- Write balanced net ionic equations for each of the following reactions. If there is no reaction then write “no reaction”.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Balanced Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A solution of Ba(NO₃)₂ is added to a solution of Na₂SO₄.</td>
<td>( \text{Ba}^{2+}(aq) + \text{SO}_4^{2-}(aq) \rightarrow \text{BaSO}_4(s) )</td>
</tr>
<tr>
<td>A solution of NaCl is added to a solution of AgNO₃.</td>
<td>( \text{Ag}^+(aq) + \text{Cl}^-(aq) \rightarrow \text{AgCl}(s) )</td>
</tr>
<tr>
<td>A solution of Pb(NO₃)₂ is added to an acidified solution of KI.</td>
<td>( \text{Pb}^{2+}(aq) + 2\text{I}^-(aq) \rightarrow \text{PbI}_2(s) )</td>
</tr>
<tr>
<td>A 2 M solution of NH₃ is added to a 0.1 M solution of Cu(NO₃)₂.</td>
<td>([\text{Cu(H}_2\text{O})_6]^{2+} + 4\text{NH}_3(aq) \rightarrow [\text{Cu(NH}_3)_4(\text{OH})_2]^{2+} + 4\text{H}_2\text{O(l)})</td>
</tr>
<tr>
<td>H₂S(g) is bubbled through a solution of ZnSO₄ in the presence of 4 M HCl.</td>
<td>No reaction. (Although ZnS has very low solubility in water, it is soluble in acidic solution as ( S^{2-} ) reacts with ( H^+ ) to form H₂S)</td>
</tr>
</tbody>
</table>

- Write the fully balanced equation for the redox reaction that occurs when chlorine gas is bubbled through a solution of iron(II) sulfate. The unbalanced equation is given.

\[ \text{Fe}^{2+} + \text{Cl}_2 \rightarrow \text{Fe}^{3+} + \text{Cl}^- \]

Use the half-equation method: write both the oxidation and reduction half equations and the final balanced equation.

<table>
<thead>
<tr>
<th>Half Equation</th>
<th>Balanced Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation half equation</td>
<td>( \frac{1}{2} \text{Cl}_2(g) + e^- \rightarrow \text{Cl}^-(aq) )</td>
</tr>
<tr>
<td>Reduction half equation</td>
<td>( \text{Fe}^{3+}(aq) + e^- \rightarrow \text{Fe}^{2+}(aq) )</td>
</tr>
<tr>
<td>Overall reaction</td>
<td>( \text{Fe}^{2+}(aq) + \frac{1}{2} \text{Cl}_2(g) \rightarrow \text{Fe}^{3+}(aq) + \text{Cl}^-(aq) )</td>
</tr>
</tbody>
</table>
The solubility product constant of BaSO$_4$ is $1.1 \times 10^{-10}$ M$^2$. What is the solubility of BaSO$_4$ in g L$^{-1}$?

The dissolution equilibrium is: $\text{BaSO}_4(s) \rightleftharpoons \text{Ba}^{2+}(aq) + \text{SO}_4^{2-}(aq)$. As equal amounts of cations and anions are produced, the expression for the solubility product is:

$$K_{sp} = [\text{Ba}^{2+}(aq)][\text{SO}_4^{2-}(aq)] = (S) \times (S) = S^2$$

where $S$ is the molar solubility.

As $S^2 = 1.1 \times 10^{-10}$, the molar solubility is $S = 1.05 \times 10^{-5}$ M.

The formula mass of BaSO$_4$ is:

$$(137.34 \text{ (Ba)} + 32.07 \text{ (S)} + 4 \times 16.00 \text{ (O)}) \text{ g mol}^{-1} = 228.41 \text{ g mol}^{-1}$$

Hence, the solubility is $(1.05 \times 10^{-5} \text{ M}) \times (228.41 \text{ g mol}^{-1}) = 2.4 \times 10^{-3} \text{ g L}^{-1}$

**ANSWER:** $2.4 \times 10^{-3}$ g L$^{-1}$

The solubility product constant of Ag$_2$CrO$_4$ is $2.6 \times 10^{-12}$ M$^3$. What is the molar solubility of Ag$_2$CrO$_4$ in water?

The dissolution equilibrium is: $\text{Ag}_2\text{CrO}_4(s) \rightleftharpoons 2\text{Ag}^+(aq) + \text{CrO}_4^{2-}(aq)$. As two mol of cation is produced for every one mol of anion, the expression for the solubility product is:

$$K_{sp} = [\text{Ag}^+(aq)]^2[\text{CrO}_4^{2-}(aq)] = (2S)^2 \times (S) = 4S^3$$

where $S$ is the molar solubility.

As $4S^3 = 2.6 \times 10^{-12}$ M$^3$, the molar solubility is $S = 8.7 \times 10^{-5}$ M.

**ANSWER:** $8.7 \times 10^{-5}$ M

What is the molar solubility of Ag$_2$CrO$_4$ in a solution of 0.10 M AgNO$_3$?

As AgNO$_3$ is very soluble, $[\text{Ag}^+(aq)] = 0.10$ M.

If $S$ is the solubility, $K_{sp} = [\text{Ag}^+(aq)][\text{CrO}_4^{2-}(aq)] = (0.10)^2 \times S = 2.6 \times 10^{-12}$.

Hence, $S = 2.6 \times 10^{-10}$ M

**ANSWER:** $2.6 \times 10^{-10}$ M
Magnesium hydroxide, Mg(OH)$_2$, is used as treatment for excess acidity in the stomach. Calculate the pH of a solution that is in equilibrium with Mg(OH)$_2$. The solubility product constant, $K_{sp}$ of Mg(OH)$_2$ is $7.1 \times 10^{-12}$ M$^2$.

