Ionic Compounds

- **Ionic compounds** are made up of electrically equivalent numbers of cations and anions.

$Na^{+} + Cl^{-}$ Y $NaCl$ $\qquad$ $Ba^{2+} + 2Cl^{-}$ Y $BaCl_2$

$Cr^{3+} + 3Cl^{-}$ Y $CrCl_3$ $\qquad$ $2Al^{3+} + 3O^{2-}$ Y Al_2O_3

- Simple ionic compounds are *always solids* at room temperature.

- Ionic solids are composed of cations and anions arranged in a three-dimensional array, called a **crystal lattice**.

- Ionic compounds *do not* contain molecules of the compound, so there cannot be a molecular formula for them.

- Ionic compounds are represented by an **empirical formula**.

Determining Charges on Monatomic Ions

1. Metals form cations; nonmetals form anions.

2. Main-group metals tend to form cations with charges equal to their group number (North American system).

   Examples: Na^{+} (Group 1A, 1+)
   Mg^{2+} (Group 2A, 2+)
   Al^{3+} (Group 3A, 3+)

3. Nonmetals tend to form anions with charges equal to their group number minus 8.

   Examples: F^{-} (Group 7A, 7 - 8 = -1)
   O^{2-} (Group 6A, 6 - 8 = -2)
   N^{3-} (Group 5A, 5 - 8 = -3)

4. Transition metals and some heavier main group elements can form more than one kind of cation.

Examples:
Cu^{+} & Cu^{2+}
Fe^{2+} & Fe^{3+}
Co^{2+} & Co^{3+}
Cr^{2+} & Cr^{3+}
Tl^{+} & Tl^{3+}

5. Ionic charges greater than ±3 are not real. Compounds in which an element might be assigned such high charge are probably molecular (or less commonly, network solids).

Polyatomic Ions

- **Polyatomic ions** are molecular ions; i.e., molecules with certain charges.

- Polyatomic ions form ionic compounds in the same ways as simple monatomic ions; i.e., the empirical formulas depend on the charges of the ions.

$$NH_4^+ + Cl^- = NH_4Cl$$

$$2NH_4^+ + SO_4^{2-} = (NH_4)_2SO_4$$

$$3Ca^{2+} + 2PO_4^{3-} = Ca_3(PO_4)_2$$

$$Ca^{2+} + 2HCO_3^- = Ca(HCO_3)_2$$

Some Common Polyatomic Ions to Know

Cations

Ammonium ion	NH_4^+	
Hydronium ion	H_3O^+	(In solution; no common compounds)
Mercury(I)	Hg_2^{2+}	

Anions

Acetate ion	$C_2H_3O_2^-$	(Also written $CH_3CO_2^-$ or CH_3COO^-)
Carbonate ion	CO_3^{2-}	
Hydrogen carbonate ion	HCO_3^-	(Formerly called bicarbonate)
Hypochlorite ion	ClO^-	
Chlorite ion	ClO_2^-	
Chlorate ion	ClO_3^-	
Perchlorate ion	ClO_4^-	
Chromate ion	CrO_4^{2-}	
Dichromate ion	$Cr_2O_7^{2-}$	
Cyanate ion	OCN^-	
Thiocyanate ion	SCN^-	
Cyanide ion	CN^-	
Hydroxide ion	OH^-	
Nitrite ion	NO_2^-	
Nitrate ion	NO_3^-	
Oxalate ion	$C_2O_4^{2-}$	
Permanganate ion	MnO_4^-	
Peroxide	O_2^{2-}	
Phosphate ion	PO_4^{3-}	
Hydrogen phosphate ion	HPO_4^{2-}	(Also called monohydrogen phosphate)
Dihydrogen phosphate ion	$H_2PO_4^-$	
Sulfite ion	SO_3^{2-}	
Hydrogen sulfite ion	HSO_3^-	(Formerly called bisulfite)
Sulfate ion	SO_4^{2-}	
Hydrogen sulfate ion	HSO_4^-	(Formerly called bisulfate)
Thiosulfate ion	$S_2O_3^{2-}$	

Naming Binary and Ionic Inorganic Compounds

- Chemical nomenclature (naming) follows rules adopted by the International Union of Pure and Applied Chemistry (IUPAC).

