ALE 15.  Electrolytes and Precipitation Reactions
(Reference: Sections 4.1 – 4.3 in Silberberg 5th edition)

When will two aqueous solutes undergo a double displacement reaction?

The Model: Electrolytes

Key Questions

1. Why is the light bulb in Figure 1A “off” and the one in Figure 1B “on”?

2  a. Electrons cannot flow from one electrode to the second through the water to “close the circuit” in Figure 2B. Based on the Model, what particles flow through the water, thus “closing the circuit” between the electrodes in Figure 2B?

b. Besides being matter, what do the particles in your answer to Question 2a have in common with the electron? (Hint: What do their symbols have in common with the symbol for the electron?)

c. Is water a molecular or an ionic compound? (Circle your answer.)

d. Why is pure water virtually nonconductive? (Hint: According to the Model, what is necessary for electricity to be conducted through a body of water?)
3. Aqueous sodium chloride is an **electrolyte**. Based on the Model (and Question 2), define what an electrolyte is.

**The Model: Solubility Rules**

If an amount of a salt is placed in 100 mL of water, the following table describes whether or not the salt will dissolve:

<table>
<thead>
<tr>
<th></th>
<th>NO$_3^-$</th>
<th>C$_2$H$_5$O$_2^-$</th>
<th>SO$_4^{2-}$</th>
<th>Cl$^-$, Br$^-$, I$^-$</th>
<th>S$^{2-}$</th>
<th>OH$^-$</th>
<th>CO$_3^{2-}$, PO$_4^{3-}$, SO$_3^{2-}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH$_4^+$</td>
<td>s</td>
<td>s</td>
<td>s</td>
<td>s</td>
<td>s</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Na$^+$, K$^+$, Rb$^+$, Cs$^+$</td>
<td>s</td>
<td>s</td>
<td>s</td>
<td>s</td>
<td>s</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Ca$^{2+}$, Sr$^{2+}$, Ba$^{2+}$</td>
<td>s</td>
<td>s</td>
<td>ppt$^a$</td>
<td>s</td>
<td>s$^b$</td>
<td>s</td>
<td>ppt</td>
</tr>
<tr>
<td>Ag$^+$</td>
<td>s</td>
<td>s</td>
<td>ppt$^a$</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
</tr>
<tr>
<td>Hg$_2^{2+}$, Hg$^{2+}$</td>
<td>s</td>
<td>s</td>
<td>ppt$^c$</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
</tr>
<tr>
<td>Pb$^{2+}$</td>
<td>s$^d$</td>
<td>ppt</td>
<td>ppt$^c$</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
</tr>
<tr>
<td>most other metals</td>
<td>s</td>
<td>s</td>
<td>s</td>
<td>s</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
</tr>
</tbody>
</table>

**Legend:**
- s (“soluble”) = One gram or more of the salt can be dissolved in 100 mL of H$_2$O.
- ppt (“precipitate”) = A precipitate forms if as much as 0.1 g of the salt is placed in 100 mL of H$_2$O.

**Footnotes:**
- $^a$ CaSO$_4$ and Ag$_2$SO$_4$ are slightly soluble, so a precipitate is possible.
  SrSO$_4$ and BaSO$_4$ are insoluble.
- $^b$ Ca(OH)$_2$ and Sr(OH)$_2$ are slightly soluble, so a precipitate is possible.
- $^c$ HgCl$_2$ is actually a soluble weak electrolyte. HgBr$_2$, PbCl$_2$, and PbBr$_2$ are slightly soluble, so a precipitate is possible.
- $^d$ While Pb(C$_2$H$_5$O$_2$)$_2$ is soluble, it is a weak electrolyte.

If MX is a soluble salt, then MX is a **strong electrolyte** and “MX(aq)” should be written as “M$^+$ (aq) + X$^-$ (aq)” in an ionic chemical equation. If MX is insoluble, then MX is a **nonelectrolyte**. The (“molecular”) formula of a nonelectrolyte must be written out as a complete neutral formula unit in all chemical equations.

**Key Question**

4. Why is an insoluble salt a nonelectrolyte? (**Hint**: See Question 2d.)
The general chemical equation for a double displacement reaction between two salts is

\[ AB(aq) + CD(aq) \rightarrow AD + CB \]

where A and C represent cations and B and D represent anions. The double displacement reaction will occur spontaneously if one of the products is insoluble, either AD or CB in the reaction above.

