Solubility Product Constant

Solubility Constant

* Solubility equilibria: Reactions involving the dissolving or forming of a solid from solution
* Overall equation:
* $AgNO_{3(aq)} + HCl_{(aq)} \rightarrow AgCl_{(s)} + HNO3_{(aq)}$
* Net ionic equation:
* $Ag^{+}_{(aq)} + Cl^{-}_{(aq)} \rightarrow AgCl_{(s)}$

Solubility Constant

- For a partly soluble or insoluble solid such as AgCl,
  - $AgCl_{(s)} \rightleftharpoons Ag^{+}_{(aq)} + Cl^{-}_{(aq)}$
  - we define K_{sp}, the solubility product constant:
  - $K_{sp} = [Ag^{+}][Cl^{-}]$

Example

* $Fe(OH)_{3(s)} \rightleftharpoons Fe^{3+}_{(aq)} + 3OH^{-}_{(aq)}$
    * $K_{sp}=$
* $Ag_2S_{(s)} \rightleftharpoons 2Ag^{+}_{(aq)} + S^{2-}_{(aq)}$
    * $K_{sp} =$
* $Ca_3(PO_4)_{2(s)} \rightleftharpoons 3Ca^{2+}_{(aq)} + 2PO_4^{3-}_{(aq)}$
    * $K_{sp} =$

Example

* $Fe(OH)_{3(s)} \rightleftharpoons Fe^{3+}_{(aq)} + 3OH^{-}_{(aq)}$
    * $K_{sp} = [Fe^{3+}][OH^{-}]^3$
* $Ag_2S_{(s)} \rightleftharpoons 2Ag^{+}_{(aq)} + S^{2-}_{(aq)}$
    * $K_{sp} = [Ag^{+}]^2[S^{2-}]$
* $Ca_3(PO_4)_{2(s)} \rightleftharpoons 3Ca^{2+}_{(aq)} + 2PO_4{}^{3-}_{(aq)}$
    * $K_{sp} = [Ca^{2+}]^3[PO_4{}^{3-}]^2$

Example

- A scientist prepares a saturated solution of lead(II) iodide. Independent measurements show that the concentration of lead is 1.3×10^{-3} M
- $PbI_{2(s)} \rightleftharpoons Pb^{2+}_{(aq)} + 2\ I^{-}_{(aq)}$

Solution

* Determine Concentrations

[Pb] = 1.3×10^{-3} M

[I] = 2[Pb] = 2 x [Pb] = 1.3×10^{-3} M
= 2.6×10^{-3} M

Solution

* Substitute into K_{sp}

$K_{sp} = [Pb^{2+}][I^-]^2$
$K_{sp} = (1.3 \times 10^{-3})(2.6 \times 10^{-3})^2$
$K_{sp} = 8.8 \times 10^{-9}$

Solubility and the Common Ion Effect

* **Common ion effect:** a decrease in solubility which occurs when an ionic compound is dissolved in a solution that contains an ion in common with the solid
* Consistent with principle of Le Chatelier

Common Ion Effect

* What is the solubility of $BaSO_4$ in a solution of 0.250 M Na_2SO_4? The K_{sp} of $BaSO_4$ is 8.7×10^{-11}.

$$BaSO_{4(s)} \rightleftharpoons Ba^{2+} + SO_4^{2-}$$

	$BaSO_{4(s)}$	Ba^{2+}	SO_4^{2-}
I	- (solid)	0	0.25
C	- (solid)	+ x	+x
E	- (solid)	x	0.25 + x

Solution

* Solve for x

$K_{sp} = [Ba^{2+}][SO_4^{2-}]$

$K_{sp} = x\,(0.250 + x)$

$8.7 \times 10^{-11} = x\,(0.250 + x)$

$8.7 \times 10^{-11} = x\,(0.250)$ (hundred's rule)

$x = 3.5 \times 10^{-10}$

Example

* Calculate the solubility for the same solute in water with no added $SO_4^{2-}{}_{(aq)}$.

Common Ion Effect

* Calculate the solubility for the same solute in water with no added $SO_4^{2-}{}_{(aq)}$.

