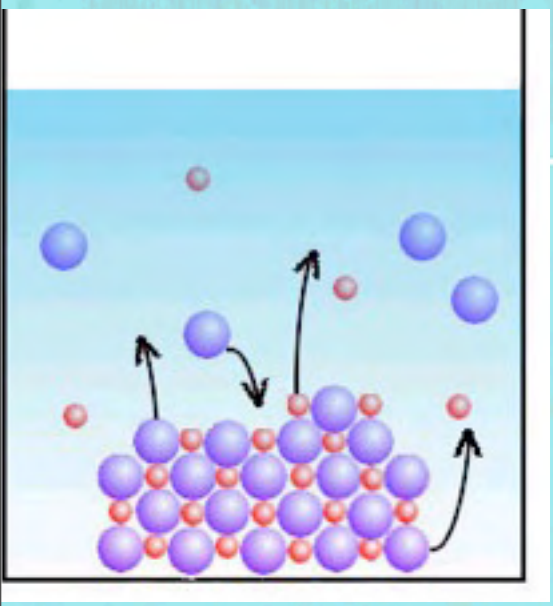
Solubility Equilibrium

This is an X-ray of the large intestine. The patient was given a drink of barium sulfate to drink which is insoluble (does NOT dissolve) and gives the doctor a better image. Barium sulfate is a toxic substance. Why would a doctor give a patient a toxic substance?

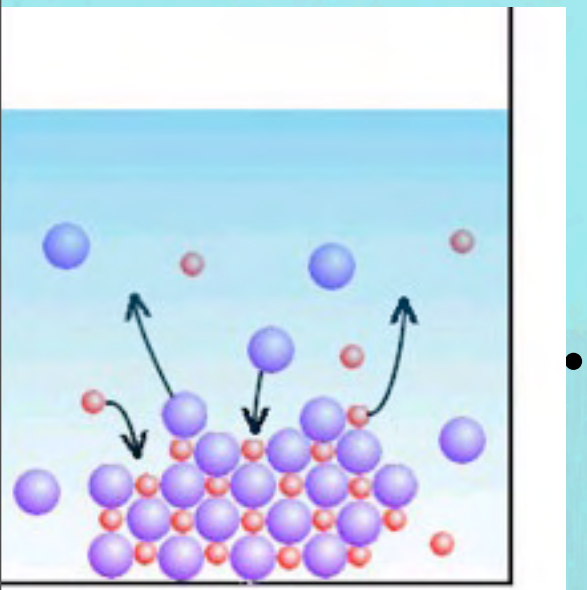
Let's review key terms!

- **Solute** - the smaller amount of a mixture
- **Solvent** - the larger amount of a mixture
- **Solubility** - the maximum amount of solute that can dissolve in a given quantity of of solvent at particular temperature
- **Saturated -** the maximum amount of solute dissolved in the solvent
- **Dissolving** - when an ionic compound is put in water, it breaks up into ions

