

# **EQUILIBRIUM AND SOLUBILITY**

# EQUILIBRIUM AND SOLUBILITY

Solids form from solution when:

1.a solution is saturated

2.two solutions are mixed to form a precipitate

Both are dependent on an equilibrium between the solution and the solid.

# EQUILIBRIUM AND SOLUBILITY



$K_{sp}$  is the **solubility product constant** for solutions that can form a solid.

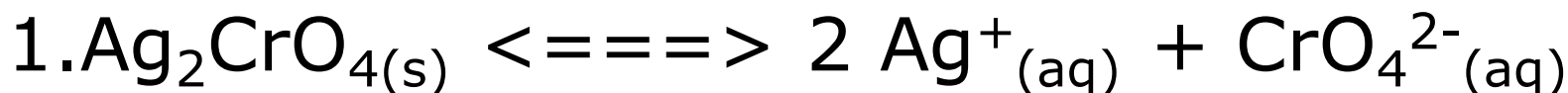
This is true for saturated solutions.

Why? Only at saturation point is equilibrium achieved.

# EQUILIBRIUM AND SOLUBILITY

## Example #1

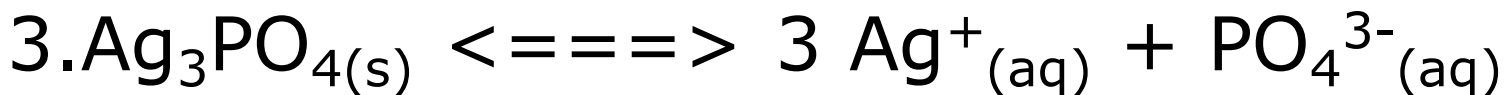
Determine the  $K_{sp}$  expressions for the following equilibria:



$$K_{sp} = [\text{Ag}^+_{(aq)}]^2 [\text{CrO}_4^{2-}_{(aq)}]$$



$$K_{sp} = [\text{Ba}^{2+}_{(aq)}][\text{CrO}_4^{2-}_{(aq)}]$$



$$K_{sp} = [\text{Ag}^+_{(aq)}]^3 [\text{PO}_4^{3-}_{(aq)}]$$

# EQUILIBRIUM AND SOLUBILITY

## Molar Solubility

The **molar solubility** for a compound is the concentration that is necessary for a solution to become saturated.

*Ex. One litre of water can dissolve  $7.1 \times 10^{-7}$  mol of AgBr*

$K_{sp}$  values may be used to calculate molar solubility and vice versa.

# EQUILIBRIUM AND SOLUBILITY

## Example #2

Silver bromide, AgBr, is the light sensitive compound in nearly all photographic film. At 25°C, one litre of water can dissolve  $7.1 \times 10^{-7}$  mol of AgBr. Calculate the  $K_{sp}$  of AgBr at 25°C.

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I Changes when  
C it dissolves, but  
E it is a solid.

$$K_{sp} = [7.1 \times 10^{-7}][7.1 \times 10^{-7}]$$

$$K_{sp} = 5.0 \times 10^{-13}$$

$$\therefore K_{sp} = 5.0 \times 10^{-13}$$

# EQUILIBRIUM AND SOLUBILITY

## Example #3

At 25°C, the molar solubility of  $\text{PbCl}_2$  in a 0.10 M NaCl solution is  $1.7 \times 10^{-3}$  M.  
Calculate the  $K_{\text{sp}}$  for  $\text{PbCl}_2$ .



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I  
C  
E

**NOTE:** 0.1M  $\text{Na}^+$   
does not affect  
equilibrium

$$K_{\text{sp}} = [1.7 \times 10^{-3}][0.1034]^2$$

$$K_{\text{sp}} = 1.8 \times 10^{-5}$$

$$\therefore K_{\text{sp}} = 1.8 \times 10^{-5}$$

# EQUILIBRIUM AND SOLUBILITY

## Example #4

The solubility of iron (II) hydroxide,  $\text{Fe}(\text{OH})_2$ , is found to be  $1.4 \times 10^{-3}$  g/L. What is the  $K_{sp}$  value?