**Example 1.** Reaction between aqueous sodium carbonate and aqueous cobalt (II) chloride:

\[ \text{Na}_2\text{CO}_3(aq) + \text{CoCl}_2(aq) \rightarrow ? \]

According to the solubility table, both \( \text{Na}_2\text{CO}_3 \) and \( \text{CoCl}_2 \) are soluble in water. Soluble salts are strong electrolytes, so we can write the reactants as:

\[ \text{Na}_2\text{CO}_3(aq) = 2\text{Na}^+(aq) + \text{CO}_3^{2-}(aq) \]
\[ \text{CoCl}_2(aq) = \text{Co}^{2+}(aq) + 2\text{Cl}^-(aq) \]

Swapping the ionic partners, we see the products are \( \text{NaCl} \) and \( \text{CoCO}_3 \). \( \text{NaCl} \) is soluble in water, but \( \text{CoCO}_3 \) is not. Therefore, the total ionic equation is:

\[ 2\text{Na}^+(aq) + \text{CO}_3^{2-}(aq) + \text{Co}^{2+}(aq) + 2\text{Cl}^-(aq) \rightarrow \text{CoCO}_3(s) + 2\text{Na}^+(aq) + 2\text{Cl}^-(aq) \]

\( \text{Na}^+ \) and \( \text{Cl}^- \) aren’t doing anything chemically. They’re just “spectating” the precipitation going on around them, so we call them spectator ions. Eliminating the spectator ions from the total ionic equation, we get the net ionic equation:

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

**Example 2.** Mixing of aqueous sodium nitrate and aqueous barium hydroxide:

\[ \text{NaNO}_3(aq) + \text{Ba(OH)}_2(aq) \rightarrow ? \]

Swapping the ionic partners, we see the products are \( \text{NaOH} \) and \( \text{Ba(NO}_3)_2 \), which are both soluble strong electrolytes. The total ionic equation is:

\[ 2\text{Na}^+(aq) + 2\text{NO}_3^-(aq) + \text{Ba}^{2+}(aq) + 2\text{OH}^-(aq) \rightarrow 2\text{Na}^+(aq) + 2\text{OH}^-(aq) + \text{Ba}^{2+}(aq) + 2\text{NO}_3^-(aq) \]

All of the species are spectator ions! So there is no reaction:

\[ \text{NaNO}_3(aq) + \text{Ba(OH)}_2(aq) \rightarrow \text{N.R.} \]

**Key Questions**

5. Why is the formula of cobalt(II) carbonate not written as “\( \text{Co}^{2+}(aq) + \text{CO}_3^{2-}(aq) \)” on the product side of the total and net ionic equations in Example 1?
6. Note that “Na₂CO₃(aq)” = “2 Na⁺(aq) + CO₃²⁻(aq)” in the total ionic equation in Example 1. Why is it wrong to write aqueous sodium carbonate as “Na₂⁺(aq) + CO₃²⁻(aq)”?

7. How is the net ionic equation different from the total ionic equation?

8. In preparation for the following Exercises, determine the solubilities of the following salts from the above solubility table (Circle your answers.):
   a. FeI₃ soluble / insoluble  g. NH₄NO₃ soluble / insoluble
   b. Na₂SO₄ soluble / insoluble  h. BaSO₄ soluble / insoluble
   c. Fe₂(SO₄)₃ soluble / insoluble  i. K₃PO₄ soluble / insoluble
   d. NaI soluble / insoluble  j. Cu(C₂H₃O₂)₂ soluble / insoluble
   e. (NH₄)₂SO₄ soluble / insoluble  k. KC₂H₃O₂ soluble / insoluble
   f. Ba(NO₃)₂ soluble / insoluble  l. Cu₃(PO₄)₂ soluble / insoluble

Exercises

Write balanced total ionic AND net ionic equations for each reaction when the following pairs of aqueous solutions are mixed together. If no reaction occurs, write “N.R.” after the reaction arrow. Please, write the phases of all reactants and products. Check that all equations are balanced by both mass and charge!

A. FeI₃(aq) + Na₂SO₄(aq) → ________________________________
   
   Total ionic equation:
   
   Net ionic equation:
   
B. (NH₄)₂SO₄(aq) + Ba(NO₃)₂(aq) → ________________________________
   
   Total ionic equation:
   
   Net ionic equation:
   
C. K₃PO₄(aq) + Cu(C₂H₃O₂)₂(aq) → ________________________________
   
   Total ionic equation:
   
   Net ionic equation: