St Andrew's Junior College

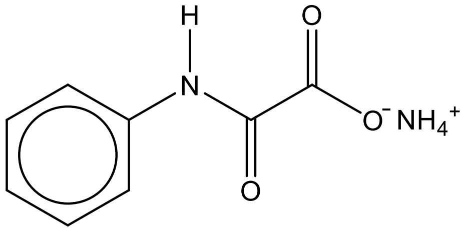
H2 Chemistry 2025

Tutorial 20: Solubility Equilibria

DISCUSSION QUESTIONS

1. 2018/P3/Q1b

Buildings and statues constructed of limestone (calcium carbonate, $CaCO_3$) can be corroded by acid rain. They can partially protected by painting them with a solution containing ammonium N-phenyloxamate.



ammonium N-phenyloxamate

The ammonium salt reacts with the surface of the limestone to produce an inert layer of calcium N-phenyloxamate. The by-product, ammonium carbonate, is water soluble.

(i) Write an equation for the reaction between calcium carbonate and ammonium N-phenyloxamate, $NH_4(C_8H_6NO_3)$. **[1]**

(ii) The solubility product, K_{sp}, for calcium N-phenyloxamate is 1.75×10^{-5} mol^3 dm^{-9}. Calculate [calcium N-phenyloxamate] in a saturated solution **in g dm^{-3}**. **[3]**

2. ACJC 2009/P3/Q4(a)

Hard water is water that has higher calcium and magnesium content. Using hard water results in sediments accumulating in electrical appliances such as water heaters and washing machines. This raises the electricity consumption rate and shortens the lifespan of the appliances. Hard water is treated through a softening process, where the metal ions are removed, before it is used for consumption.

A sample of hard water containing $Mg^{2+}(aq)$ was collected. The presence of Mg^{2+} is to be tested by precipitating $MgCO_3$.

(a) Write an expression for the solubility product, K_{sp}, of magnesium hydroxide. **[1]**

(b) The solubility of $Mg(OH)_2$ in pure water at 25 °C is 9.08×10^{-3} g dm^{-3}. For a saturated aqueous solution of $Mg(OH)_2$ at 25 °C, calculate the concentrations of Mg^{2+} and OH^- and prove that the solubility product, K_{sp}, of $Mg(OH)_2$ is 1.5×10^{-11} mol^3 dm^{-9}. **[2]**

(c) How would you expect the solubility of magnesium hydroxide in aqueous magnesium nitrate to compare with that in pure water? Discuss this effect using Le Chatelier's Principle. **[2]**

(d) The concentration of Mg^{2+} in the water sample was found to be 3.2×10^{-4} mol dm^{-3}.

A 50 cm^3 sample was used in this test. To this sample, 30 cm^3 of a 5.0×10^{-4} mol dm^{-3} aqueous sodium hydroxide was added. Using the K_{sp} value in **(b)**, deduce if a precipitate would appear when the two solutions were added. **[2]**

3. 2020/P3/Q5c

Zinc hydroxide, $Zn(OH)_2$, is sparingly soluble in water.

$$Zn(OH)_2(s) \rightleftharpoons Zn^{2+}(aq) + 2OH^-(aq)$$

The numerical value of K_{sp} is 2.0×10^{-17} at 25 °C.

(i) Write an expression for the K_{sp} of $Zn(OH)_2$ stating its units. [1]

(ii) Calculate the pH of a saturated aqueous solution of $Zn(OH)_2$ at 25 °C. [3]

(iii) Describe and explain how the solubility of $Zn(OH)_2$ is affected:

- by adding $HCl(aq)$
- by adding $ZnCl_2(aq)$. **[2]**

$$Zn(OH)_2(s) \rightleftharpoons Zn^{2+}(aq) + 2OH^-(aq)$$

4. 2024/P2/Q5d

A sample of sea water contains 0.0050 mol dm^{-3} of Ca^{2+} (aq) and 0.0480 mol dm^{-3} of Mg^{2+} (aq). The K_{sp} of the metal hydroxides of these ions is shown in the table below.

	Ca^{2+}	Mg^{2+}
K_{sp} for metal hydroxides at 298K / $mol^3\,dm^{-9}$	5.5×10^{-6}	1.1×10^{-11}

(i) Use your knowledge of solubility products and the information in the table above to explain why Ca^{2+} ions in this sample remain in solution at pH 12 but the Mg^{2+} ions do not. **[2]**

(ii) Show by relevant calculations that almost all the Mg^{2+}(aq) present in this sample forms a precipitate at pH 12. **[2]**

5. **2012/P2/Q3(d)**

Selective precipitation of sulfides may be used to separate the cations present in a solution containing Cu^{2+}, Ni^{2+} and Zn^{2+}.

The reagent used is hydrogen sulfide which behaves as a dibasic (diprotic) weak acid when in aqueous solution.

$$H_2S(g) + aq \rightleftharpoons H^+(aq) + HS^-(aq) \qquad K_a = 9.1 \times 10^{-8}\ \text{mol dm}^{-3}$$

and

$$HS^-(aq) + aq \rightleftharpoons H^+(aq) + S^{2-}(aq) \qquad K_a = 1.0 \times 10^{-15}\ \text{mol dm}^{-3}$$

Metal sulfides are precipitated by the following reaction.

$$M^{2+}(aq) + S^{2-}(aq) \rightarrow MS(s)$$

Relevant K_{sp} values are given in the table.

Salt	K_{sp} / mol^2 dm^{-6}
CuS	6.3×10^{-36}
NiS	4.0×10^{-21}
ZnS	1.6×10^{-24}

The results of passing hydrogen sulfide through separate solutions of Cu^{2+}, Ni^{2+}, and Zn^{2+} are shown in the table below.

M^{2+} being tested	**H_2S passed through an acidic solution of M^{2+}**	**H_2S passed through a neutral solution of M^{2+}**	**H_2S passed through an alkaline solution of M^{2+}**
Cu^{2+}	black precipitate of CuS	black precipitate of CuS	black precipitate of CuS
Ni^{2+}	no precipitate	no precipitate	black precipitate of NiS
Zn^{2+}	no precipitate	white precipitate of ZnS	white precipitate of ZnS

Use the data from above to give an explanation for each of the following questions. You should give equations where appropriate. You are **not** expected to do any calculations in this part.

(i) Why is CuS the only sulfide of these three precipitated in acid solution? **[2]**

(ii) Why is NiS precipitated in alkaline solution and not in neutral or acidic solution?
[2]

6. 2019/P2/Q5g

The plaster between the tiles which line a swimming pool is made mainly from the sparingly soluble solid, calcium sulfate.

In acid conditions, the sulfate ions combine with hydrogen ions to form aqueous hydrogen sulfate ions and the solubility of the calcium sulfate increases causing the plaster to dissolve.

$K_{sp}(CaSO_4) = 2.4 \times 10^{-5}\ mol^2 dm^{-6}$

$K_{sp}(Ca(OH)_2) = 5.5 \times 10^{-6}\ mol^3 dm^{-9}$

(i) Explain, by using the relevant ionic equation, how addition of calcium chloride prevents the plaster from dissolving.

The water in a particular swimming pool at pH 8.0 turns cloudy. The owner thinks that the cloudiness is caused by solid calcium hydroxide forming in the water.

(ii) Calculate the concentration of calcium ions which must be present in pool water at pH 8.0 in order for the cloudiness to be caused by formation of solid calcium hydroxide.

Comment on whether or not the cloudiness is due to the formation of solid calcium hydroxide.