# EQUILIBRIUM AND SOLUBILITY

## Example #4

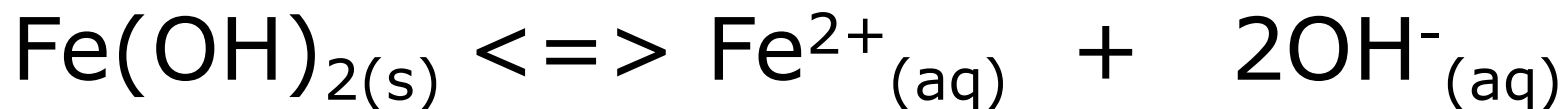
The solubility of iron (II) hydroxide,  $\text{Fe}(\text{OH})_2$ , is found to be  $1.4 \times 10^{-3} \text{ g/L}$ . What is the  $K_{\text{sp}}$  value?

$$n = \frac{m}{M}$$

M

$$= \frac{(1.4 \times 10^{-3} \text{ g})}{(89.861 \text{ g/mol})}$$

$$= 1.557961741 \times 10^{-5} \text{ mol}$$



I  
C  
E

$$K_{\text{sp}} = [1.55796 \times 10^{-5}][3.11592 \times 10^{-5}]^2$$

$$K_{\text{sp}} = 1.5 \times 10^{-14}$$

$$\therefore K_{\text{sp}} = 1.5 \times 10^{-14}$$

# EQUILIBRIUM AND SOLUBILITY

## Example #5

What is the molar solubility of AgCl in pure water at 25°C when  $K_{sp} = 1.8 \times 10^{-10}$ ?

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What is the molar solubility of AgCl in pure water at 25°C when  $K_{sp} = 1.8 \times 10^{-10}$ .



I  
C  
E

$$K_{sp} = [x][x]$$

$$K_{sp} = x^2$$

$$1.8 \times 10^{-10} = x^2$$

$$1.34 \times 10^{-5} \text{M} = x$$

∴ the molar solubility is  $1.34 \times 10^{-5} \text{mol/L}$

# EQUILIBRIUM AND SOLUBILITY

## Example #6

The  $K_{sp}$  for magnesium fluoride,  $MgF_2$ , has a value of  $6.4 \times 10^{-9}$ . What is its solubility in g/L?

# EQUILIBRIUM AND SOLUBILITY

## Example #6

The  $K_{sp}$  for magnesium fluoride,  $MgF_2$ , has a value of  $6.4 \times 10^{-9}$ . What is its solubility in g/L?



I  
C  
E

$$K_{sp} = [x][2x]^2 = 6.4 \times 10^{-9}$$

$$4x^3 = 6.4 \times 10^{-9}$$

$$x = \sqrt[3]{\frac{6.4 \times 10^{-9}}{4}}$$

$$x = 1.16 \times 10^{-3} \text{ mol/L}$$

$\therefore$  the solubility is  $7.2 \times 10^{-2} \text{ g/L}$

# EQUILIBRIUM AND SOLUBILITY

## Predicting Precipitation

Similar to  $K_{eq}$  problems, calculating  $Q$  can be used to determine whether a precipitate will form when provided with  $K_{sp}$ .

Three possibilities:

1.  $Q <$

2.  $Q =$

3.  $Q >$




# EQUILIBRIUM AND SOLUBILITY

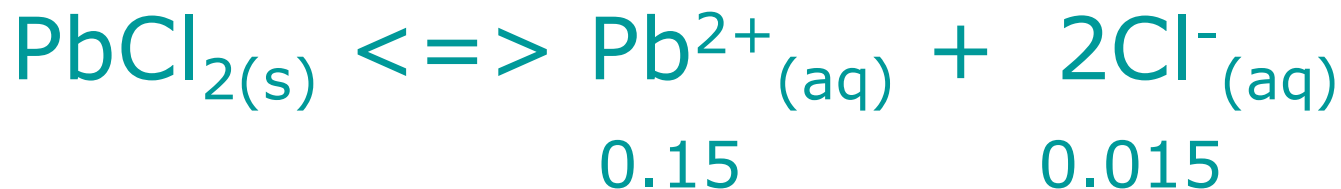
## Example #7

A student wished to prepare 1.0 L of a solution containing 0.015 mol of NaCl and 0.15 mol of  $\text{Pb}(\text{NO}_3)_2$ . Knowing from the solubility rules that the chloride of  $\text{Pb}^{2+}$  is insoluble, there was a concern that  $\text{PbCl}_2$  might form. If the  $K_{\text{sp}}$  for this reaction is  $1.7 \times 10^{-5}$ , will a ppt form?

