Solubility

Unit: Solutions

MA Curriculum Frameworks (2016): HS-PS2-7(MA)

Mastery Objective(s): (Students will be able to…)

- Use solubility tables/rules to predict whether a solute will dissolve in water.
- Determine the amount of a solute that can dissolve from a solubility curve.

Success Criteria:

- Predictions about dissolution in water are correct.
- Amounts of solute that can dissolve are determined correctly.

Tier 2 Vocabulary: solution, curve

Language Objectives:

- Explain how solutes dissolve in solvents.

Notes:

In class, you saw a demonstration of the reaction between sodium carbonate (Na_2CO_3) and calcium chloride ($CaCl_2$):

$$Na_2CO_3\,(aq) + CaCl_2\,(aq) \rightarrow NaCl\,(aq) + CaCO_3\,(ppt) \quad (1)$$

When the solutions were mixed, the calcium carbonate that was formed immediately precipitated (formed an insoluble solid). Note that once the calcium carbonate is formed, it doesn't redissolve. *I.e.*, reaction (1) happens, but the reverse reaction (2), doesn't:

$$CaCO_3\,(s) + NaCl\,(aq) \not\rightarrow CaCl_2\,(aq) + Na_2CO_3\,(aq) \quad (2)$$

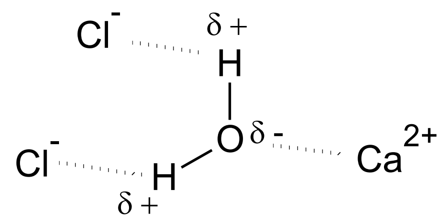
This is because of the way ionic compounds behave when they are dissolved in water.

If an ionic compound dissolves in water, it <u>dissociates</u> (splits) into its ions. In a chemical equation, we write "(aq)" (meaning "aqueous") after an ionic compound to show that it is dissolved, and is floating around in the solution as separate positive and negative ions.

For example, $CaCl_2$ splits into one Ca^{2+} ion and two Cl^- ions. The Ca^{2+} ions are attracted to the negative part of the H_2O molecule (the oxygen atoms), and Cl^- ions are attracted to the positive parts (the hydrogen atoms).

Use this space for summary and/or additional notes:

The combined attraction between the ions and the water molecules is stronger than the attraction between the Ca^{2+} ion and the Cl^{-} ion. The stronger attraction wins, which means the $CaCl_2$ dissolves:



$CaCO_3$, on the other hand, does not dissociate. This must mean that the attraction between the Ca^{2+} ion and the CO_3^{2-} ion is stronger than the combined attraction between the ions and the water molecules. The stronger attraction wins, which means the $CaCO_3$ precipitates.

Note that if you mix the reactants and all of the ions remain in solution, nothing changes. *This means a chemical reaction **did not** occur*.

In other words, *a chemical reaction in an aqueous solution happens **only** if one of the products forms its own distinct phase—either a precipitate, a gas, or a separate liquid phase.*

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Solubility Rules

Solubility rules are rules of thumb that describe which compounds are likely to be soluble in water, and which are not.

Recall that the strength of ion-ion intermolecular forces is given by Coulomb's Law:

$$F = \frac{kq_1q_2}{d^2}$$

I.e., the attraction is proportional to the absolute value of the product of the charges ($|q_1q_2|$ — multiply the charges, and then change the sign so that the result is a positive number) and inversely proportional to the square of the distance between the ions.

It is usually (but not always) true that for the solute:

- if $|q_1q_2| \geq 4$, then the ***ions'*** attraction to each other is usually stronger, and the compound usually precipitates.
- if $|q_1q_2| < 4$, then the ***solvent's*** attraction to the ions is usually stronger, and the compound usually dissolves.

Note that there are several exceptions to both of these rules. Two examples are:

- hydroxides (OH^-) and fluorides (F^-) tend to form precipitates with +2 ions because they are very small ions, so the force of intermolecular attraction (F) is stronger because d^2 is smaller.
- cations (positive ions) of atoms with electronegativities significantly greater than 1 (such as Cu^{+1}, Ag^{+1}, and Pb^{+2}) have a stronger attraction for negative ions, and form precipitates with halogens (Cl^-, Br^-, and I^-).

Use this space for summary and/or additional notes:

The following is a detailed set of solubility rules:

<table>
<tr><th>Ions That Form SOLUBLE Compounds</th><th>EXCEPT with</th><th>Ions That Form INSOLUBLE Compounds</th><th>EXCEPT with</th></tr>
<tr><td>Group 1 ions (Li^+, Na^+, etc.)</td><td rowspan="6"></td><td>carbonate (CO_3^{2-})</td><td rowspan="4">Group 1 ions, NH_4^+</td></tr>
<tr><td>ammonium (NH_4^+)</td><td>chromate (CrO_4^{2-})</td></tr>
<tr><td>nitrate (NO_3^-)</td><td>phosphate (PO_4^{3-})</td></tr>
<tr><td>hydrogen carbonate (HCO_3^-)</td><td>sulfite (SO_3^{2-})</td></tr>
<tr><td>chlorate (ClO_3^-)</td><td rowspan="2">sulfide (S^{2-})</td><td rowspan="2">Group 1 ions, NH_4^+
Group 2 ions</td></tr>
<tr><td>perchlorate (ClO_4^-)</td></tr>
<tr><td>acetate ($C_2H_3O_2^-$ or CH_3COO^-)</td><td>Ag^+</td><td>hydroxide (OH^-)</td><td rowspan="2">Group I ions, NH_4^+, Ba^{2+}, Sr^{2+}, Tl^+</td></tr>
<tr><td>halides (Cl^-, Br^-, I^-)</td><td>Ag^+, Cu^+, Pb^{2+}, Hg_2^{2+}</td><td>oxide (O^{2-})</td></tr>
<tr><td>sulfates (SO_4^{2-})</td><td>Ca^{2+}, Sr^{2+}, Ba^{2+}, Ag^+, Pb^{2+}</td><td></td><td></td></tr>
</table>

