Solubility Equilibrium

Chemistry 30

Solutions

- Mixture containing two or more components, but looks like one homogeneous substance
- **Solute**: dissolved substance
- **Solvent**: dissolving substance
- In this course: ionic compounds dissolved in water only

Dissociation Equations

- Ionic compounds dissolve in water by dissociation (breaking apart)
- For example:
  $Ba(NO_3)_2\ (s) \rightarrow Ba^{2+}\ (aq) + 2\ NO_3^-\ (aq)$

Example: Dissociation Equations

Na_2SO_4

$Ca(C_2H_3O_2)_2$

DIY Dissociation Equations

$AgNO_3$

K_2O

$Ba(OH)_2$

Describing Solutions

The amount of solute in a solvent can be described qualitatively by the terms **dilute** and **concentrated**. These are qualitative terms:

- Concentrated: lots of solute per volume of solvent
- Dilute: very little solute per volume of solvent

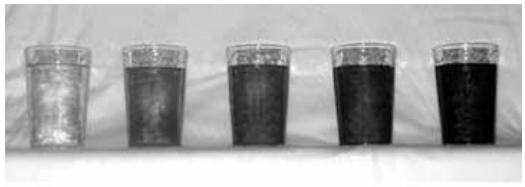
Describing Solutions

Every substance has a maximum amount of solute that can dissolve in the solvent. This allows for a quantitative description:

- **Unsaturated:** less than maximum amount of solute
- **Saturated:** maximum amount of solute
- **Supersaturated:** more than maximum amount of solute (achieved by raising temperature to dissolve solute, then slowly cooling)

Describing Solutions

Unsaturated		Saturated	Supersaturated
Dilute	Concentrated		

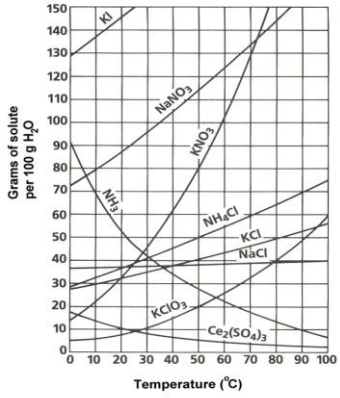


Diluted ⟷ Concentrated

Solubility

- **Solubility**: how much of something can dissolve in something else
  - At maximum amount, solution is **saturated**
- Very soluble will dissolve a lot, low solubility will dissolve very little
- Based on attraction of ions – strong attraction means it will not dissolve well

Solubility Chart



Solubility

- Solubility is a scale
- Soluble compounds dissociate 100% in solution (reaction favours products)
  - Dissociation equation has a one-way arrow

$$NaCl\ (s) \rightarrow Na^{+}\ (aq) + Cl^{-}\ (aq)$$

Solubility

- Low solubility means it dissociates less than 100% (some ions will stay attached, reaction favours reactants)
  - Dissociation equation has an equilibrium arrow

$$PbI_2\ (s) \rightleftharpoons Pb^{2+}\ (aq) + 2I^{-}\ (aq)$$

Determining Solubility

Option 1: Solubility Rules Chart
- Qualitative
- Sorted by anion

Note: soluble = aqueous, low solubility = solid

"If these ions are together in a solution, will a solid form?"

Examples: Solubility Rules

Soluble (aq) or low solubility (s)?

$Ba(OH)_2$ Na_3PO_4

CuI_2 $Pb(NO_3)_2$

$AgC_2H_3O_2$ $CaCO_3$

DIY Solubility Rules

CuI $ZnSO_4$

KNO_3 CaF_2

H_2CO_3 Fe_2S_3

Double Displacement Reactions

General form:

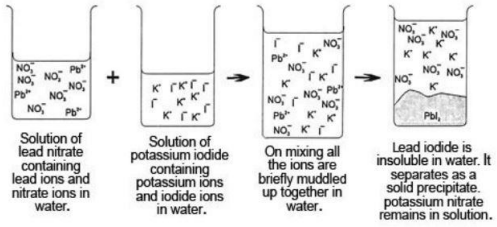
$$AB + CD \rightarrow AD + CB$$

But really…

$$A^+ + B^- + C^+ + D^- \rightarrow ???$$

If AD and/or CB has **low solubility**, it will make a solid. Otherwise no reaction occurs – everything stays dissolved as ions.

