CHEM1902/4 Worksheet 11 – Answers to Critical Thinking Questions

The worksheets are available in the tutorials and form an integral part of the learning outcomes and experience for this unit.

Model 1: The Unit Cell

1. (a) Number of Cl atoms = 8 × ⅛ (atoms on corners) + 6 × ½ (atoms on faces) = 4.
   (b) Number of Na atoms = 12 × ¼ (atoms on edges) + 1 (atom at centre) = 4.
   (c) Cation : anion = 4 : 4 or 1 : 1. This is consistent with the formula NaCl.

2. (a) Number of Ti atoms = 1 (atom at centre).
   (b) Number of Ca atoms = 8 × ⅛ (atoms on corners) = 1
   (c) Number of O atoms = 6 × ½ (atoms on edges) = 3.
   (d) The formula is Ca\textsubscript{1}Ti\textsubscript{1}O\textsubscript{3} or CaTiO\textsubscript{3}.
   (e) Calcium always forms Ca\textsuperscript{2+} ions. Oxygen always forms O\textsuperscript{2-} ions. To make the charges balance, titanium must be present as Ti\textsuperscript{4+}: (Ca\textsuperscript{2+})(Ti\textsuperscript{4+})(O\textsuperscript{2-})\textsubscript{3}.

Model 2: The solubility product

1. See opposite. The system is only at equilibrium at the concentrations on the line.

2. (a) AgCl(s) $\rightleftharpoons$ Ag\textsuperscript{+}(aq) + Cl\textsuperscript{-}(aq);
   $K_{sp} = [\text{Ag}^+][\text{Cl}^-]$
   (b) Ag\textsubscript{2}SO\textsubscript{4}(s) $\rightleftharpoons$ 2Ag\textsuperscript{+}(aq) + SO\textsubscript{4}\textsuperscript{2-}(aq);
   $K_{sp} = [\text{Ag}^+]^2[\text{SO}_4^{2-}]$
   (c) PbCl\textsubscript{2}(s) $\rightleftharpoons$ Pb\textsuperscript{2+}(aq) + 2Cl\textsuperscript{-}(aq);
   $K_{sp} = [\text{Pb}^{2+}][\text{Cl}^-]^2$

3. (a) [Pb\textsuperscript{2+}(aq)] = x and [Cl\textsuperscript{-}(aq)] = 2x.
   (b) $K_{sp} = [\text{Pb}^{2+}][\text{Cl}^-]^2 = (x)(2x)^2 = 4x^3$
   If $4x^3 = 1.6 \times 10^{-5}$, then $x = 1.59 \times 10^{-2}$.
   [Pb\textsuperscript{2+}(aq)] = $1.59 \times 10^{-2}$ M and [Cl\textsuperscript{-}(aq)] = $2x = 3.17 \times 10^{-2}$ M

4. Molar solubility = $(K_{sp} / 27)^{1/4}$

5. (a) and (d) are salts with 1:1 stoichiometry so molar solubility = $(K_{sp})^{1/2}$
   (b) and (c) are salts with 1:2 stoichiometry so molar solubility = $(K_{sp} / 4)^{1/3}$
   Hence:
   (a) molar solubility = $(2.8 \times 10^{-7})^{1/2} = 5.3 \times 10^{-4}$ M
   (b) molar solubility = $(4.5 \times 10^{-17} / 4)^{1/3} = 2.2 \times 10^{-6}$ M
   (c) molar solubility = $(8.7 \times 10^{-9} / 4)^{1/3} = 1.3 \times 10^{-3}$ M
(d) molar solubility = \((5 \times 10^{-15})^{1/2} = 7 \times 10^{-8}\) M

The solubility increases in the order (d) < (b) < (a) < (c).

