Slides on solubility and precipitation, CH102 Spring 2016

Solubility equilibria

$$MX_2(s) \rightleftharpoons M^{2+}(aq) + 2\,X^-(aq),\ K = K_{sp}$$

Five kinds of problems

1. From $K_{sp} \rightarrow$ get solubility
2. From solubility $\rightarrow$ get K_{sp}
3. Solubility in presence of common ion
4. Will precipitation occur?
5. What remains after precipitation?

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1. From $K_{sp} \rightarrow$ get solubility

What is the molar solubility of CaF_2? $K_{sp} = 3.9 \times 10^{-11}$

$$CaF_2(s) \rightleftharpoons Ca^{2+}(aq) + 2\,F^-(aq)$$

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	MX_2	M^{2+}	X^-
Initial	excess	0	0
Change			
Equilibrium			

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	MX_2	M^{2+}	X^-
Initial	excess	0	0
Change	$-\,x$	$+\,x$	$+\,2\,x$
Equilibrium	excess	x	$2\,x$

$$K_{sp} = (M^{2+})\,(X^-)^2 = (x)\,(2x)^2 = 4\,x^3$$

Answer: 0.00021 mol/L

Check: $0.00021 \times (2 \times 0.00021)^2 = 3.9 \times 10^{-11} = K_{sp}$

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2. From solubility → get K_{sp}

The solubility of magnesium phosphate is 0.000259 g/(100 g) of water at 20 °C. Calculate its K_{sp} at this temperature.

$$Mg_3(PO_4)_2 \rightleftharpoons 3\ Mg^{2+}(aq) + 2\ PO_4^{3-}(aq)$$

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	M_3X_2	M^{2+}	X^{3-}
Initial	excess	0	0
Change			
Equilibrium			

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	M_3X_2	M^{2+}	X^{3-}
Initial	excess	0	0
Change	$-\ x$	$+\ 3\ x$	$+\ 2\ x$
Equilibrium	excess	$3\ x$	$2\ x$

0.000259 g / 100 g → mol/L = x

$$K_{sp} = (M^{2+})^3(X^{3-})^2 = (3\ x)^3(2\ x)^2 = 108\ x^5$$

Answer: 1.00×10^{-23}

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3. Solubility in presence of common ion

The molar solubility of CaF_2, $K_{sp} = 3.9 \times 10^{-11}$, is 0.00021 mol/L. Calculate the molar solubility in a solution of 0.015 M NaF.

$$CaF_2(s) \rightleftharpoons Ca^{2+}(aq) + 2\ F^-(aq)$$

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	MX_2	M^{2+}	X^-
Initial	excess	0	c_{ion}
Change			
Equilibrium			

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	MX_2	M^{2+}	X^-
Initial	excess	0	c_{ion}
Change	$-\ x$	$+\ x$	$+\ 2\ x$
Equilibrium	excess	x	$c_{ion} + 2\ x \approx c_{ion}$

$$K_{sp} = (M^{2+})\ (X^-)^2 = (x)\ (c_{ion})^2$$

Large c_{ion} makes x smaller

Answer: 1.7×10^{-7}, 0.08 % of the value in pure water!

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4. Will precipitation occur?

0.2 mmol of NaF and 10 mmol of $Ca(NO_3)_2$ are combined in a total volume of 1 L of water. Will a precipitate form? The K_{sp} of CaF_2 is 3.9×10^{-11}.

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Initial			

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$$CaF_2(s) \rightleftharpoons Ca^{2+}(aq) + 2\,F^-(aq)$$

	MX_2	M^{2+}	X^-
Initial	0	c_M	c_X

Is $(M^{2+})\,(X^-)^2 = (c_M)\,(c_X)^2 = Q_{sp} > K_{sp}$?

If no, then no precipitation.

If yes, then a precipitate will form.

Answer: $Q_{sp} = 4 \times 10^{-10} > K_{sp}$, so $CaF_2(s)$ will precipitate

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5. What remains after precipitation

When 0.2 mmol of NaF and 10 mmol of $Ca(NO_3)_2$ are combined in 1 L of water, $CaF_2(s)$ precipitates. How much Ca^{2+} and F^- remain in solution? The K_{sp} of CaF_2 is 3.9×10^{-11}.

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	MX_2	M^{2+}	X^-
Initial			
Revised			
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Equilibrium			

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	MX_2	M^{2+}	X^-
Initial	0	c_M	$c_X < 2\ c_M$
Revised			
Change			
Equilibrium			

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	MX_2	M^{2+}	X^-
Initial	0	c_M	$c_X < 2\ c_M$
Revised	excess	$c_M - ½\ c_X$	0
Change			
Equilibrium			

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	MX_2	M^{2+}	X^-
Initial	0	c_M	$c_X < 2\ c_M$
Revised	excess	$c_M - ½\ c_X$	0
Change	$-\ y$	$+\ y$	$+\ 2\ y$
Equilibrium			

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When 0.2 mmol of NaF and 10 mmol of $Ca(NO_3)_2$ are combined in 1 L of water, $CaF_2(s)$ precipitates. How much Ca^{2+} and F^- remain in solution? The K_{sp} of CaF_2 is 3.9×10^{-11}.

	MX_2	M^{2+}	X^-
Initial	0	c_M	$c_X < 2\ c_M$
Revised	excess	$c_M - ½\ c_X$	0
Change	$-\ y$	$+\ y$	$+\ 2\ y$
Equilibrium	excess	$c_M - ½\ c_X + y \approx c_M - ½\ c_X$	$2\ y$

$$K_{sp} = (M^{2+})\ (X^-)^2 \approx (c_M - ½\ c_X)\ (2\ y)^2$$

Answer: $[Ca^{2+}] = (c_M - ½\ c_X) = 9.9$ mmol, $[F^-] = 2\ y = 0.063$ mmol

Check: $Q_{sp} = (0.0099)\ (0.000063)^2 = 3.9 \times 10^{-11} = K_{sp}$

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