Double Displacement Reactions



Example: Solubility Rules

$Na_2CO_3\ (aq) + 2\ AgNO_3\ (aq) \rightleftharpoons 2\ NaNO_3\ \_\_ + Ag_2CO_3\ \_\_$

$Al_2(CrO_4)_3\ (aq) + H_2SO_4\ (aq) \rightleftharpoons$

$Cu_2SO_4\ (aq) + CaCl_2\ (aq) \rightleftharpoons$

Total Ionic Equations

$2\ NaOH\ (aq) + CuCl_2\ (aq) \rightleftharpoons 2\ NaCl\ (aq) + Cu(OH)_2\ (s)$

Total ionic equation: all aqueous compounds are represented as ions:

$2\ Na^+\ (aq) + 2\ OH^-\ (aq) + Cu^{2+}\ (aq) + 2\ Cl^-\ (aq) \rightleftharpoons 2\ Na^+\ (aq) + 2\ Cl^-\ (aq) + Cu(OH)_2\ (s)$

Net Ionic Equations

Spectator ions: ions that do not participate in the reaction

Net ionic equation: remove spectator ions from total ionic equation (no net ionic if no precipitate)

$2\ OH^-\ (aq) + Cu^{2+}\ (aq) \rightleftharpoons Cu(OH)_2\ (s)$

Net Ionic Equations

- Why do double displacement reactions have equilibrium arrows instead of regular arrows?
- How is a net ionic equation related to a dissociation equation?
- When should you use a dissociation equation vs a net ionic equation?

Example: Net Ionic Equations

Write the reaction, total ionic and net ionic equations for the reaction between barium nitrate and sodium carbonate that produces a barium carbonate precipitate. (Use the right arrow!)

DIY Net Ionic Equations

Write the molecular, total ionic and net ionic equations for silver nitrate and magnesium sulfate.

Determining Solubility

Option 2: Solubility Product Constant (K_{sp})

- Constant for a compound, in water, at 25°C.
- Describes how much will dissolve
- Compounds with no K_{sp} listed are soluble
- If listed, compound has low solubility.
  - Large K_{sp} = more soluble, small K_{sp} = less soluble

Example: K_{sp}

Which is more **soluble**?
$PbBr_2$ or $PbCl_2$

$BaSO_4$ or Ag_2SO_4

$Co(OH)_2$ or $CuCO_3$

DIY K_{sp}

Write the K_{sp} for each ionic compound, then rank them in order from most to least soluble.

$Co(OH)_2$

CoS

$CoCO_3$

Solubility Product

- To determine solubility or concentration of one or more ions, given the dissociation equation:

$$A_aB_b\ (s) \rightleftharpoons a\ A^+\ (aq) + b\ B^-\ (aq)$$

Use an equilibrium constant expression!

$$K_{sp} = [A^+]^a[B^-]^b$$

(Remember solids have a concentration of "1" and are not included in the expression.)

Determining Solubility

$$A_aB_b\ (s) \rightleftharpoons a\ A^+\ (aq) + b\ B^-\ (aq)$$
$$-x \qquad +a\ x \qquad +b\ x$$

Use K_{sp} to determine how many moles of the solid will dissolve per litre of solution .

Use *x* like in the "C" row on an ICE chart to compare moles for each ion.

Example 1: Setting Up Problems

For $Ca_3(PO_4)_2$:

a. Write the dissociation equation.
b. Write the "change" column using *x* values
c. Write the K_{sp} expression.
d. Substitute into the K_{sp} expression and simplify. (Don't solve.)

Example 2: Determining Solubility

Determine the solubility of AgBr in mol/L at 25°C.

Example 3: Determining Solubility

Determine the concentration of fluoride ions in a saturated solution of magnesium fluoride.

Example 4: Solubility

Determine the K_{sp} for $Co(OH)_3$ if its solubility is 1.7×10^{-11}.

DIY Solubility

1. Determine the solubility of $Ba(OH)_2$.

2. If 9.1×10^{10} mol/L will dissolve to make a saturated solution of $Sn(OH)_2$, what is its K_{sp}?

Ion Product Constant

- Similar to Q_c
- Determines if a precipitate will form
- Basically: are there enough of each of the ions to saturate the solution?
- Same calculation as K_{sp}, but use concentrations of ions being mixed together

$Q_{sp} \geq K_{sp}$, precipitate will form

$Q_{sp} < K_{sp}$, no precipitate

Example 1: Ion Product

You are mixing two solutions of <u>equal volume</u>: 0.0010 M NaCl and 0.0050 M $Pb(NO_3)_2$. Will a precipitate form?

1. Determine solid produced and net ionic equation.

2. Determine <u>new</u> concentrations of ions.

Example 1: Ion Product (continued)

3. Calculate Q_{sp}.

4. Compare K_{sp} and Q_{sp}.

Example 2: Ion Product

Will a precipitate form if 200.0 mL of 0.00300 M $Ba(NO_3)_2$ solution is mixed with 100.0 mL of 2.00×10^{-6} M K_2SO_4 solution?

DIY Ion Product Constant

Will a precipitate form if 50.0 mL of 4.1×10^{-5} mol/L $AgNO_3$ solution is mixed with 100.0 mL of 0.012 mol/L $NaCrO_4$ solution?