SOLUTIONS

Homogeneous mixture — uniformly mixed on the molecular level

Solvent & Solute

we will focus on aqueous solutions
SOLUTE-SOLVENT INTERACTIONS

Why do solutions form?
Processes occur spontaneously when:
A. Energy is released (exothermic)
B. Disorder increases (entropy increases)

These are linked – sometimes an endothermic process will occur because increase in entropy is large enough.

SOLUTION PROCESSES

ENERGY CONSUMED
1. solute-solute intermolecular attraction broken
2. solvent-solvent intermolecular attraction broken

ENERGY RELEASED
1. solute-solvent intermolecular attractions formed
SOLUTION PROCESSES

$\Delta H_1$: separation of solute molecules

$\Delta H_2$: separation of solvent molecules

$\Delta H_3$: formation of solute-solvent interactions

$\Delta H_3 + \Delta H_2 + \Delta H_1 = \Delta H_{\text{soln}}$

$\Delta H_{\text{soln}}$ not always negative (exothermic)
example: $\text{NH}_4\text{NO}_3$ in water demo

But entropy change (increased disorder) may make process happen
DISSOLVING AN IONIC SOLUTE

NaCl(s) + H₂O → Na⁺(aq) + Cl⁻(aq)

ion-ion

dipole-dipole

H-bond

ion-dipole interactions in solution

Polarity of water determines its interaction with ions
OIL & WATER

Observations:
Water beads on oil
Oil spreads on water

✓ water-water interactions are stronger than water-oil interactions

✓ oil-oil interactions are weaker than oil-water interaction
SOLUBILITY
GENERALIZATION

LIKE DISSOLVES LIKE

- polar solvents dissolve polar (and ionic) solutes
- non-polar solvents dissolve non-polar solutes

Consider the intermolecular forces broken and those formed. If they are the same, then dissolution is probable.

<table>
<thead>
<tr>
<th>EXAMPLES</th>
<th>SOLUBLE?</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl in H\textsubscript{2}O</td>
<td></td>
</tr>
<tr>
<td>KCl in hexane</td>
<td></td>
</tr>
<tr>
<td>Sugar C\textsubscript{12}H\textsubscript{22}O\textsubscript{11} in H\textsubscript{2}O</td>
<td></td>
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<tr>
<td>Metal Ni in H\textsubscript{2}O</td>
<td></td>
</tr>
</tbody>
</table>
LIKE DISSOLVES LIKE

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Solubility in Water @ 25°C (g/100 g of Water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃OH</td>
<td>total</td>
</tr>
<tr>
<td>CH₃CH₂OH</td>
<td>total</td>
</tr>
<tr>
<td>CH₃CH₂CH₂OH</td>
<td>total</td>
</tr>
<tr>
<td>CH₃(CH₂)₃OH</td>
<td>8.06</td>
</tr>
<tr>
<td>CH₃(CH₂)₄OH</td>
<td>2.82</td>
</tr>
<tr>
<td>CH₃(CH₂)₅OH</td>
<td>0.62</td>
</tr>
</tbody>
</table>

As the length of the hydrocarbon chain increases, the solubility of the alcohol in water decreases.

Structure determines properties
EXPRESSING CONCENTRATION

weight percent = \( \frac{\text{mass component}}{\text{total mass}} \times 100 \) (\%)

mole fraction of component = \( \frac{\text{moles component}}{\text{total moles}} \) (fraction)

molarity = \( \frac{\text{moles solute}}{\text{liters solution}} \) (M)

molality = \( \frac{\text{moles solute}}{\text{mass solvent (kg)}} \) (m)
Example Problems

Calculate the molarity of Na\(^+\) ions in a solution made by mixing 150 mL of a 0.250 \(M\) solution of Na\(_2\)SO\(_4\) with 350 mL of a 0.150 \(M\) NaCl solution.

How many moles of KMnO\(_4\) are present in 250 g of a 0.0475 \(m\) solution?

What mass of KMnO\(_4\) would be present in a solution prepared by diluting 125 g of the 0.0475 \(m\) KMnO\(_4\) solution to a final volume of 1.0 L?
Example Problems

How many milliliters of an 11.6 \( M \) HCl solution are needed to prepare 250 mL of a 0.125 \( M \) HCl solution?

Blood alcohol content (BAC) is given in units of grams of ethanol per 100 mL of blood. The average adult male has 5.0 L of blood. If Joe Brewski drinks a few beers and has a BAC of 0.10, what mass of ethanol is circulating in his blood?
ELECTROLYTES

A substance that yields ions when dissolved in water is an *electrolyte*

Strong electrolytes
  completely ionized in solution
  good conductors
Weak electrolytes
  partially ionized in solution
  poor conductors
Nonelectrolytes
  not ionized in solution
  non-conductors
STRONG & WEAK ELECTROLYTES

STRONG

\[ \text{NaCl(s) + H}_2\text{O} \rightarrow \text{Na}^+(aq) + \text{Cl}^-(aq) + \text{H}_2\text{O} \]

salt completely ionized

\[ \text{HCl(aq) + H}_2\text{O} \rightarrow \text{H}_3\text{O}^+(aq) + \text{Cl}^-(aq) \]

complete ionization of strong acid

WEAK

\[ \text{NH}_3(aq) + \text{H}_2\text{O} \leftrightharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq) \]

partial ionization of weak base or weak acid

\[ \text{HC}_2\text{H}_3\text{O}_2(aq) + \text{H}_2\text{O} \leftrightharpoons \text{H}_3\text{O}^+(aq) + \text{C}_2\text{H}_3\text{O}_2^-(aq) \]

