following equations. Classify each reaction as combination, decomposition, single- or double displacement.
H₂ + O₂ → H₂O
N₂H₄(l) → NH₃(g) + N₂(g)
Δ
H₂SO₄ + NaOH → H₂O + Na₂SO₄
Al₂(CO₃)₃ → Al₂O₃ + CO₂
NH₄I + Cl₂ → NH₄Cl + I₂
11 (a,c,f). Change these word equations into formula equations and balance. Use the proper symbols to indicate the state of each substance, as given.
a) Magnesium metal is placed into hydrobromic acid solution, forming hydrogen gas and aqueous magnesium bromide.
c) Lithium metal reacts with oxygen gas to form solid lithium oxide.
f) Solutions of silver nitrate and aluminum iodide are mixed together, forming solid silver iodide and aqueous aluminum nitrate.
15. Use the activity series to predict whether a reaction will occur, and balance it. Write “no reaction” as product, if needed.
Ca(s) + H₂O(l) →
Br₂(l) + KI(aq) →
Cu(s) + HCl(aq) →
Al(s) + H₂SO₄(aq) →
25. Write balanced eq. with heat term:
a) Solid mercury(II) oxide decomposes into liquid mercury and oxygen gas upon absorption of 90.8 kJ.
b) Hydrogen gas reacts with oxygen gas to form liquid water, liberating 285.8 kJ for each mole of water.