

# Thinking Like a Chemist About Solubility Equilibrium

UNIT 5 DAY 6

What are we going to learn today?

Thinking Like a Chemist in the  
Context of the Solution Equilibria

Reaction Quotient

Common Ion Effect

Temperature & Solubility & Supersaturated

## IMPORTANT INFORMATION

LM10 and LM11 due this morning

LM12 and HW3 due Tue 9AM

Looking ahead:

EXAM 1, Feb 5<sup>th</sup> 7 – 9 PM

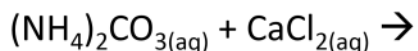
Details of room assignments will be posted on  
website next week

Independent Quiz:, No talking!

The  $K_{sp}$  expression for the dissolution of  $Cd_3(PO_4)_2$  is:

- A.  $K_{sp} = [Cd^{2+}][PO_4^{3-}]$
- B.  $K_{sp} = [Cd^{2+}]^2[PO_4^{3-}]^2$
- C.  $K_{sp} = [x] [y]$
- D.  $K_{sp} = [x]^2 [x]^3$
- E.  $K_{sp} = [Cd^{2+}]^3[PO_4^{3-}]^2$

The net ionic equation for the following is:



- A.  $(\text{NH}_4)_2\text{CO}_3(\text{aq}) + \text{CaCl}_2(\text{aq}) \rightarrow 2\text{NH}_4\text{Cl}(\text{aq}) + \text{CaCO}_3(\text{aq})$
- B.  $(\text{NH}_4)_2\text{CO}_3(\text{aq}) + \text{CaCl}_2(\text{aq}) \rightarrow 2\text{NH}_4\text{Cl}(\text{aq}) + \text{CaCO}_3(\text{s})$
- C.  $2\text{NH}_4^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) + \text{Ca}^{2+}(\text{aq}) + 2\text{Cl}^- \rightarrow 2\text{NH}_4^+(\text{aq}) + 2\text{Cl}^-(\text{aq}) + \text{CaCO}_3(\text{s})$
- D.  $2\text{NH}_4^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) + \text{Ca}^{2+}(\text{aq}) + 2\text{Cl}^- \rightarrow \text{CaCO}_3(\text{s})$
- E.  $\text{CO}_3^{2-}(\text{aq}) + \text{Ca}^{2+}(\text{aq}) \rightarrow \text{CaCO}_3(\text{s})$

## A few useful definitions and ideas

### Precipitation

Formation of an insoluble solid in solution  
(usually form mixing two solutions)

### Spectator Ions

Ions that don't participate in the chemistry  
(aqueous ions that appear as both reactants and products)

### What is soluble?

Many solubility rules  
Typically  $K_{sp}$  is given for "insoluble" compounds

All  $\text{Na}^+$ ,  $\text{K}^+$ , and  $\text{NO}_3^-$  salts are soluble

## ACTIVITY - SOLUBILITY II

Mix a solution of lead II nitrate with a solution of potassium iodide  
Fully describe:



fully describe in words and pictures

2 clear sol<sup>n</sup>s mixed  
ended up w/ yellow solid suspended  
in sol<sup>n</sup> → it will settle out as a  
precipitate

↑ tiny amount of solid

Also → you need to be able to draw nice microscopic pictures on your activity sheet → See key for details.

POLL: Clicker Question

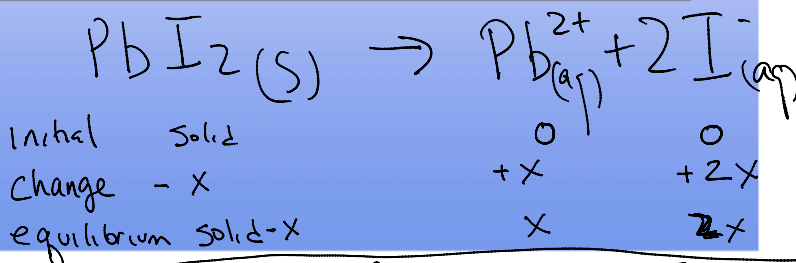
The  $K_{sp}$  of  $\text{PbI}_2$  is  $1.4 \times 10^{-8}$ . Predict  $[\text{Pb}^{2+}]$  and  $[\text{I}^-]$  in the saturated solution.

