Solutions: An Introduction

David A. Katz
Department of Chemistry
Pima Community College
A solution is a HOMOGENEOUS mixture of 2 or more substances in a single phase.

One constituent is usually regarded as the SOLVENT (usually water) and the others as SOLUTES.
Solutions

- In a solution, the solute is dispersed uniformly throughout the solvent.

<table>
<thead>
<tr>
<th>State of Solution</th>
<th>State of Solvent</th>
<th>State of Solute</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>Gas</td>
<td>Gas</td>
<td>Air</td>
</tr>
<tr>
<td>Liquid</td>
<td>Liquid</td>
<td>Gas</td>
<td>Oxygen in water</td>
</tr>
<tr>
<td>Liquid</td>
<td>Liquid</td>
<td>Liquid</td>
<td>Alcohol in water</td>
</tr>
<tr>
<td>Liquid</td>
<td>Liquid</td>
<td>Solid</td>
<td>Salt in water</td>
</tr>
<tr>
<td>Solid</td>
<td>Solid</td>
<td>Gas</td>
<td>Hydrogen in palladium</td>
</tr>
<tr>
<td>Solid</td>
<td>Solid</td>
<td>Liquid</td>
<td>Mercury in silver</td>
</tr>
<tr>
<td>Solid</td>
<td>Solid</td>
<td>Solid</td>
<td>Silver in gold</td>
</tr>
</tbody>
</table>
Solutions: Gases mixed with gases

Dry Air Expressed in Volumes

<table>
<thead>
<tr>
<th>Gas</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen ($N_2$)</td>
<td>78.1%</td>
</tr>
<tr>
<td>Oxygen ($O_2$)</td>
<td>20.9%</td>
</tr>
<tr>
<td>Argon (Ar)</td>
<td>0.9%</td>
</tr>
<tr>
<td>Carbon dioxide (CO$_2$)</td>
<td>0.035%</td>
</tr>
<tr>
<td>Others</td>
<td>0.065%</td>
</tr>
</tbody>
</table>

Others:
- Neon (Ne)
- Helium (He)
- Krypton (Kr)
- Hydrogen (H$_2$)
- Xenon (Xe)
- Ozone (O$_3$)
- Radon (Rn)
Solutions:
Gas mixed with liquid
Solutions: Liquid mixed with liquid
Solutions:
Solid mixed with liquid
Solutions:
Gas mixed with solid
Photomicrographs of Hydrogen on palladium
Solutions:
Liquid mixed with solid
(a mercury amalgam with gold)
Solutions:
Solid mixed with solid (alloys)

Brass: a substitution alloy
Carbon steel: an interstitial alloy
Intermolecular Forces

Why does a substance dissolve?

The intermolecular forces between solute and solvent particles must be strong enough to compete with those between solute particles and those between solvent particles.
How Does a Solution Form?

In this example, we have an ionic solid, NaCl, and a polar solvent, H₂O.

The solution forms because the solvent pulls solute particles apart and surrounds, or solvates, them. In water this is called hydration.

Solute (NaCl) in water  The solute is dissolving  Hydrated ions in solution
Solutions

- Just because a substance disappears when it comes in contact with a solvent, it doesn’t mean the substance dissolved.
- Dissolution is a physical change — you can get back the original solute by evaporating the solvent.
- If you can’t, the substance didn’t dissolve, it reacted.
Water as a Solvent

• How water dissolves molecular compounds:
  – When the nonpolar part of an organic molecule is considerably larger than the polar part, the molecule no longer dissolves in water.

  For example ethanol, \( \text{CH}_3\text{CH}_2\text{OH} \) is soluble in water but butanol \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \) is not
Factors Affecting Solubility

- Chemists use the axiom "like dissolves like":
  - Polar and ionic substances tend to dissolve in polar solvents.
  - Nonpolar substances tend to dissolve in nonpolar solvents.

### TABLE 13.3 Solubilities of Some Alcohols in Water and in Hexane*

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Solubility in H₂O</th>
<th>Solubility in C₆H₁₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃OH (methanol)</td>
<td>∞</td>
<td>0.12</td>
</tr>
<tr>
<td>CH₃CH₂OH (ethanol)</td>
<td>∞</td>
<td>∞</td>
</tr>
<tr>
<td>CH₃CH₂CH₂OH (propanol)</td>
<td>∞</td>
<td>∞</td>
</tr>
<tr>
<td>CH₃CH₂CH₂CH₂OH (butanol)</td>
<td>0.11</td>
<td>∞</td>
</tr>
<tr>
<td>CH₃CH₂CH₂CH₂CH₂OH (pentanol)</td>
<td>0.030</td>
<td>∞</td>
</tr>
<tr>
<td>CH₃CH₂CH₂CH₂CH₂CH₂OH (hexanol)</td>
<td>0.0058</td>
<td>∞</td>
</tr>
<tr>
<td>CH₃CH₂CH₂CH₂CH₂CH₂CH₂OH (heptanol)</td>
<td>0.0008</td>
<td>∞</td>
</tr>
</tbody>
</table>

*Expressed in mol alcohol/100 g solvent at 20°C. The infinity symbol indicates that the alcohol is completely miscible with the solvent.
Types of Solutions

Saturated

Solvent holds as much solute as is possible at that temperature.