- When writing formulas for binary compounds, elements are arranged in group order, except for H, O, and F. The accepted order by groups and these elements is:

$$1A < 2A < 3A < 4A < 5A < H < 6A < 7A < O < F$$

$NaCl$ not $ClNa$	HCl not ClH
NF_3 not F_3N	NH_3 not H_3N
ClF_3 not F_3Cl	SCl_4 not Cl_4S

Ionic or Molecular?

Determine whether the compounds is *ionic* or *molecular*:

(a) Binary compounds of two nonmetals, two metalloids, or a metalloid and a nonmetal are usually *molecular*.

(b) Binary compounds of a metal and a nonmetal are usually *ionic*.

(c) A compound that contains a polyatomic cation or anion and any kind of counter ion (monatomic or polyatomic anion or cation) is *ionic*.

(d) Molecular compounds are named from their molecular formulas; ionic compounds are named from their empirical formulas.

Naming Molecular Compounds

For molecular compounds, name the first element followed by the stem of the second element plus "ide". Use Greek prefixes to indicate numbers of each atom in the molecular formula. (If there is only one of the first element, "mono" is not used.)

Examples:

NO_2	nitrogen dioxide ("mono" not needed)
N_2O_4	dinitrogen tetroxide ("a" of "tetra" usually dropped)
SCl_4	sulfur tetrachloride
H_2S	(di)hydrogen sulfide ("di" not needed, since no other HS compound exists)
H_2O	water (not systematically named)
NH_3	ammonia (not systematically named)
CH_4	methane (not systematically named)
H_2O_2	hydrogen peroxide (not systematically named)

Naming Ionic Compounds

For binary ionic compounds, name the first element followed by the stem of the second element plus "ide", *but do not use Greek prefixes to indicate numbers of atoms*.

If a cation might have one of two or more possible charges, the charge is indicated by using a Roman numeral (Stock system).

If the cation or anion is a polyatomic ion, use its usual name.

Examples:

LiF	lithium fluoride
$BaBr_2$	barium bromide ("di" not used)
$NaCN$	sodium cyanide (must know CN^- = cyanide)
Hg_2Cl_2	mercury(I) chloride (Note: Hg_2^{2+} = mercury(I) ion, a diatomic ion)
NH_4NO_3	ammonium nitrate
NH_4NO_2	ammonium nitrite
$FeCl_2$	iron(II) chloride (formerly, ferrous chloride)
$FeCl_3$	iron(III) chloride (formerly, ferric chloride)

Hydrates

Some ionic compounds may contain water molecules as part of their regular crystal structure. These compounds are called **hydrates** or **hydrated salts**.

L The number of water molecules per ionic formula unit is appended to the usual compound name, using Greek prefixes added to *hydrate*.

L In writing the formula, the waters of hydration are written after the compound formula, separated by a centered dot (•).

$BeSO_4 \cdot 4H_2O$	beryllium sulfate tetrahydrate
$Na_2CO_3 \cdot 10H_2O$	sodium carbonate decahydrate
$CuSO_4 \cdot 5H_2O$	copper(II) sulfate pentahydrate
$CrCl_3 \cdot 6H_2O$	chromium(III) chloride hexahydrate

$2CaSO_4 \cdot H_2O = CaSO_4 \cdot \frac{1}{2}H_2O$	calcium sulfate hemihydrate ("Plaster of Paris")

Naming Acids

- Acids are important hydrogen-containing molecular compounds, whose names follow special rules.

- For the moment, we can define an acid as a compound that in water can produce electrically equivalent numbers of hydrogen ions and anions; e.g.,

$$HCl \ 6 \ H^+ + Cl^-$$
$$H_2SO_4 \ 6 \ 2H^+ + SO_4^{2-}$$

- In general, the formulas of inorganic acids have H written first, whereas hydrogen-containing inorganic compounds that are not acids do not have H written first.

Acids: HCl, HCN, HNO_3, H_2SO_4, H_3PO_4

Not acids: LiH, BeH_2, NH_3, PH_3

Oxoacids

An **oxoacid** is an acid containing hydrogen, oxygen, and another element. The anion produced when an oxoacid dissolves in water is an **oxoanion**. The names of oxoacids and their related oxoanions follow these rules:

1. If an element can form two different oxoanions, the one with more oxygen atoms is named with the -*ate* suffix, and the one with fewer oxygen atoms is named with the -*ite* suffix.

Anion	Name	Anion	Name
NO_3^-	nitr*ate* ion	NO_2^-	nitr*ite* ion
SO_4^{2-}	sulf*ate* ion	SO_3^{2-}	sulf*ite* ion

2. If the anion name ends in -*ate*, the corresponding acid name ends in -*ic*.

Anion	Name	Acid	Name
NO_3^-	nitr*ate* ion	HNO_3	nitr*ic* acid
SO_4^{2-}	sulf*ate* ion	H_2SO_4	sulfur*ic* acid

Oxoacids

3. If the anion name ends in *-ite*, the corresponding acid name ends in *-ous*.

Anion	Name	Acid	Name
NO_2^-	nitr*ite* ion	HNO_2	nitr*ous* acid
SO_3^{2-}	sulf*ite* ion	H_2SO_3	sulfur*ous* acid

4. When an element can form three or four oxoacids, both the anions and the oxoacids are distinguished with the prefix *hypo-* and *per-* for the species with the fewest and most oxygen atoms, respectively.

Anion	Name	Acid	Name
ClO^-	*hypo*chlor*ite* ion	$HClO$	*hypo*chlor*ous* acid
ClO_2^-	chlor*ite* ion	$HClO_2$	chlor*ous* acid
ClO_3^-	chlor*ate* ion	$HClO_3$	chlor*ic* acid
ClO_4^-	*per*chlor*ate*	$HClO_4$	*per*chlor*ic* acid

Acid Anions

Acid anions have H atoms that they can lose as H^+ in water. The names of these ions add *hydrogen* in front of the name of the corresponding ion that does not have H in it. If the acid anion has two or more hydrogen atoms capable of forming H^+, the appropriate Greek prefix is used to indicate the number. *Mono-* is omitted if only one acid anion is possible.

Acid Ion	Name
HCO_3^-	hydrogen carbonate ion
HSO_4^-	hydrogen sulfate ion
HPO_4^{2-}	monohydrogen phosphate ion
$H_2PO_4^-$	dihydrogen phosphate ion

Binary Acids

Binary hydrogen compounds with nonmetals may form H^+ and an anion when dissolved in water. The acidic solutions are named as if they were molecular acids, using the usual name for the compound itself, replacing *hydrogen* with *hydro-* and the suffix *-ide* with *-ic* . The word *acid* is then added. The formula for such a compound in water is often distinguished from the compound itself by (*aq*), indicating water (aqueous) solution.

Comp.	Name	Acid Soln.	Name
HCl	hydrogen chloride	HCl(*aq*)	hydrochloric acid
HCN	hydrogen cyanide	HCN(*aq*)	hydrocyanic acid
H_2S	hydrogen sulfide	H_2S(*aq*)	hydrosulfuric acid

HCN, although not a binary compound, is analogous to the binary hydrogen halides (HCl, HBr, HI), and so as an acid is named in a similar manner.

The name of H_2S(*aq*) as an acid is slightly irregular in using the full stem name of the element.