	$BaSO_{4(s)}$ $\rightleftharpoons$	Ba^{2+} +	SO_4^{2-}
I	- (solid)	0	0
C	- (solid)	+ x	+x
E	- (solid)	x	x

Solution

* Solve for x

$K_{sp} = [Ba^{2+}][SO_4^{2-}]$

$K_{sp} = x\,(x)$

$8.7 \times 10^{-11} = x^2$

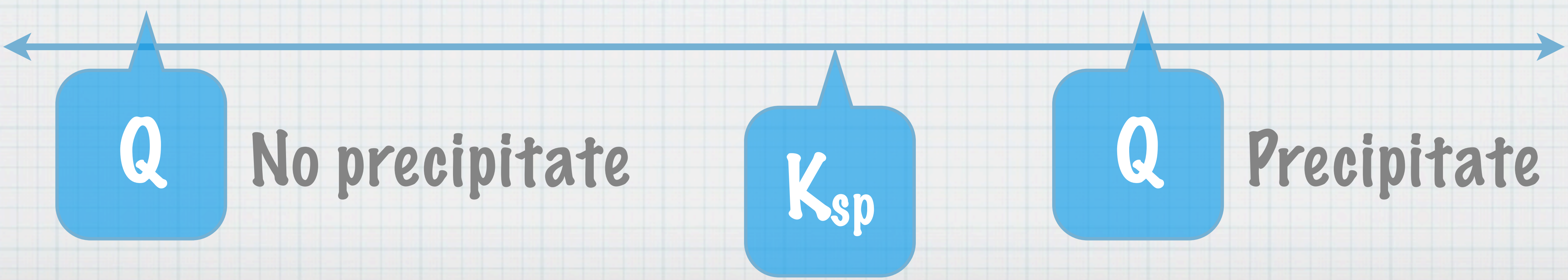
$x = 9.3 \times 10^{-6}$

Summary

* The solubility of $BaSO_4$ is
    * 9.3×10^{-6} M in water
    * 3.5×10^{-10} M in 0.250 M SO_4^{2-}

Formation of a Precipitate

- Predict if a precipitate forms when two solutions are mixed
- Calculate Q and compare it to K_{sp} to determine if a precipitate will form when mixing solutions of soluble compounds



Example

* 25.00 mL of 0.050 M Na_2CO_3 and 25.00 mL of 0.0020 M $Ca(NO_3)_2$ are mixed. Will a precipitate form?

Solution

* $Na_2CO_{3(aq)} + Ca(NO_3)_{2(aq)} \rightleftharpoons 2\ NaNO_{3(aq)} + CaCO_{3(s)}$

  * $CaCO_{3(s)} \rightleftharpoons Ca^{2+}{}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$

Solution

* $Na_2CO_{3(aq)} + Ca(NO_3)_{2(aq)} \rightleftharpoons 2\ NaNO_{3(aq)} + CaCO_{3(s)}$

* $CaCO_{3(s)} \rightleftharpoons Ca^{2+}{}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$

Find number of moles present that were added to the system

$n_{Ca} = CV$
$n_{Ca} = (0.0020\ M)(0.02500\ L)$
$n_{Ca} = 5.0 \times 10^{-5}\ mol$

$n_{CO3} = (0.050\ M)(0.02500\ L)$
$n_{CO3} = 1.25 \times 10^{-3}\ mol$

Solution

* Now find the concentration of each ion present.

$C_{Ca} = n/V$
$C_{Ca} = (5.0\times10^{-5})/(0.05000)$
$C_{Ca} = 1.0 \times 10^{-3}$ M

$C_{CO3} = (1.25\times10^{-3})/(0.05000)$
$C_{CO3} = 0.025$ M

Solution

- Now find Q

$Q = [Ca^{2+}][CO_3^{2-}]$

$Q = (1.0 \times 10^{-3})(0.025)$

$Q = 2.5 \times 10^{-5}$

Find K_{sp} from chart

$K_{sp} = 5.0 \times 10^{-9}$

Solution

- Now find Q

$Q = [Ca^{2+}][CO_3^{2-}]$

$Q = (1.0 \times 10^{-3})(0.025)$

$Q = 2.5 \times 10^{-5}$

$2.5 \times 10^{-5} > 5.0 \times 10^{-9}$

$Q > K_{sp}$

Therefore a precipitate WILL form

Homework

* p. 549 #121-128