A.  $[\text{Pb}^{2+}] = 4.7 \times 10^{-9}$   $[\text{I}^-] = 4.7 \times 10^{-9}$

B.  $[\text{Pb}^{2+}] = 4.7 \times 10^{-9}$   $[\text{I}^-] = 9.3 \times 10^{-9}$

**C.**  $[\text{Pb}^{2+}] = 1.5 \times 10^{-3}$   $[\text{I}^-] = 3.0 \times 10^{-3}$

D.  $[\text{Pb}^{2+}] = 8.4 \times 10^{-5}$   $[\text{I}^-] = 1.7 \times 10^{-4}$



$$1.4 \times 10^{-8} = [\text{Pb}^{2+}][\text{I}^-]^2$$

$$1.4 \times 10^{-8} = (x)(2x)^2$$

Add more KI to sol<sup>n</sup> to what happens to  $[\text{I}^-]$ ? IT GOES UP!

POLL: Clicker Question

The  $K_{sp}$  of  $\text{PbI}_2$  is  $1.4 \times 10^{-8}$ . Predict  $[\text{Pb}^{2+}]$  and  $[\text{I}^-]$  in

✓  $\Gamma_{0.12+1} \Gamma_{0.2}$

The  $K_{sp}$  of  $PbI_2$  is  $1.4 \times 10^{-8}$ . Predict  $[Pb^{2+}]$  and  $[I^-]$  in the saturated solution after the addition of 0.5 moles of KI. in 1 Liter of soln

- A.  $[Pb^{2+}] = 1.5 \times 10^{-3}$   $[I^-] = 3.0 \times 10^{-3}$
- B.  $[Pb^{2+}] = 1.5 \times 10^{-3}$   $[I^-] = 1.5 \times 10^{-3}$
- C.  $[Pb^{2+}] = 5.6 \times 10^{-8}$   $[I^-] = 0.5$**
- D.  $[Pb^{2+}] = 5.6 \times 10^{-8}$   $[I^-] = 0.25$

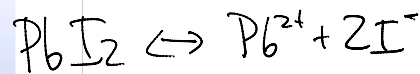
ion product is constant!  
So at equilibrium if one concentration goes up the other must go down

Reaction Quotient, Q

Q is the value of the ion product at any point in a process, not necessarily at the equilibrium ion concentrations.

Q is useful, because you can compare it to the value of K to decide if a precipitate will form.

$$K_{sp} = [Pb^{2+}][I^-]^2$$



initial	solid	0	.5
Change	-x	+x	+2x
final	solid-x	x	.5+2x

$$1.4 \times 10^{-8} = [x][.5+2x]^2$$

x is tiny!

So you can ignore it!

$$1.4 \times 10^{-8} = x(.5)^2$$

$$x = [Pb^{2+}] =$$

$$Q_{sp} = [Pb^{2+}][I^-]^2$$

Same form as  $K_{sp}$  but not necessarily at equilibrium

$Q_{sp} > K_{sp}$  too high precipitate will form

$Q_{sp} = K_{sp} \rightarrow$  at equilibrium

$Q_{sp} < K_{sp}$  too low precipitate will not form

POLL: Clicker Question

Reaction Quotient, Q

For AgCl  $K_{sp} = [Ag^+]_{eq}[Cl^-]_{eq} = 1.8 \times 10^{-10}$

## Reaction Quotient, Q

For AgCl  $K_{sp} = [Ag^+]_{eq}[Cl^-]_{eq} = 1.8 \times 10^{-10}$

You have a solution such that the instantaneous concentrations of ions gives a  $Q_{sp} = [Ag^+][Cl^-] = 1.8 \times 10^{-6}$

Will a precipitate form?

