**Appendix**

# B Net Ionic Equations

## Introduction

For reactions which occur in aqueous solution, the net ionic equation is particularly useful since only those species which participate in the reaction, i.e. *reacting species*, are included. The principal step in writing the net ionic equation is to determine which molecular species or salts are *strong electrolytes* in aqueous solution. Therefore, it is necessary to have a complete understanding of strong electrolytes before proceeding to the writing of net ionic equations.

## Strong Electrolytes

In aqueous solution, strong electrolytes dissolve and dissociate (separate) 100% to form ions. Thus, an aqueous solution of a strong electrolyte contains a relatively high concentration of ions. For example, when dissolved in water, the ionic compound NaCl is classified as a strong electrolyte. As a result, NaCl(aq) really exists in solution as dissociated and separated ions of $Na^+$(aq) and $Cl^-$(aq). Neutral formula units of NaCl do not exist dissolved in solution. *Strong acids*, *strong bases*, and *soluble ionic compounds* are classified as strong electrolytes in aqueous solution.

Most general chemistry books agree that the seven compounds given below are strong acids (ergo strong electrolytes) when dissolved in water. Consequently, an aqueous solution of the

**Strong Acids**

| | | |
|---|---|---|
| HCl(aq) | $HClO_4$(aq) | $H_2SO_4$(aq) |
| HBr(aq) | $HClO_3$(aq) | $HNO_3$(aq) |
| HI(aq) | | |

strong acid perchloric acid, $HClO_4$(aq), actually consists of dissociated and separated ions of $H^+$(aq) and $ClO_4^-$(aq). Neutral molecules of $HClO_4$ do not exist dissolved in solution. Likewise, an aqueous solution of the strong acid hydrochloric acid, HCl(aq), really consists of $H^+$(aq) and $Cl^-$(aq). Neutral molecules of HCl do not exist dissolved in solution. The dissolution equations for $HClO_4$ and HCl are represented as shown below. When dissolved in water, any other acid,

$$\underbrace{HClO_4}_{\text{0\% dissolved as neutral molecules}} \xrightarrow[100\%]{H_2O} \underbrace{H^+(aq) + ClO_4^-(aq)}_{\text{100\% dissociated and dissolved as separate ions}}$$

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$$\underbrace{HCl}_{\text{0\% dissolved as neutral molecules}} \xrightarrow[100\%]{H_2O} \underbrace{H^+(aq) + Cl^-(aq)}_{\text{100\% dissociated and dissolved as separate ions}}$$

e.g., $HC_2H_3O_2$, $H_2CO_3$, HF, $H_2S$, etc., is a *weak acid* and therefore a *weak electrolyte*. Weak electrolytes dissolve but dissociate less than 100% to form ions. Thus, an aqueous solution of a weak electrolyte contains a relatively low concentration of ions. For example, the weak acid acetic acid, $HC_2H_3O_2$, readily dissolves in water. However, the majority of this acid (~99%) dissolves as neutral molecules of $HC_2H_3O_2$. Only a small amount (~1%) dissociates and exists as separate ions of $H^+(aq)$ and $C_2H_3O_2^-(aq)$. The dissolution equation for $HC_2H_3O_2$ is represented as shown below.

$$\underbrace{HC_2H_3O_2(aq)}_{\text{\textasciitilde 99\% dissolved as neutral molecules}} \overset{H_2O}{\underset{\sim 1\%}{\rightleftharpoons}} \underbrace{H^+(aq) + C_2H_3O_2^-(aq)}_{\text{\textasciitilde 1\% dissociated and dissolved as separate ions}}$$

Most general chemistry books agree that the Group IA metal hydroxides and the heavier Group IIA metal hydroxides given below are strong bases (ergo strong electrolytes) when dissolved in water. Consequently, an aqueous solution of the strong base calcium hydroxide,

**Strong Bases**

| **IA** | | **IIA** |
|---|---|---|
| LiOH(aq) | RbOH(aq) | $Ca(OH)_2(aq)$ |
| NaOH(aq) | CsOH(aq) | $Sr(OH)_2(aq)$ |
| KOH(aq) | | $Ba(OH)_2(aq)$ |

$Ca(OH)_2(aq)$, really consists of dissociated and separated ions of $Ca^{+2}(aq)$ and $OH^-(aq)$. Neutral formula units of $Ca(OH)_2$ do not exist dissolved in solution. However, if the solution is saturated with $Ca^{+2}$ and $OH^-$ ions, solid undissolved $Ca(OH)_2$ may be present as a precipitate at the bottom of the vessel. The dissolution equation for $Ca(OH)_2$ is represented as shown below. When dissolved in water, *weak bases*, such as ammonia and its derivatives,are classified as

$$\underbrace{Ca(OH)_2(s)}_{\text{0\% dissolved as as neutral formula units}} \xrightarrow[100\%]{H_2O} \underbrace{Ca^{+2}(aq) + 2\,OH^-(aq)}_{\text{100\% dissociated and dissolved as separate ions}}$$

weak electrolytes. For example, the weak base ammonia, $NH_3$, readily dissolves in water. However, the majority of this base (~99%) dissolves as neutral molecules of $NH_3$. A small amount (~1%) reacts with water to form separated ions of $NH_4^+(aq)$ and $OH^-(aq)$, as shown below in the dissolution equation.

