Solubility

K_s
Solubility
Common Ion Effect

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The Solubility Constant (K_s)

- We know that if you drop a substance in water it could dissolve (it is soluble) or it might just sit there (it is insoluble).
- This year we look at the fact that even insoluble substances break down and dissolve in water just a little bit, and this solubility is an equilibrium reaction:

$$AB_{(s)} \leftrightharpoons A_{(aq)}^{+} + B_{(aq)}^{-}$$

- When we arrange this into an equilibrium expression it turns out like this:

$$K_s = [A_{(aq)}^{+}][B_{(aq)}^{-}]$$

- As you can see we ignore the concentration of the solid in the water…. why?

Note: This Solubility Constant is also called the Solubility Product

Solubility

- When a substance dissolves we can work out it's solubility – a value that is measured in moles per litre (a concentration). This concentration is the maximum concentration that you can squeeze into the water at 25˚C
- This solubility is sometimes represented by an 's' in calculations
- For example, NaCl has solubility of 0.6 $molL^{-1}$. In other words I can only squeeze 0.6 moles (36g) of NaCl into 1 litre of water
- Solubility can be used to calculate the K_s and the K_s can be used to calculate solubility. One thing you do have to watch out for is this:

$$Ag_2S_{(s)} \leftrightharpoons 2Ag_{(aq)}^{+} + S_{(aq)}^{2-}$$

- The solubility for Ag_2S is $1.2x10^{-11}$ $molL^{-1}$ but you will notice that there is 2 moles of Ag^+ produced in the solution. That means that there is $2.4x10^{-11}$ $molL^{-1}$ of Ag^+ in solution
- This is important when putting solubility into an equilibrium expression…

Calculations – K_s from Solubility

- There are three types of solubility reactions we look at this year:

$$AB \leftrightharpoons A^+ + B^-$$
$$A_2B \leftrightharpoons 2A^+ + B^{2-}$$
$$AB_2 \leftrightharpoons A^{2+} + 2B^-$$

- When we calculate the Ks from the solubility we need to deal with the first one differently from the last two.
- For the first example imagine the solubility is represented by the letter 's' then:

Ks	$= [A_{(aq)}^{+}][B_{(aq)}^{-}]$	becomes…
	= s x s	or…
	$= s^2$	

- For the second (and third) example

Ks	$= [A_{(aq)}^{+}][B_{(aq)}^{-}]^2$	becomes…
	$= s \times (2s)^2$	or…
	$= 4s^3$	

Calculations – K_s from Solubility - Examples

$PbS \leftrightharpoons Pb^{2+} + S^{2-}$

Solubility of PbS = 5.5×10^{-15} $molL^{-1}$

$$
\begin{aligned}
Ks &= [Pb^{2+}][S^{2-}] \quad \text{or....} \\
&= s^2 \quad \text{becomes....} \\
&= (5.5 \times 10^{-15})^2 \\
&= 3 \times 10^{-29}
\end{aligned}
$$

$PbCl_2 \leftrightharpoons Pb^{2+} + 2Cl^-$

Solubility of $PbCl_2$ = 3.4×10^{-7} $molL^{-1}$

$$
\begin{aligned}
Ks &= [A_{(aq)}^+][B_{(aq)}^-]^2 \quad \text{or....} \\
&= 4s^3 \quad \text{becomes....} \\
&= 4 \times (3.4 \times 10^{-7})^3 \\
&= 1.6 \times 10^{-19}
\end{aligned}
$$

Calculations – Solubility from K_s

- The calculations can also work in the opposite direction, following the same rules

$AB \leftrightharpoons A^+ + B^-$

$A_2B \leftrightharpoons 2A^+ + B^{2-}$

$AB_2 \leftrightharpoons A^{2+} + 2B^-$

- With the first example:

$K_s = s^2$ so…

$s = \sqrt{K_s}$

- With the second and third examples:

$Ks = 4s^3$ so…

$s = \sqrt[3]{(K_s/4)}$

Calculations – Solubility from K_s - Examples

$PbS \rightleftharpoons Pb^{2+} + S^{2-}$

$K_s (PbS) = 3x10^{-29}$

Ks $= s^2$ so….
s $= \sqrt{K_s}$
$= \sqrt{3x10^{-29}}$
$= 5.5 x10^{-15}$ $molL^{-1}$