6. (a) (ii) \(X_2Y\)
   (b) (iii) \(2 \times 10^{-9}\)

**Model 3: To dissolve or not to dissolve?**

1. (a) \([\text{Mg}^{2+}(\text{aq})] = 0.050 \text{ M and } [\text{OH}^- (\text{aq})] = 0.060 \text{ M}\)
   (b) \(Q_{sp} = [\text{Mg}^{2+}(\text{aq})] [\text{OH}^- (\text{aq})]^2 = (0.050)(0.060)^2 = 1.8 \times 10^{-4}\)
   (c) \(Q_{sp} > K_{sp}\) so \(\text{Mg(OH)}_2\) (s) precipitate forms.

2. (a) \([\text{Mg}^{2+}(\text{aq})] = 0.025 \text{ M and } [\text{F}^- (\text{aq})] = 0.0050 \text{ M}\)
   \(Q_{sp} = [\text{Mg}^{2+}(\text{aq})][\text{F}^- (\text{aq})]^2 = (0.025)(0.0050)^2 = 6.3 \times 10^{-7}\)
   \(Q_{sp} > K_{sp}\) so precipitation will occur.
   (b) \([\text{Mg}^{2+}(\text{aq})] = 0.025 \text{ M and } [\text{F}^- (\text{aq})] = 0.00050 \text{ M}\)
   \(Q_{sp} = [\text{Mg}^{2+}(\text{aq})][\text{F}^- (\text{aq})]^2 = (0.025)(0.00050)^2 = 6.3 \times 10^{-9}\)
   \(Q_{sp} < K_{sp}\) so no precipitation will occur.

**Model 4: Le Châtelier’s Principle and Solubility**

1. \(K_{sp} = [\text{Pb}^{2+}(\text{aq})][\text{Cl}^-(\text{aq})]^2\)

2. Adding \(\text{Cl}^-\) ions would push the equilibrium in the direction of reactants: the solubility would decrease.

3. With \([\text{Cl}^-(\text{aq})] = 0.5 \text{ M}\),
   \([\text{Pb}^{2+}(\text{aq})] = K_{sp} / [\text{Cl}^-(\text{aq})]^2 = K_{sp} / (0.5)^2 = K_{sp} / 0.25 = 4K_{sp}\)

4. Adding extra \(\text{PbCl}_2\) has no effect. As the \([\text{Pb}^{2+}(\text{aq})]\) and \([\text{Cl}^-(\text{aq})]\) are already such that \([\text{Pb}^{2+}(\text{aq})][\text{Cl}^- (\text{aq})]^2 = K_{sp}\), the solution is saturated and it is not possible to dissolve more solid.

**Model 5: Solubility and pH**

1. \(K_{sp} = [\text{Fe}^{3+}(\text{aq})][\text{OH}^- (\text{aq})]^3\)

2. \(\text{pOH} = 14.000 - 8.179 = 5.821\). As \(\text{pOH} = -\log[\text{OH}^- (\text{aq})]\), \([\text{OH}^- (\text{aq})] = 10^{-5.821}\) M.

3. From Q5, \([\text{Fe}^{3+}(\text{aq})] = K_{sp} / [\text{OH}^- (\text{aq})]^3 = (1 \times 10^{-39}) / (10^{-5.821})^3 = 2.9 \times 10^{-22}\).

4. If the pH decreases, \([\text{OH}^- (\text{aq})]\) will also decrease. It is predicted that the pH of the ocean will fall by about 0.3 pH units over this century. \(\text{pOH}\) will thus increase by about 0.3 units.

As \([\text{Fe}^{3+}(\text{aq})] = K_{sp} / [\text{OH}^- (\text{aq})]^3\), this will lead to an increase in \([\text{Fe}^{3+}(\text{aq})]\). It is uncertain what the effect of this will be for marine life - see, for example:

\(\text{http://www.sciencemag.org/cgi/content/full/327/5966/676}\)

5. \([\text{Fe}^{3+}(\text{free})] \approx 10^{-19}\) M. Most of the \(\text{Fe}^{3+}\) is complexed in proteins such as transferrin and ferritin.