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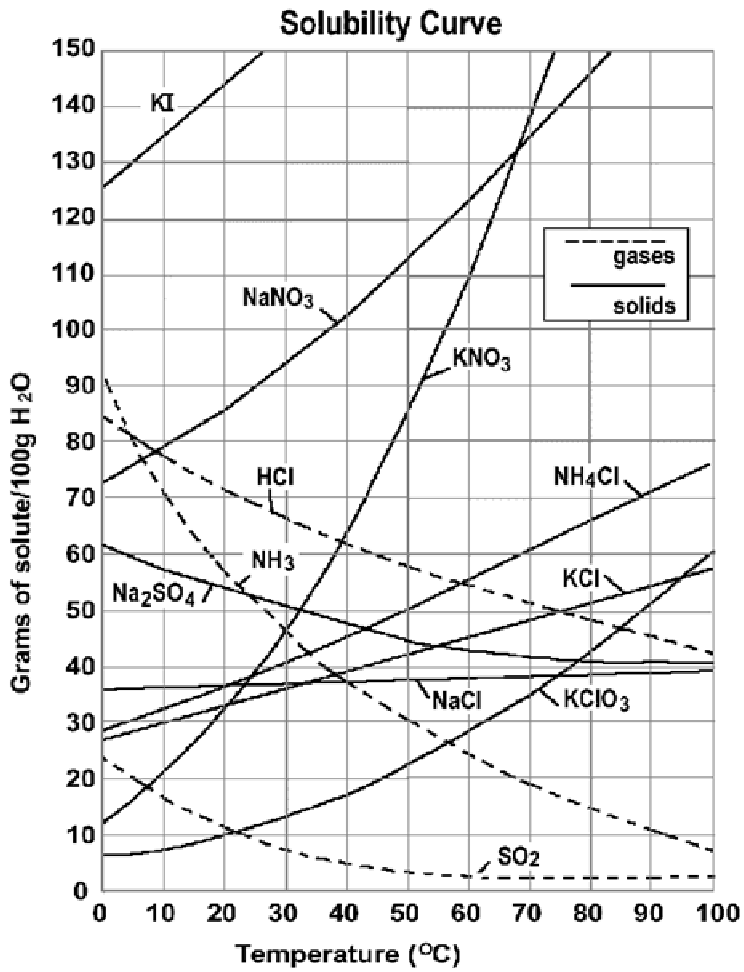
Solubility Curves

solubility curve: a graph that shows the solubility of one or more compounds as a function of the temperature. Solubilities are usually expressed either in moles of solute per liter of solution (molarity) or grams of solute per 100 g of solvent.



Sample Problem:

Q: How much $NaNO_3$ can dissolve in 50 g of water at 70 °C?

A: From the graph on the following page, the solubility of $NaNO_3$ at 70 °C is 135 g $NaNO_3$/100 g H_2O. Using this number as a conversion factor:

$$50\,\text{g H}_2\text{O} \times \frac{135\,\text{g NaNO}_3}{100\,\text{g H}_2\text{O}} = 67.5\,\text{g NaNO}_3$$

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Homework Problems

For these problems, you will need to use the solubility curves in "Figure I. Solubilities of Selected Compounds" on page 511 of your Chemistry Reference Tables.

1. How much ammonium chloride could you dissolve in 100 g of water at 70 °C?

   Answer: about 61 g NH_4Cl

2. How much HCl could you dissolve in 25 g of water at 45 °C?

   Answer: 15 g HCl

3. If you made a saturated solution of ammonia in 40. g of water at 50. °C, how many grams of ammonia would it contain?

   Answer: 12 g NH_3

4. You want to dissolve 0.75 mol of KCl (F.W. = $74.55\,\frac{g}{mol}$) in 150. mL of water. What is the minimum temperature to which you would have to heat the water to dissolve all of the KCl?

   Answer: 34 °C

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5. You have a solution that contains 43 g of an unknown compound dissolved in 100. g of H_2O at a temperature of 55 °C. The unknown compound could be either KCl, Na_2SO_4, KNO_3, or $NaNO_3$. Describe how you could perform a series of heating or cooling experiments and use a solubility chart to identify the solute in the unknown solution.

6. If you had 95 g of a saturated solution of sodium nitrate at room temperature (25 °C) and you cooled it to 10. °C, how much precipitate would form?
(*Note: the* 95 g *of solution includes both the* $NaNO_3$ *and the water.*)

Answer: 6 g

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