Equilibrium of Solutions

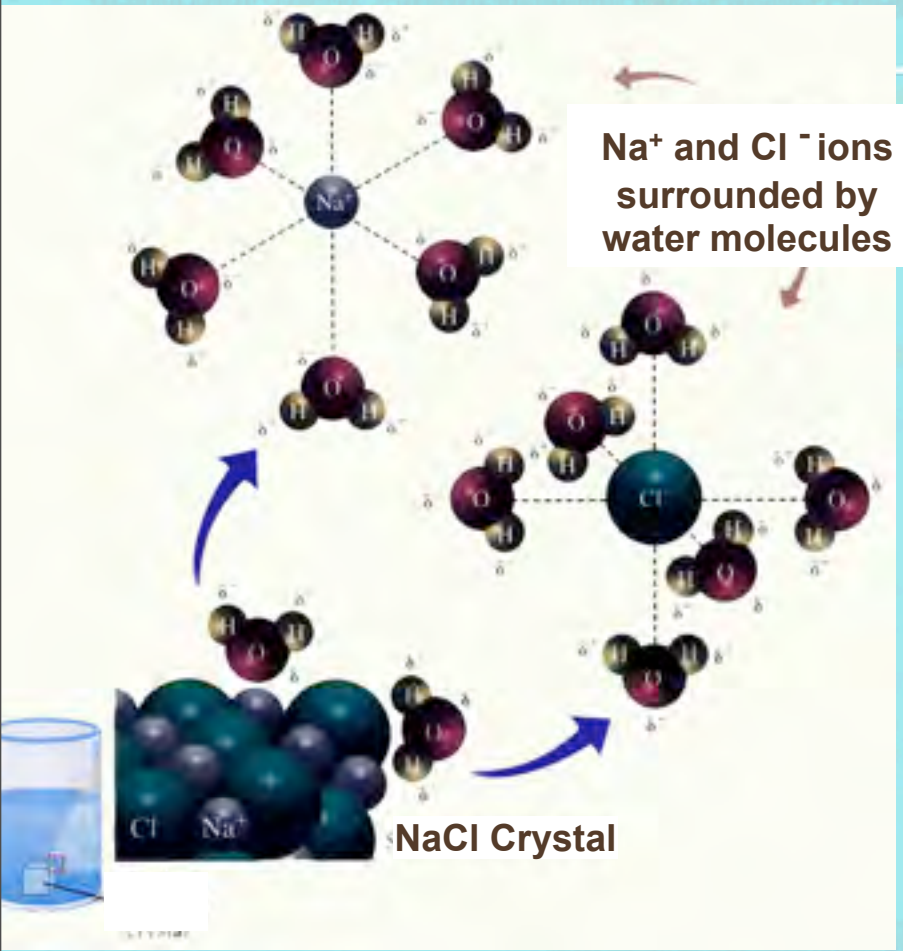


- Let's look at dissolving **AgCl** in water.
- **Dissociation**
- **Precipitation**



- **Saturated** means it's at **equilibrium**

Solubility Equilibrium



Dissolving NaCl in water

In a saturated solution, there is no change in amount of solid precipitate at the bottom of the beaker.

The rate at which the salt is dissolving into solution equals the rate of precipitation.

The solution is at equilibrium!

Solubility Product Constant, Ksp

- Ksp is the equilibrium constant for slightly soluble ionic compounds. It is written the exact same way as all the other equilibrium constants (Keq, Kc, etc)
- Try writing Ksp for Ag_2SO_4

Writing Ksp expressions

Write the solubility product expression for each compound.

(a) barium carbonate

(b) calcium iodate

(c) copper(II) phosphate

Molar Solubility

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

In other words, it is the minimum concentration of insoluble solid that is required to make a saturated solution.

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

Calculating Ksp

- **A saturated solution of silver chromate, Ag_2CrO_4, has $[Ag^+] = 1.3 \times 10^{-4}$ M. What is the K_{sp} for Ag_2CrO_4?**
- Hint! A "saturated solution" means that it is at equilibrium.

Calculating Ksp

The molar solubility of silver sulfate is 0.014 mol/L. This means that 0.0144 mol of Ag_2SO_4 will dissolve to make 1.0 L of saturated solution (at equilibrium). Calculate Ksp .

Hint! Solubility is the "x" in your ICE charts!

Ksp and Solubility

- Generally, it is fair to say that salts with very small solubility product constants (Ksp) are only slightly soluble in water.
  - If something is soluble in water, like NaCl, it will **NOT** have a Ksp

- When comparing the solubilities of two salts, however, you can sometimes simply compare the relative sizes of their Ksp values.

- This works if the salts have the same number of ions!

- For example… CuI has Ksp = 5.0×10^{-12} and $CaSO_4$ has Ksp = 6.1×10^{-5}. Since the Ksp for calcium sulfate is larger than that for the copper (I) iodide, we can say that calcium sulfate is more soluble.
- Large Ksp means MORE soluble

Calculating solubility, given Ksp

- The Ksp of $NiCO_3$ is 1.4×10^{-7} at 25 °C. Calculate its molar solubility.

- Hint! Solubility is the "x" in your ICE chart.

$$NiCO_3\,(s) \leftrightarrows Ni^{2+}\,(aq) + CO_3^{2-}\,(aq)$$

Other ways to express solubility…

- We just saw that the solubility of nickel (II) carbonate is 3.7×10^{-4} mol/L. What mass of $NiCO_3$ is needed to prepare 500 mL of saturated solution?

0.022 g of $NiCO_3$ will dissolve to make 500 mL solution.

So back to X-rays & $BaSO_4$...