$$\underbrace{NH_3(aq) + H_2O(l)}_{\sim 99\% \text{ dissolved as neutral molecules}} \underset{\sim 1\%}{\overset{H_2O}{\rightleftharpoons}} \underbrace{NH_4^{+}(aq) + OH^{-}(aq)}_{\sim 1\% \text{ dissolved as separate ions}}$$

Soluble ionic compounds are also classified as strong electrolytes when dissolved in water. The solubility rules, given in Appendix C, are used to determine whether an ionic compound is soluble (ergo a strong electrolyte) or insoluble (ergo not a strong electrolyte). For example, consider the two ionic compounds, $K_2SO_4$ and $BaSO_4$. The fourth solubility rule specifies that $K_2SO_4$ is soluble; whereas $BaSO_4$ is insoluble. Therefore, of the two sulfates, only the $K_2SO_4$ is a strong electrolyte. Consequently, an aqueous solution of potassium sulfate, $K_2SO_4(aq)$, really consists of dissociated and separated ions of $K^{+}(aq)$ and $SO_4^{-2}(aq)$. Neutral formula units of $K_2SO_4$ do not exist dissolved in solution. However, if the solution is saturated with $K^{+}$ and $SO_4^{-2}$ ions, solid undissolved $K_2SO_4$ may be present as a precipitate at the bottom of the vessel. The dissolution equation for $K_2SO_4$ is represented as shown below. Conversely, the insoluble $BaSO_4$ does not dissolve to any significant extent and will remain as a precipitate at the bottom of the vessel.[1]

$$\underbrace{K_2SO_4(s)}_{\substack{0\% \text{ dissolved as} \\ \text{as neutral formula units}}} \underset{100\%}{\overset{H_2O}{\rightarrow}} \underbrace{2\,K^{+}(aq) + SO_4^{-2}(aq)}_{\substack{100\% \text{ dissociated and dissolved} \\ \text{as separate ions}}}$$

<u>Net Ionic Equations</u>

For chemical reactions taking place in aqueous solution, three different balanced equations can be written, the *molecular equation*, the *full ionic equation*, and the *net ionic equation*. The molecular equation includes full chemical formulas for all reactants and products. The full ionic equation shows all reactants and products as they actually exist in solution, i.e., strong electrolytes are shown dissociated into ions. The net ionic equation includes only the reacting species, i.e., ions or compounds that change in some way during the course of the reaction. Systematic and correct writing of the three equations in the order molecular, full ionic, and net ionic will result in correct derivation of the net ionic equation. This process is outlined in the following two examples.

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[1]The small amount of an insoluble ionic compound that does dissolve is dissociated 100% into ions. For example, insoluble $BaSO_4$ has a molar solubility of $1\times10^{-5}$ M. This small amount of $BaSO_4$ that dissolves, dissociates 100% to give relatively low $Ba^{+2}$ and $SO_4^{-2}$ concentrations of $1\times10^{-5}$ M.

**Appendix B** **Net Ionic Equations**

**EXAMPLE:** Aqueous solutions of calcium chloride and sodium carbonate are mixed. Write the net ionic equation.

**Step 1:** A. Write correct chemical formulas for each compound given.

calcium chloride = $CaCl_2$ } Reactants
sodium carbonate = $Na_2CO_3$ }

B. If not given, predict products by allowing reactants to trade partners.

$Ca^{+2}$ $Cl^{-}$ → $CaCO_3$ } Products
$Na^{+}$ $CO_3^{-2}$ → $NaCl$ }

C. Write the balanced molecular equation.

**Balanced Molecular Equation:**
$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2\ NaCl$

**Step 2:** A. Identify strong electrolytes. Remember.....strong electrolytes are strong acids, strong bases, and soluble ionic compounds. **Use Appendix C** to determine whether an ionic compound is soluble or insoluble.

**$CaCl_2$:** ionic compound→soluble by Rule #3→**strong electrolyte**
**$Na_2CO_3$:** ionic compound→soluble by Rule #1→**strong electrolyte**
$CaCO_3$: ionic compound→insoluble by Rule #6→precipitates
**NaCl:** ionic compound→soluble by Rule #1→**strong electrolyte**

B. Write the full ionic equation by showing all species as they really exist in solution, i.e., strong electrolytes are shown dissociated into ions.