NON

\[ \text{C}_6\text{H}_{12}\text{O}_6(s) + \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(aq) + \text{H}_2\text{O} \]

glucose no ionization
Flowchart for identifying electrolytes

- **Water soluble compound**
  - Ionic
    - Strong electrolyte
  - Molecular
    - Acid??
      - Yes
        - Strong acid??
          - Yes
            - Strong electrolyte
          - No
            - Weak electrolyte
      - No
        - Molecular base?? (e.g., NH₃)
          - Yes
            - Weak electrolyte
          - No
            - Non-electrolyte

**Note:** Ionic compounds are strong electrolytes but they could be insoluble(!!!)

- **Memorize strong acids and bases** (BLB Table 4.2); If a compound is an acid or a base, but NOT one of the strong acids or bases, then it **MUST** be a weak electrolyte

- **Common misconception:** Electrolytes are ionic compounds: this is **NOT TRUE** (e.g., HCl)
Electrolytes (con’t.)

• strong or weak electrolytes are **NOT** determined by *how much* of a compound goes into solution

• rather, strong or weak electrolytes **ARE** determined by *what the compound does* once it is in solution!

*examples:*

CH$_3$COOH: very soluble in water **but** weak *electrolyte* (**partially ionizes**)

Ba(OH)$_2$: very slightly soluble in water **but** **strong electrolyte** (**completely ionizes**) once it gets into solution
Examples of water soluble compounds

Are these strong, weak or non-electrolytes?

HCl  electrolyte
NaCl  electrolyte
CH₃OH  electrolyte
CH₃COOH  electrolyte
  (acetic acid)
NH₃  electrolyte
Fe(NO₃)₂  electrolyte
Ca(OH)₂  electrolyte
AQUEOUS SOLUBILITY OF IONIC COMPOUNDS

The ions comprising an ionic compound determine its solubility

Simplified Rules:

(1) Almost all ammonium and alkali metal salts are soluble
(2) Most nitrates, acetates, chlorides, bromides, iodides, and sulfates are soluble. Important exceptions are silver halides, Ca, Ba, Pb sulfates.
(3) Most sulfides, carbonates, phosphates, and hydroxides are insoluble. Important exceptions are the alkali and ammonium salts.
**SATURATION**

many substances are partially soluble

\[
\begin{align*}
30 \text{ g NaCl} & \quad 100 \text{ mL } \text{H}_2\text{O} & \text{unsaturated soln} \quad 100 \text{ mL } \text{H}_2\text{O} & \text{&} \quad 30 \text{ g NaCl} \\
40 \text{ g NaCl} & \quad 100 \text{ mL } \text{H}_2\text{O} & \text{saturated soln} \quad 100 \text{ mL } \text{H}_2\text{O} & \text{&} \quad 36 \text{ g NaCl} \\
& & & (4 \text{ g NaCl undissolved})
\end{align*}
\]

\[
\text{NaCl}(s) \rightleftharpoons \text{Na}^+(aq) + \text{Cl}^-(aq)
\]
When the rates of 2 processes are equal, then **dynamic equilibrium**

Saturated solution: max conc of solute under the given conditions **solubility**

Supersaturated solution: more than the max conc of solute – above the equm amount
FACTORS THAT AFFECT SOLUBILITY

molecules just like to mix, if they can

ENTROPY!

IMPORTANT FACTORS INCLUDE

• type of intermolecular interactions involved and their strengths (like dissolves like)

• temperature

• pressure
PRESSURE EFFECT ON GAS SOLUBILITY

Dynamic equm: rate of escape equals rate of solubilization

Equum is disturbed by incr P
rate into soln > rate out of soln

After some time, equm is reestablished at new concs

Henry’s Law

\[ C_g = k P_g \]

\( C_g \) solubility of gas in soln
\( P_g \) pressure of gas over solution

Gas dissolved \( \propto \) partial pressure of that gas
TEMPERATURE EFFECT ON GAS SOLUBILITY

As $T$ increases, more molecules have sufficient energy to escape liquid. So gases less soluble in warmer solute. More oxygen for fish in cold $H_2O$.

TEMPERATURE EFFECT ON SALT SOLUBILITY

Solubility rises as $T$ rises, usually:

$$KCl(s) + H_2O + \text{heat} \rightleftharpoons KCl(aq)$$

endothermic
GAS SOLUBILITY

SALT SOLUBILITY
NH$_3$ gas

H$_2$O with dissolved NH$_3$

H$_2$O moves up tube

H$_2$O and phenolphthalein

As the NH$_3$ dissolves in the water, the pressure falls and more H$_2$O is brought up.

Phenolphthalein is **pink in base**
What ions are present upon dissolving each of the following substances in water.

MgI₂

HOCH₂CH₂OH

Al(NO₃)₃

NH₄Cl

The correct formula for ammonium carbonate is

A. (NH₄)₂CO₃
B. NH₄CO₂
C. (NH₃)₂CO₄
D. NH₄CO₃
E. N₂(CO₃)₃
Pure acetic acid (C$_2$H$_3$OOH), known as glacial acetic acid, is a liquid with a density of 1.049 g/mL at 25°C. Calculated the molarity of a solution of acetic acid made by dissolving 20.00 mL of glacial acetic acid in enough water to make 250.0 mL of solution.
What is the final concentration of sodium ion if 40.0 mL of 0.13 M sodium chloride is mixed with 40.0 mL of 0.13 M sodium carbonate?
Concentrated nitric acid is 71% by mass. (a) What is the molarity of this solution? (b) What is the mole fraction of nitric acid in this solution? The density is 1.42 g/mL.
Example
A What is the molality of KBr in a solution made by dissolving 2.21 g of KBr in 897 g of water?
B What is the molality of “particles”? C what is the molarity of KBr? Density = 1.1 g/mL