The dissolution equilibrium is: Mg(OH)$_2$(s) $\rightleftharpoons$ Mg$^{2+}$(aq) + 2OH$^-$ (aq). As two mol of anion is produced for every one mol of cations, the expression for the solubility product is:

$$K_{sp} = [\text{Mg}^{2+}(\text{aq})][\text{OH}^- (\text{aq})]^2 = (S)(2S)^2 = 4S^3$$

where $S$ is the molar solubility.

Hence, $[\text{OH}^- (\text{aq})] = 2S = 2 \times \sqrt[3]{\frac{7.1 \times 10^{-12}}{4}} = 2.4 \times 10^{-4}$ M.

The pOH = $-\log_{10}[\text{OH}^- (\text{aq})] = -\log_{10}[2.4 \times 10^{-4}] = 3.6$

As pH + pOH = 14.0, the pH = 14.0 – 3.6 = 10.4

**ANSWER:** 10.4

Determine whether 2.0 g of Mg(OH)$_2$ will dissolve in 1.0 L of a solution buffered to a pH of 7.00.

At pH = 7.00, pOH = 14.00 – 7.00 = 7.00 and hence $[\text{OH}^- (\text{aq})] = 10^{-7}$ M.

The formula mass of Mg(OH)$_2$ is:

$$\text{formula mass} = (24.31 \text{ (Mg)} + 2 \times (16.00 \text{ (O)} + 1.008 \text{ (H)}) \text{ g mol}^{-1}$$

$$= 58.326 \text{ g mol}^{-1}$$

Therefore 2.0 g contains:

$$\text{number of moles} = \frac{\text{mass}}{\text{formula mass}} = \frac{2.0 \text{ g}}{58.326 \text{ g mol}^{-1}} = 0.034 \text{ mol}$$

As each mole of Mg(OH)$_2$ generates 1 mole of Mg$^{2+}$, if all of the Mg(OH)$_2$ dissolves in 1.0 L of solution then $[\text{Mg}^{2+}(\text{aq})] = 0.034$ M. The buffer removes the OH$^-$ produced so that $[\text{OH}^- (\text{aq})] = 10^{-7}$ M.

The ionic product is then:

$$Q = [\text{Mg}^{2+}(\text{aq})][\text{OH}^- (\text{aq})]^2 = (0.034) \times (10^{-7})^2 = 3.4 \times 10^{-16}$$

As $Q$ is much smaller than $K_{sp}$, all of the solid will dissolve.

**ANSWER:** YES / NO
• Calcium oxalate is a major constituent of kidney stones. Calculate the solubility product constant for calcium oxalate given that a saturated solution of the salt can be made by dissolving 0.0061 g of CaC_2O_4-H_2O(s) in 1.0 L of water.

The molar mass of CaC_2O_4·H_2O is:

\[
\text{Molar mass} = (40.08(\text{Ca}) + 2 \times 12.01(\text{C}) + 5 \times 16.00(\text{O}) + 2 \times 1.008(\text{H})) \text{ g mol}^{-1} = 146.116 \text{ g mol}^{-1}
\]

Hence, 0.0061 g corresponds to

\[
0.0061 \text{ g} = 4.2 \times 10^{-5} \text{ mol}.
\]

As this amount dissolves in 1.0 L, the molar solubility = \( \mathcal{S} = 4.2 \times 10^{-5} \text{ M} \).

The dissolution equilibrium is:

\[
\text{CaC}_2\text{O}_4\cdot\text{H}_2\text{O(s)} \leftrightarrow \text{Ca}^{2+}(\text{aq}) + \text{C}_2\text{O}_4^{2-}(\text{aq}) + \text{H}_2\text{O(l)}.
\]

As one mol of cation and one mol of anion is produced, the solubility product is:

\[
\mathcal{K}_\text{sp} = [\text{Ca}^{2+}(\text{aq})][\text{C}_2\text{O}_4^{2-}(\text{aq})] = \mathcal{S}^2 = (4.2 \times 10^{-5})^2 = 1.7 \times 10^{-9}
\]

Answer: 1.7 \times 10^{-9}

• A sample of 2.0 mg of Cu(OH)_2 is added to 1.0 L of a solution buffered at a pH of 8.00. Will all of the Cu(OH)_2 dissolve? Show all working.

(The \( \mathcal{K}_\text{sp} \) of Cu(OH)_2 is \( 4.8 \times 10^{-20} \text{ M}^3 \).)

As pH + pOH = 14.00, pOH = 14.00 – 8.00 = 6.00. Hence, [OH^–(aq)] = 10^{-6} \text{ M}.

The dissolution equilibrium is: Cu(OH)_2(s) \( \rightarrow \) Cu^{2+}(aq) + 2OH^–(aq)

Hence, if \( S \) is the molar solubility, \( \mathcal{K}_\text{sp} = [\text{Cu}^{2+}(\text{aq})][\text{OH}^–(\text{aq})]^2 = \mathcal{S} \times [\text{OH}^–(\text{aq})]^2 \).

As \( \mathcal{K}_\text{sp} = 4.8 \times 10^{-20} \), \( S = \frac{4.8 \times 10^{-20}}{(10^{-6})^2} = 4.8 \times 10^{-8} \text{ M} \)

The molar mass of Cu(OH)_2 is (63.55 (Cu) + 2 \times (16.00 (O) + 1.008 (O)) g mol\(^{-1}\) = 97.566 g mol\(^{-1}\).

The solubility in g L\(^{-1}\) is therefore \( (4.8 \times 10^{-8}) \times 97.566 = 4.7 \times 10^{-6} \).

Hence, only \( 4.7 \times 10^{-3} \text{ mg} \) will dissolve.

Answer: NO