A. Yes

B. No

IS  $Q > K$  or  $Q < K$ ?  
That is the question?

$Q_{sp} < K_{sp}$  too low precipitate will not form

Mix 1 liter of 0.2 molar of the lead salt with 1 liter of 0.2 molar of the iodide salt.  
What is the value of  $Q_{sp}$  and will a precipitate form?

A.  $Q_{sp} = 1.4 \times 10^{-8}$  ; no

B.  $Q_{sp} = 1.0 \times 10^{-3}$  ; no

C.  $Q_{sp} = 1.0 \times 10^{-3}$  ; yes

D.  $Q_{sp} = 4.0 \times 10^{-3}$  ; yes

POLL: Clicker Question

What is the mass of the  $\text{PbI}_2$  that was precipitated?

- A. 461 g  $\text{PbI}_2$
- B. 46.1 g  $\text{PbI}_2$
- C. 92.2 g  $\text{PbI}_2$
- D. Impossible to tell because equilibrium

POLL: Clicker Question

What concentration will the lead ion need to be dropped to to prevent precipitation?

- A.  $7.0 \times 10^{-9} \text{ M}$
- B.  $7.0 \times 10^{-8} \text{ M}$
- C.  $1.4 \times 10^{-10} \text{ M}$
- D.  $1.4 \times 10^{-6} \text{ M}$



### Temperature Dependence of Solubility –

Solubility Increases with T for ENDOTHERMIC solutions  
because makes  $K_{sp}$  bigger

Solubility Decreases with T for EXOTHERMIC solutions  
because makes  $K_{sp}$  smaller

### DEMONSTRATE

Solubility Increases with T for ENDOTHERMIC solutions  
because makes  $K_{sp}$  bigger

SUPER SATURATED SOLUTION

METASTABLE SOLUTION

## What did we learn today?

Solubility is an equilibrium condition.

Determine the solubility of an insoluble salt in the presence of a common ion.

Q is the reaction quotient and indicates the extent of the reaction.

## Learning Outcomes

Calculate solubilities in the presence of a common ion.

Given concentrations of specific ions, predict if a precipitate will form (amount or concentration) using the concept of the reaction quotient, Q.

I have all of these ions in solution,  
do I get a precipitate?

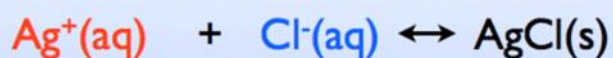
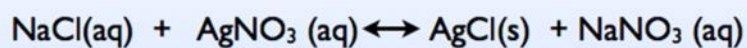
This is just equilibrium,  
compare Q to K

$$K_{sp} = 1.7 \times 10^{-5} \text{ for PbCl}_2$$

I have a solution in which  $[\text{Pb}^{2+}] = 10^{-2} \text{ M}$  and  $[\text{Cl}^-] = 10^{-2} \text{ M}$

- A. some  $\text{PbCl}_2$  will precipitate
- B. all the  $\text{PbCl}_2$  will be in solution

If I mix a 100 mL of 1 M NaCl solution  
with a 200 mL of 1 M  $\text{AgNO}_3$  solution  
how much solid AgCl will form ( $K_{sp} = 1.8 \times 10^{-10}$ )?



Assume all the maximum amount of AgCl forms

Need to convert from concentration to moles!

Silver Nitrate ( $\text{AgNO}_3$ ) and Sodium Chloride ( $\text{NaCl}$ ) are both soluble salts.

What will happen if I mix 200 mL of 1 M  $\text{AgNO}_3$  solution with 100 ml of 1 M  $\text{NaCl}$  solution given that  $K_{sp}$  for  $\text{AgCl}$  is  $1.8 \times 10^{-10}$

- A. I'll have a solution with  $\text{Ag}^+$ ,  $\text{Cl}^-$ ,  $\text{Na}^+$ , and  $\text{NO}_3^-$  ions
- B. some solid  $\text{AgCl}$  will form
- C. both B & C