**Balanced Full Ionic Equation:**
$Ca^{+2} + 2\ Cl^{-} + 2\ Na^{+} + CO_3^{-2} \rightarrow CaCO_3(s) + 2\ Na^{+} + 2\ Cl^{-}$

**Step 3:** A. Identify *spectator ions*. Spectator ions are ions that appear on both sides of the equation in exactly the same form.

Spectator Ions: $Na^{+}$ and $Cl^{-}$
These ions are present on both sides of the equation in the same form (dissolved in solution) and with the same charge.

Reacting Ions: $Ca^{+2}$ and $CO_3^{-2}$

These ions are changing form. On the reactant side they are dissolved in solution; whereas, on the product side they are present in an insoluble precipitate.

B. Write the net ionic equation by removing spectator ions from the full ionic equation and balance (if the molecular equation was not previously balanced in Step 1C).

**Balanced Net Ionic Equation:**

$Ca^{+2} + CO_3^{-2} \rightarrow CaCO_3(s)$

**EXAMPLE:** Aqueous solutions of ammonium chloride and magnesium hydroxide are mixed. Write the net ionic equation if the products of this reaction are magnesium chloride, ammonia, and water.

**Step 1:** A. Write correct chemical formulas for each compound given.

ammonium chloride = $NH_4Cl$
magnesium hydroxide = $Mg(OH)_2$
} Reactants

magnesium chloride = $MgCl_2$
ammonia = $NH_3$
water = $H_2O$
} Products

B. Write the balanced molecular equation

**Balanced Molecular Equation:**

$2\ NH_4Cl + Mg(OH)_2 \rightarrow MgCl_2 + 2\ NH_3 + 2\ H_2O$

**Step 2:** A. Identify strong electrolytes.

**$NH_4Cl$:** ionic compound→soluble by Rule #1→**strong electrolyte**
$Mg(OH)_2$: ionic compound→insoluble by Rule #6→solid
**$MgCl_2$:** ionic compound→soluble by Rule #3→**strong electrolyte**
$NH_3$: molecular compound→weak base→weak electrolyte
$H_2O$: molecular compound→weak or non-electrolyte

B. Write the full ionic equation by showing all species as they really exist in solution, i.e., strong electrolytes are shown dissociated into ions.

**Balanced Full Ionic Equation:**

$2\ NH_4^+ + 2\ Cl^- + Mg(OH)_2(s) \rightarrow Mg^{+2} + 2\ Cl^- + 2\ NH_3 + 2\ H_2O$

**Step 3:** A. Identify *spectator ions*.

Spectator Ion: $Cl^-$

B. Write the net ionic equation by removing spectator ions.

**Balanced Net Ionic Equation:**

$2\ NH_4^+ + Mg(OH)_2(s) \rightarrow Mg^{+2} + 2\ NH_3 + 2\ H_2O$

**Appendix B** **Net Ionic Equations** **Name:** ________________

**Questions:** Predict products and write the balanced net ionic equation for each of the following reactions. (Note: $BaSO_3$ is insoluble.)

1. $Zn(C_2H_3O_2)_2 + Na_2S \rightarrow$

2. $Pb(NO_3)_2 + NH_4Cl \rightarrow$

3. $Na_3PO_4 + MgCl_2 \rightarrow$

4. $Cu(NO_3)_2 + NaOH \rightarrow$

5. $ZnSO_4 + BaS \rightarrow$

6. $Na_2CO_3 + HCl \rightarrow$
   (HINT: $H_2CO_3(aq)$ normally decomposes to $CO_2(g)$ and $H_2O(l)$)

7. $NiS + HCl \rightarrow$

8. $BaCl_2 + Na_2SO_3 \rightarrow$

9. $Zn + HCl \rightarrow$
   (HINT: This is a redox reaction. Zn is oxidized to $Zn^{+2}$ and $H^+$ is reduced to $H_2(g)$)

10. $Hg(NO_3)_2 + (NH_4)_2SO_4 \rightarrow$

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**Questions:** Write the balanced net ionic equation for each of the following reactions.

1. barium acetate + ammonium sulfate →

2. calcium hydroxide + sodium carbonate →

3. iron(III) nitrate + barium hydroxide →

4. barium hydroxide + hydrochloric acid →

5. silver nitrate + magnesium bromide →

6. acetic acid + potassium hydroxide →

7. sodium chromate + silver nitrate →

8. calcium chlorate + sodium phosphate →

9. ammonium chloride + sodium hydroxide →
   (HINT: $NH_4OH$(aq) does not exist and decomposes to $NH_3$(g or aq) and $H_2O$(l))

10. calcium carbonate + sulfuric acid →
    (HINT: $H_2CO_3$(aq) normally decomposes to $CO_2$(g) and $H_2O$(l))