Skills to Develop

- Estimate the pH of the solution due to precipitate of a metal hydroxide.
- Calculate the maximum metal ion concentration when the pH is known.
- Explain behavior of amphoteric metal hydroxides.

Most metal hydroxides are insoluble; some such as \( \ce{Ca(OH)2} \), \( \ce{Mg(OH)2} \), \( \ce{Fe(OH)2} \), \( \ce{Al(OH)3} \) etc. are sparingly soluble. However, alkali metal hydroxides \( \ce{CsOH} \), \( \ce{KOH} \), and \( \ce{NaOH} \) are very soluble, making them strong bases. When dissolved, these hydroxides are completely ionized. Since the hydroxide concentration, \( \ce{[OH^-]} \), is an integrated property of the solution, the solubility of metal hydroxide depends on pH, pOH or \( \ce{[OH^-]} \).

Alkali metal hydroxides \( \ce{LiOH} \), \( \ce{NaOH} \), \( \ce{KOH} \), \( \ce{CsOH} \) are soluble, and their solutions are basic. Hydroxides of alkali earth metals are much less soluble. For example, quicklime \( \ce{CaO} \) reacts with water to give slaked lime, which is slightly soluble.

\[
\begin{array}{ccccl}
\text{quicklime} & & & \text{slaked lime (slightly soluble)}
\end{array}
\]

\( \ce{CaO &+ &H2O &\rightleftharpoons &Ca(OH)2} \)

Milk of magnesia is \( \ce{Mg(OH)2} \) (\( K_{sp} = 7e-12 \)) suspension. In an acidic solution such as stomach juice, the following reaction takes place,

\[
\ce{Mg(OH)2 + H+ &\rightleftharpoons &Mg^2+ &+ &2 H2O}
\]

Thus, it can neutralize excess acid in the stomach.

Example 1

Calculate the maximum concentration of \( \ce{Mg^2+} \) in a solution which contains a buffer so that pH = 3 at 298 K.

**SOLUTION**

As usual, we write the equilibrium equation so that we can write the concentration below the formula. If we do not know the concentration, we assume it to be a variable \( x \).

\[
\begin{array}{cccccc}
\text{Mg(OH)2} & & \text{Mg}^2+ & & 2 \text{OH-})\backslash
\&x & & 1 \times 10^{-11}\end{array}
\]

\[
[K_{sp}] = x (1 \times 10^{-11})^2 = 7 \times 10^{-12}\]

Solving for \( x \) results in \( x = 7 \times 10^{-10} \)
DISCUSSION

This value certainly is too large, unrealistic.

Example 2

Calculate the pH of a saturated $\ce{Mg(OH)2}$ solution.

SOLUTION

We assume the concentration to be $x$ M of $\ce{Mg(OH)}$, and note that $\ce{[OH-]} = 2x$,

\[
\begin{array}{cccc}
\ce{Mg(OH)2 &\rightleftharpoons &Mg^2+ &+ &2 OH-}\ \\
&&x &&2 x
\end{array}
\]

\[K_{\ce{sp}} = x (2 x)^2 = \text{7e-12}\]

Solving for $x$; $x = 1.2e-4$

\[
\begin{align}
\ce{[OH]} &= \text{2.4e-4} \\
\ce{pOH} &= 3.62 \\
\mathrm{pH} &= 14 - 3.62 = 10.38
\end{align}
\]

DISCUSSION

The pH of a saturated lime ($\ce{Ca(OH)2}$) solution is about 10.0.

Amphoteric Hydroxides

Not all metal hydroxides behave the same way - that is precipitate as hydroxide solids. Metal hydroxides such as $\ce{Fe(OH)3}$ and $\ce{Al(OH)3}$ react with acids and bases, and they are called amphoteric hydroxide. In reality, $\ce{Al(OH)3}$ should be formulated as $\ce{Al(H2O)3(OH)3}$, and this neutral substance has a very low solubility. It reacts in the following way as $\ce{[H+]}$ increases.

\[
\begin{align}
\ce{Al(H2O)3(OH)3 + H3O+ &\rightleftharpoons Al(H2O)4(OH)2+ + HOH}\ \\
\ce{Al(H2O)4(OH)2+ + H3O+ &\rightleftharpoons Al(H2O)5(OH)^2+ + H2O}\ \\
\ce{Al(H2O)5(OH)^2+ + H3O+ &\rightleftharpoons Al(H2O)6^3+ + H2O}
\end{align}
\]

When the pH increases, the following reactions take place:
\[
\begin{align}
\ce{Al(H2O)3(OH)3 + OH- &\rightleftharpoons Al(H2O)2(OH)4- + H2O} \\
\ce{Al(H2O)2(OH)4- + OH- &\rightleftharpoons Al(H2O)(OH)5^2- + H2O} \\
\ce{Al(H2O)(OH)5^2- + OH- &\rightleftharpoons Al(OH)6^3- + H2O}
\end{align}
\]

The charged species are soluble in water. As a result, amphoteric hydroxides dissolve in acidic and basic solutions.

Questions

1. Assume the pH of gastric juice to be 2. Calculate the maximum $\ce{[Mg^2+]})$.
2. Calculate the pH of a 0.10 M $\ce{[NH3]}$ solution.
3. Calculate the maximum $\ce{[Fe^2+]})$ in a 0.10 M $\ce{[NH3]}$ solution. Give the value in M.
4. What are amphoteric metal hydroxides? (enter no more than one line)

Solutions

1. Answer $\mathrm{[Mg^{2+}] = 7e12\ M]}$)
   
   Consider...
   
   We assume the temperature to be 298 K, which is too low.

   \[
   \ce{[Mg^{2+}] = \dfrac{\text{7e-12}}{\text{(1e-12)}^2} = \text{?}}
   \]

   This value is unrealistically large. The result is correct, but meaningless.

2. Answer pH = 11.12
   
   Consider...
   
   \[
   \ce{[OH-]} = (0.10 \times \text{1.8e-5})^{1/2} = \text{1.34e-3})\]
   \[
   \ce{[H+] = \dfrac{\text{1e-14}}{\text{1.34e-3}}} = \text{7.5e-12}}\], \ce{[pH] = \text{?}}\)

   This value is required for the calculation in next question. Better yet, remember that $\ce{[OH-]} = \text{1.34e-4}).$

3. Answer 4.4e-10 M
   
   Consider...
   
   $\ce{[Fe^2+]} = \dfrac{\text{7.9e-16}}{\text{1.34e-3})^2} = \text{?} \ce{M})$

   What is the value in g/L? Molar mass of $\ce{Fe} is 55.8 g/mol.

4. Answer Metal hydroxides such as $\ce{[Fe(OH)3]}$ and $\ce{[Al(OH)3]}$ that react with acids and bases are called amphoteric hydroxide.
Contributors

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