**WRITING BALANCED NET IONIC EQUATIONS** **CHEMISTRY BC2001x**

## REACTIONS INVOLVING ACIDS, BASES, AND SALTS IN AQUEOUS SOLUTION

Consider in turn each substance, either present initially as a reactant or that may be formed as a product. You must *recognize* whether each particular substance is best written as *separate ions* in solution, or as dissolved *undissociated molecules*, or as an *insoluble solid* salt, or as a *gas*. Some reactions involve gases, which may or may not be very soluble in water.

**Acids** have names of the form "[xxx] acid", where "[xxx]" specifies the particular acid.
Acids have chemical formulas starting with H-, if they are mineral acids, or ending with -COOH, if they are organic acids (called carboxylic acids). Some polyatomic ions are also acids.
*Examples*: hydrofluoric acid, HF; nitric acid, $HNO_3$; sulfuric acid, $H_2SO_4$; boric acid, $H_3BO_3$; acetic acid, $CH_3COOH$; benzoic acid, $C_6H_5COOH$; oxalic acid, HOOCCOOH; $HSO_4^-$; $NH_4^+$.

**Salts** have names of the form "[metal(N)][anion]" and formulas written "$[metal(N)]_x[anion]_y$".
The Roman numeral N, specifying the charge on the metal cation, is given if necessary.
The subscripts x and y balance the total positive charges and the total negative charges.
Metals all form cations. The only common nonmetal cation in salts is the ammonium ion, $NH_4^+$.
Anions can be formed from monatomic nonmetals (examples: $Cl^-$, $I^-$, $O^{2-}$, $S^{2-}$), or from polyatomic groupings of nonmetals (examples: $OH^-$, $NO_2^-$, $ClO_3^-$, $SO_4^{2-}$, $PO_4^{3-}$, $HCO_3^-$), or from polyatomic combinations of metals with nonmetals (examples: $Cr_2O_7^{2-}$, $MnO_4^-$).
*Examples*: lithium oxide, $Li_2O$; aluminum chloride, $AlCl_3$; cobalt(II) nitrate, $Co(NO_3)_2$.

**Bases** studied in this course are of three types: (1) Hydroxide salts, composed of a metal cation $M^{n+}$ and n hydroxide anions $OH^-$. *Examples*: KOH, $Ni(OH)_2$, $Al(OH)_3$. (2) Ammonia, its derivatives, and other organic amines are molecular weak bases. *Examples*: ammonia, $NH_3$; diphenylamine, $(C_6H_5)_2NH$; pyridine, $C_5H_5N$. (3) Basic anions. *Examples*: $OH^-$, $CO_3^{2-}$, $PO_4^{3-}$.

## SYSTEMATIC PROCEDURE to obtain CORRECT NET IONIC EQUATIONS

**I**. Examine each **reactant**. Ask the following series of questions:
1) Is the reactant an **acid**? If not, go to Question 2 below.
   Is the acid a **strong** acid? (Memorize the six *strong* acids, given on another sheet.)
      If the reactant is a **strong** acid, write it as *separate* **ions**, e.g. $H^+(aq) + NO_3^-(aq)$.
      If the reactant is a **weak** acid, write it as an *undissociated* **molecule**, e.g. $HNO_2(aq)$.
2) Is the reactant a **salt** (including hydroxides)? If not, go to Question 3 below.
   Is the salt **soluble** in water? (Memorize the *solubility* rules, given on another sheet.)
      If the reactant is a **soluble** salt, write it as *separate* **ions**, e.g. $Na^+(aq) + Br^-(aq)$.
      If the reactant is an **insoluble** salt, write it as a **solid**, e.g. AgBr(s).
3) If a reactant is neither an acid nor a salt, is it a **weak base**, either ammonia or an amine?
   (Check for nitrogen (N) in the chemical formula.) Also check to see if it is a basic anion.
   If the reactant is a **weak base**, write it as an *undissociated* **molecule**, e.g. $C_3H_7NH_2(aq)$.

**II**. **Pair** all possible cations and anions to check for *all possible* **products**.
For each possible **product**, follow the procedures in Part I above, and make the tests below.

**III**. **Check** for possible **acid-base reactions**. Both molecules and ions can be acids or bases.
An acid reacting with a base will **transfer protons** ($H^+$) to the base.
   If the base is a hydroxide ($OH^-$), proton transfer will form water, $H_2O$.
   In strongly acidic solution, anions of weak acids become fully protonated.
      For example, the anion $S^{2-}$ will react with $2\ H^+$ to form $H_2S(g)$.