To insure saturation, a small amount of solute remains undissolved on the bottom of the container.

Dissolved solute is in dynamic equilibrium with solid solute particles.
Types of Solutions

• Unsaturated

  ➢ Less than the maximum amount of solute for that temperature is dissolved in the solvent.
  ➢ The amount of solute in the solution can vary from a small amount to almost saturated.
Types of Solutions

• Supersaturated

- Solvent holds more solute than is normally possible at that temperature.
- These solutions are unstable; crystallization can usually be stimulated by adding a “seed crystal” or scratching the side of the flask.
Gases in Solution

• In general, the solubility of gases in water increases with increasing mass.
• Larger molecules have stronger dispersion forces.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Solubility (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>$0.69 \times 10^{-3}$</td>
</tr>
<tr>
<td>CO</td>
<td>$1.04 \times 10^{-3}$</td>
</tr>
<tr>
<td>O₂</td>
<td>$1.38 \times 10^{-3}$</td>
</tr>
<tr>
<td>Ar</td>
<td>$1.50 \times 10^{-3}$</td>
</tr>
<tr>
<td>Kr</td>
<td>$2.79 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
Gases in Solution

- The solubility of liquids and solids does not change appreciably with pressure.
- The solubility of a gas in a liquid is directly proportional to its pressure in contact with the liquid.
Generally, the solubility of solid solutes in liquid solvents increases with increasing temperature.
Temperature

- The opposite is true of gases:
  - Carbonated soft drinks are more “bubbly” if stored in the refrigerator.
  - Warm lakes have less O$_2$ dissolved in them than cool lakes.
Expressing Concentrations of Solutions
Percent, %

Can be expressed as:

Percent by mass, \(\%_{(m/m)}\)

Percent by volume, \(\%_{(v/v)}\) for solutions of liquids

Percent mass-volume, \(\%_{(m/v)}\) for solids in liquids

\[
\% \text{ of } A = \frac{\text{amount of A in solution}}{\text{total amount of solution}} \times 100
\]

Most commonly, we use percent by mass
Parts per Million and Parts per Billion

Parts per Million (ppm)

\[ \text{ppm} = \frac{\text{mass of A in solution}}{\text{total mass of solution}} \times 10^6 \]

Parts per Billion (ppb)

\[ \text{ppb} = \frac{\text{mass of A in solution}}{\text{total mass of solution}} \times 10^9 \]
Molarity ($M$)

$$M = \frac{\text{mol of solute}}{\text{L of solution}}$$

An alternate equation is

$$M = \frac{g_{\text{solute}} \times 1000 \, \text{mL/L}}{MW_{\text{solute}} \times mL_{\text{solution}}}$$

- Note: Because volume is temperature dependent, Molarity can change with temperature.
Electrolytes

**Strong electrolyte**: a compound that dissociates completely to ions in an aqueous solution.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Dissociates to</th>
<th>No. of ions per formula unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>Na(^+) and Cl(^-)</td>
<td>2</td>
</tr>
<tr>
<td>CaCl(_2)</td>
<td>Ca(^{2+}) and 2 Cl(^-)</td>
<td>3</td>
</tr>
<tr>
<td>K(_2)SO(_4)</td>
<td>2 K(^+) and SO(_4^{2-})</td>
<td>3</td>
</tr>
<tr>
<td>Mg(_3)(PO(_4))(_2)</td>
<td>3 Mg(^{2+}) and 2 PO(_4^{3-})</td>
<td>5</td>
</tr>
</tbody>
</table>

Ionic substances dissociate into the ions and polyatomic ions used in writing the chemical formulas of the compounds.

**Weak electrolyte**: a compound that only partially dissociates to ions in an aqueous solution.

An example is acetic acid, H\(_2\)C\(_2\)H\(_3\)O\(_2\), which exists as H\(_2\)C\(_2\)H\(_3\)O\(_2\) molecules, H\(^+\) and C\(_2\)H\(_3\)O\(_2^{2-}\) in water solution.