$PbCl_2 \rightleftharpoons Pb^{2+} + 2Cl^-$

$K_s (PbCl_2) = 1.6x10^{-19}$

Ks $= 4s^3$ so….
s $= \sqrt[3]{(K_s/4)}$
$= \sqrt[3]{(1.6x10^{-19}/4)}$
$= 3.4x10^{-7}$ $molL^{-1}$

Common Ion Effect

- The K_s expressions can be used in another way – to predict if there will be a precipitate when two solutions are mixed.
- A precipitate is a solid (insoluble) chemical that appears because the solution is saturated (it can't hold any more of the chemical)
- The two ions being mixed is called an Ionic Product and it has a special formulae for calculating it:

IP = $[A^+][B^-]$ or $[A^{2+}][B^-]^2$ etc…

- As you can see its just the same as the K_s expression.
- The rule for the use of the Ionic Product is:

If the IP is greater than the K_s there will be a precipitate

Note: when you add equal volumes of two solutions together you halve their concentrations… why?

Common Ion Effect - Example

- Jimmy adds equal volumes of $1x10^{-2}molL^{-1}$ Li^{+} and $3x10^{-1}molL^{-1}$ F^{-} solutions together.

  $K_s(LiF) = 3.8 \times 10^{-3}$

- Will there be a precipitate forming?

  IP $= [Li^{+}][F^{-}]$
  $= 0.5x10^{-2} \times 1.5x10^{-1}$
  $= 7.5x10^{-4}$

- Is the IP > K_s? – No
- Will there be a precipitate forming? - No

Example 2

- It can also be used to predict the maximum concentration of an ion in solution
- Julie has a flask of $0.100molL^{-1}$ HCl solution. She wants to know how much Pb^{2+} she can add before there is a precipitate. The K_s $(PbCl_2) = 1.60x10^{-5}$
  - When IP = Ks we have the maximum of each ion present:

  IP $= [Pb^{2+}][Cl^{-}]^2$
  $1.60x10^{-5} = [Pb^{2+}] \times 0.100^2$

  Now we rearrange…

  $1.60x10^{-5}/0.100^2 = [Pb^{2+}]$
  $[Pb^{2+}] = 0.0016\ molL^{-1}$

Examples of Solubility Products:

Some examples of K_s values at 25°C	
Carbonates $BaCO_3$ -- 2 x 10^{-9} $CaCO_3$ -- 5 x 10^{-9} $MgCO_3$ -- 2 x 10^{-8}	**Iodides** AgI -- 1 x 10^{-16} PbI_2 -- 1 x 10^{-8}
Chlorides AgCl -- 1.6 x 10^{-10} Hg_2Cl_2 -- 1 x 10^{-18} $PbCl_2$ -- 1.7 x 10^{-5}	**Sulfates** $BaSO_4$ -- 1.4 x 10^{-9} $CaSO_4$ -- 3 x 10^{-5} $PbSO_4$ -- 1 x 10^{-8}
Hydroxides $Al(OH)_3$ -- 5 x 10^{-33} $Cr(OH)_3$ -- 4 x 10^{-38} $Fe(OH)_2$ -- 1 x 10^{-15} $Fe(OH)_3$ -- 5 x 10^{-38} $Mg(OH)_2$ -- 1 x 10^{-11} $Zn(OH)_2$ -- 5 x 10^{-17}	**Sulfides** Ag_2S -- 1 x 10^{-49} CuS -- 1 x 10^{-35} FeS -- 1 x 10^{-17} PbS -- 1 x 10^{-27} ZnS -- 1 x 10^{-20}

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- Two

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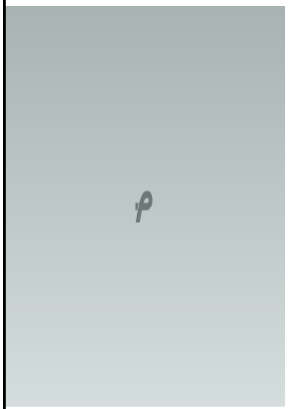

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