**IV**. **Check** for **unstable** products that *decompose* to form *gases*.
   For example, any $H_2CO_3$ made as a product decomposes to form $CO_2(g) + H_2O$.

**V**. **Eliminate** any **spectator ions** (bystander ions, non-participating ions), that is, ions present on both sides of the chemical reaction equation which do not take part in the reaction at all.

**VI**. Now **balance** the chemical equation so that the total numbers of atoms of each **element**, in whatever chemical form or combination, are the same on each side of the equation.

**Check** that total net **charge** is the same on each side of the equation.

**SUMMARY – GENERAL RULES USED IN WRITING CORRECTLY BALANCED NET IONIC EQUATIONS**

**1.** Write all *soluble*, *strong electrolytes* as *separate ions*: $M^{n+}(aq)$, $X^{q-}(aq)$.
*Ions* in *solution* must always be written with the proper *charge* superscript.

**2.** Write all *gases*, *insoluble solids*, *nonelectrolytes*, and *weak electrolytes* in *molecular* form.
For example, $CO_2(g)$; $Fe(OH)_3(s)$; $CH_3OH(aq)$; $CH_3COOH(aq)$.
Do *not* write charges with any *solids* or with *molecules* in solution.

**3.** In the final net reaction equation, *do not include* any substance or ion that is present but that does not take part in the reaction.

**4.** While not strictly necessary, it is useful and good practice to specify in parentheses, as shown below, the *state* of any substance or ion taking part in a chemical reaction.
Ions or non-electrolyte or weak electrolyte molecules dissolved in water: $M^{n+}(aq)$, Q(aq).
Insoluble solids, or solid precipitates formed: R(s) or R↓ .
Gases as reactants, or gases evolved as products: G(g) or G↑.

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**Important Note:** Students often confuse the property of being soluble in water or insoluble in water with the property of being a strong electrolyte or a weak electrolyte. *There is simply no connection whatever between these two properties*. The rules and the exceptions regarding each of these properties must be learned independently.

**1.** Substances said to be s**oluble** in water, whether they are solids, liquids, or gases, will dissolve completely in water (up to a maximum concentration, which may be quite large; certain liquid substances are in fact miscible with water in all proportions).
Examples of soluble substances: NaCl; $KNO_3$; HCl; $NH_3$; $CH_3COOH$; $CH_3OH$.

**a.** Substances that are **soluble** in water may be **strong** electrolytes: *all* of the dissolved substance *dissociates entirely* into *ions*, and none of it exists as undissociated molecules dissolved in the solution. Examples: HCl; $HNO_3$; NaCl; KBr; $Na_2SO_4$; NaOH.

**b.** Substances that are **soluble** in water may be **weak** electrolytes: *most* of the dissolved substance exists as *undissociated molecules* in the solution, and only a small fraction is dissociated into ions. Examples: HF; $HNO_2$; $CH_3COOH$; $NH_3$; $C_5H_5N$.

**c.** Substances that are **soluble** in water may be **non**-electrolytes: *all* of the dissolved substance exists as *undissociated* molecules in solution, and no ions at all are formed. Examples: methanol, $CH_3OH$; acetone, $CH_3COCH_3$; glucose, $C_6H_{12}O_6$.

**2.** Substances said to be **insoluble** in water actually do dissolve, but only to a very small extent (the maximum dissolved concentration may be extremely small). Examples: AgCl; $Ni(OH)_2$.
What does dissolve, however little that is, may be a strong electrolyte, or may be a weak electrolyte, or may be a non-electrolyte.

**a.** Substances that are **insoluble** in water may be **strong** electrolytes: *all* of the dissolved substance, however little that is, *dissociates entirely* into *ions*, and none of it exists as undissociated molecules dissolved in the solution. Example: AgCl.

**b.** Substances that are **insoluble** in water may be **weak** electrolytes: *most* of the dissolved substance, however little that is, exists as *undissociated molecules* in solution, and only a small fraction is dissociated into ions. Example: $C_8H_{17}COOH$.

**c.** Substances that are **insoluble** in water may be **non**-electrolytes: *all* of the dissolved substance, however little that is, exists as *undissociated molecules* in solution, and no ions are formed at all. Examples: $H_2$; $P_4$; $S_8$; cholesterol, $C_{27}H_{46}O$.