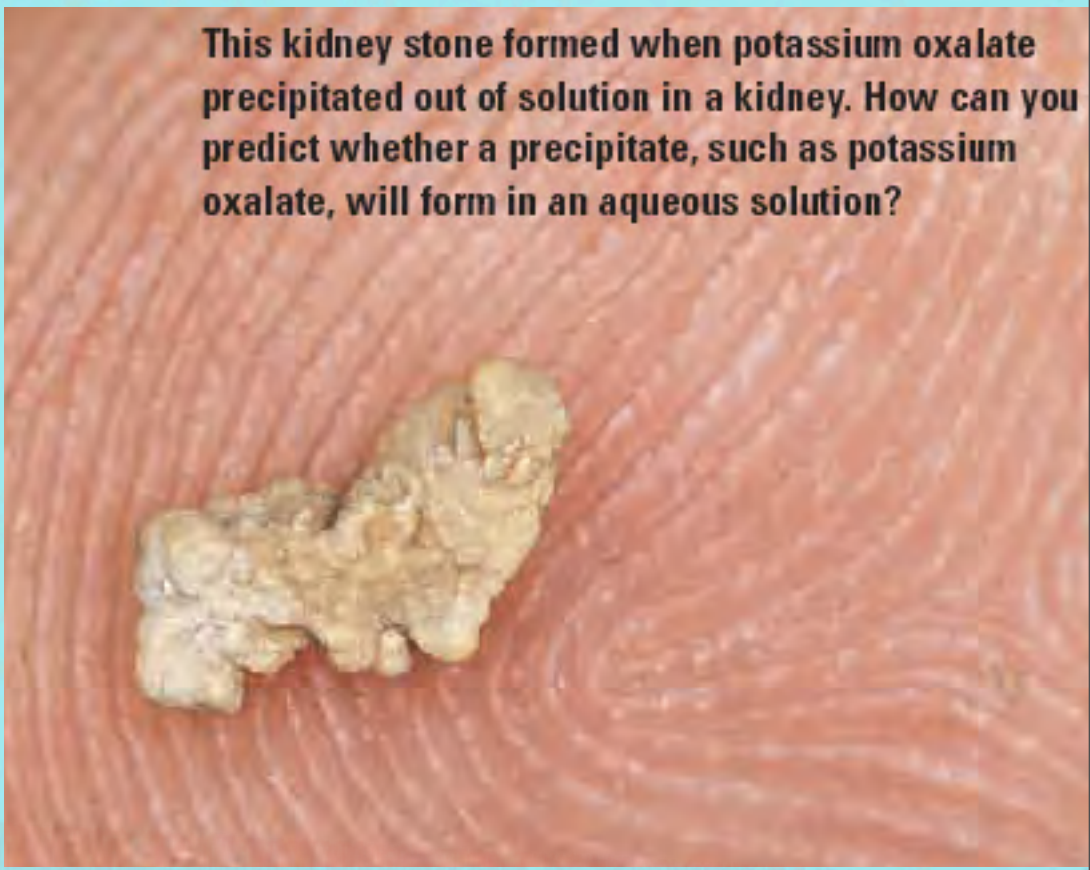
- $BaSO_{4(s)} \leftrightarrow Ba^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)}$
- Ksp for $BaSO_4$ is 1.08×10^{-10}
- This means it is not very soluble in water
- The low Ksp means that most of what you drink will remain in the $BaSO_4$ form
- This is good news since Barium ions are extremely toxic!

Try it!

- p. 21 #1-5

So far…

- We looked at the equilibrium of slightly soluble ionic compounds
- We defined saturated solutions as being in equilibrium
- We wrote Ksp expressions (solubility product constants)
- We solved for molar solubility using ICE charts



Predicting the Formation of a Precipitate

- When we started the Equilibrium unit, we introduced the Equilibrium constant, K_{eq}
- Then we introduced Q_{eq}, which was written the same way as K_{eq}, except that it may or may not be at equilibrium
- In solubility equilibrium, we can compare Q_{sp} and K_{sp} in order to determine if a precipitate is going to form