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

$$Q = [\text{Pb}^{2+}_{(aq)}][\text{Cl}^{-}_{(aq)}]^2$$

$$Q = [0.15][0.015]^2$$

$$Q = 3.375 \times 10^{-5}$$

$Q > K_{\text{sp}}$ , so a precipitate WILL form

$\therefore$  a precipitate will form

# EQUILIBRIUM AND SOLUBILITY

## Example #8

What possible precipitate might form by mixing 50.0 mL of 0.0010 M  $\text{CaCl}_2$  with 50.0 mL of 0.010 M  $\text{Na}_2\text{SO}_4$ ? Will the precipitate form? ( $K_{\text{sp}} = 7.1 \times 10^{-5}$ )

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<u>Ion</u>	<u>Solubility</u>	<u>Exceptions</u>
$\text{NO}_3^-$	soluble	none
$\text{ClO}_4^-$	soluble	none
$\text{Cl}^-$	soluble	except $\text{Ag}^+$ , $\text{Hg}_2^{2+}$ , $\text{Pb}^{2+}$
$\text{I}^-$	soluble	except $\text{Ag}^+$ , $\text{Hg}_2^{2+}$ , $\text{Pb}^{2+}$
$\text{SO}_4^{2-}$	soluble	except $\text{Ca}^{2+}$ , $\text{Ba}^{2+}$ , $\text{Sr}^{2+}$ , $\text{Hg}^{2+}$ , $\text{Pb}^{2+}$ , $\text{Ag}^+$
$\text{CO}_3^{2-}$	insoluble	except Group IA and $\text{NH}_4^+$
$\text{PO}_4^{3-}$	insoluble	except Group IA and $\text{NH}_4^+$
$\text{-OH}$	insoluble	except Group IA, $\text{Ca}^{2+}$ , $\text{Ba}^{2+}$ , $\text{Sr}^{2+}$
$\text{S}^{2-}$	insoluble	except Group IA, IIA and $\text{NH}_4^+$
$\text{Na}^+$	soluble	none
$\text{NH}_4^+$	soluble	none
$\text{K}^+$	soluble	none

\*slightly soluble

$\text{CaSO}_4$  has low solubility.

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$$C_1V_1 = C_2V_2$$

$$C_2 = \frac{C_1V_1}{V_2}$$

$$C_2 = \frac{0.0010\text{M} \times 0.050\text{L}}{0.100\text{L}}$$

$$C_2 = 5 \times 10^{-4}\text{M}$$

$$C_2 = \frac{C_1V_1}{V_2}$$

$$C_2 = 5 \times 10^{-3}\text{M}$$

$$Q = [\text{Ca}^{2+}_{(aq)}][\text{SO}_4^{2-}_{(aq)}]$$

$$Q = [0.0005][0.005]$$

$$Q = 2.5 \times 10^{-6}$$

$Q < K_{\text{sp}}$ , so a precipitate will NOT form (unsaturated)

$\therefore$  the possible precipitate,  $\text{CaSO}_4$ , will not form

# EQUILIBRIUM AND SOLUBILITY

## Example #9

Will a precipitate form if 20.0 mL of 0.010 M  $\text{CaCl}_2$  are mixed with 30.0 mL of 0.0080 M  $\text{Na}_2\text{SO}_4$ ? ( $K_{\text{sp}} = 2.45 \times 10^{-5}$ )

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## Example #9

Will a precipitate form if 20.0 mL of 0.010 M  $\text{CaCl}_2$  are mixed with 30.0 mL of 0.0080 M  $\text{Na}_2\text{SO}_4$ ? ( $K_{\text{sp}} = 2.45 \times 10^{-5}$ )



$$C_2 = \frac{C_1 V_1}{V_2}$$

$$C_2 = \frac{0.010\text{M} \times 0.020\text{L}}{0.050\text{L}}$$

$$C_2 = 4 \times 10^{-3}\text{M}$$

$$C_2 = \frac{C_1 V_1}{V_2}$$

$$C_2 = \frac{0.0080\text{M} \times 0.030\text{L}}{0.050\text{L}}$$

$$C_2 = 4.8 \times 10^{-3}\text{M}$$

$$Q = [\text{Ca}^{2+}_{(aq)}][\text{SO}_4^{2-}_{(aq)}]$$

$$Q = [0.004][0.0048]$$

$$Q = 1.92 \times 10^{-5}$$

$Q < K_{\text{sp}}$ , so a precipitate will NOT form (unsaturated)

$\therefore$  a precipitate will not form