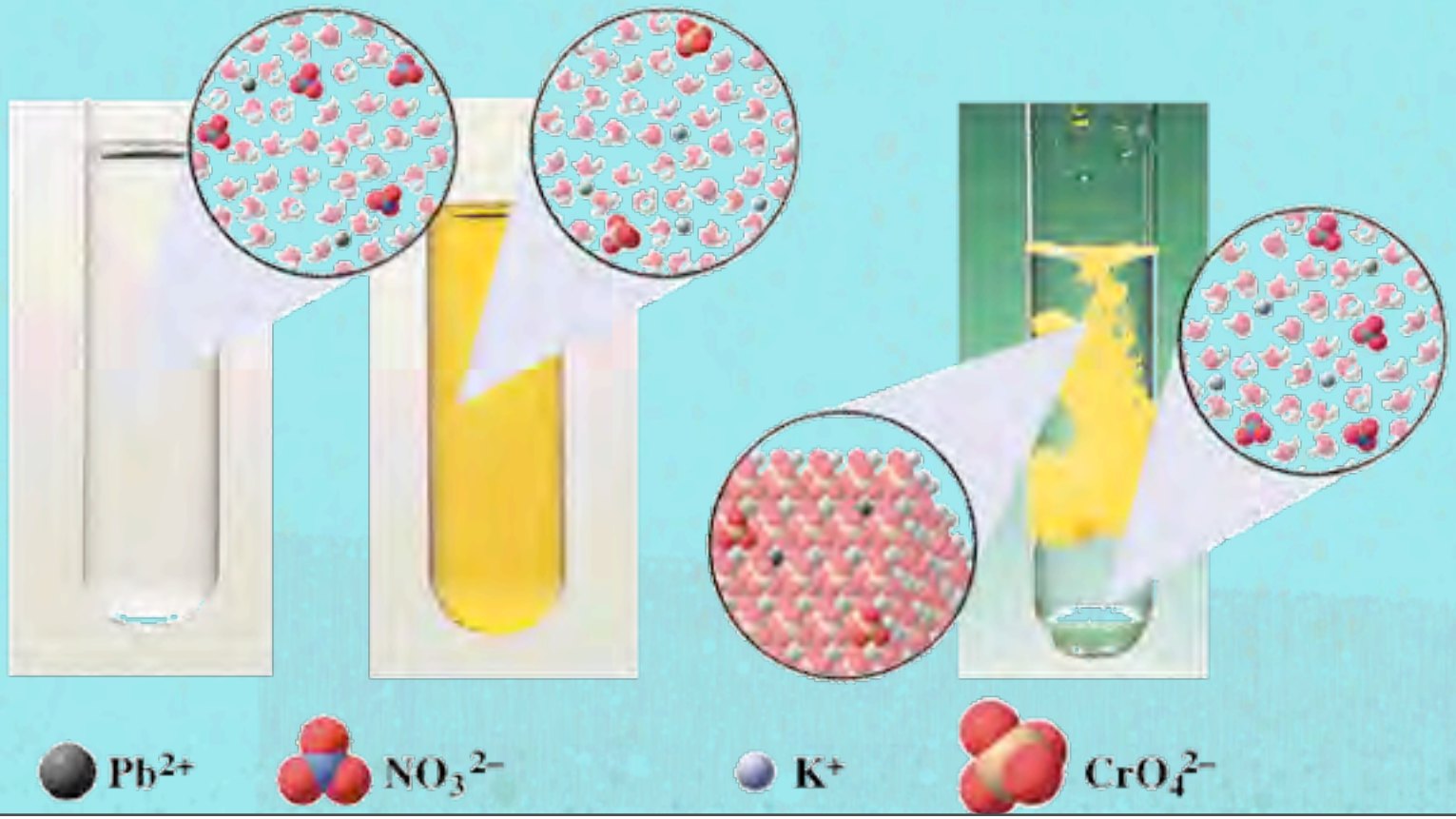
Q_{sp} vs. K_{sp}

- $Q_{sp} < K_{sp}$ No precipitate forms
- $Q_{sp} = K_{sp}$ At eq'm, no change
- $Q_{sp} > K_{sp}$ Precipitate forms

Will a Precipitate Form?

If 15 mL of 0.024M lead nitrate is mixed with 30 mL of 0.030 M potassium chromate will a precipitate of $PbCrO_4$ form?

$$Pb(NO_3)_2\,(aq) + K_2CrO_4\,(aq) \leftrightarrow PbCrO_4\,(s) + 2\,KNO_3\,(aq)$$



$$Pb(NO_3)_2(aq) + K_2CrO_4(aq) \leftrightarrows \mathbf{PbCrO_4(s)} + 2\,KNO_3\,(aq)$$

Step 1: Is a sparingly soluble salt formed?

The question tell us the potential precipitate is **$PbCrO_4$**. Write the equation and Ksp expression for this sparingly soluble salt. The solubility equilibrium is:

Step 2: Find the concentrations of the ions that form the sparingly soluble salt.

Step 3: Calculate Qsp for the mixture

Step 4: Compare Qsp to Ksp

Try it!

200 mL of 0.0040 M barium chloride is mixed with 600 mL of 0.0080 M potassium sulfate. The resulting products are barium sulfate and potassium chloride. Will a precipitate of barium sulfate form ($K_{sp} = 1.1 \times 10^{-10}$)?