Chapter 12: Solutions

Solutions may exist in three states of matter; gases, liquids and solids.

Components of a solution:

Solute is the gas or solid dissolved into a liquid, the solute is the component in smaller amount.

Solvent is the liquid or the component in greater amount.

Miscible fluids - fluids that mix with or dissolve in each other in all proportions

Solubility is the amount of a substance that dissolves in a given quantity of water at a given temperature.

\[
\begin{align*}
\text{H}_2\text{O} \\
\text{NaCl(s)} & \rightleftharpoons \text{Na}^{+\text{(aq)}} + \text{Cl}^{-}
\end{align*}
\]

Saturated solution is a solution that is in equilibrium with respect to a given dissolved substance.

Unsaturated solution is a solution not in equilibrium with respect to a given dissolved substance and in which more of that substance can dissolve.

Supersaturated solution contains more dissolved substance that a saturated solution does.

"Like dissolves like"

Solubility can be explained by two factors:

1. The natural tendencies towards disorder.

2. Relative forces of attraction.

Molecular solutions vs Ionic solutions
Effects of Temperature on Solubility

Effects of Pressure Change on Solubility

In general, pressure change has little effect on the solubility of a liquid or solid in water, but the solubility of a gas is very much affected by pressure, which can be predicted from:

Le Châtelier's principle

When a system in equilibrium is disturbed by a change of temperature, pressure or concentration variable, the system shifts in equilibrium composition in a way that tends to counteract this change in variable.

\[ \text{CO}_2(g) \rightleftharpoons \text{CO}_2(aq) \]

All gases become more soluble in a liquid at a given temperature when the partial pressure of the gas over the solution is increased.
Henry's Law - states the solubility of a gas is directly proportional to the partial pressure of the gas above the solution.

\[ S = k_H P \]

Where

- \( S \) is the solubility of the gas
- \( k_H \) is Henry's Law constant for the gas for a particular liquid at a given temperature
- \( P \) is the partial pressure of the gas

Example:

27 grams of acetylene, \( \text{C}_2\text{H}_2 \), dissolves in 1L of acetone at 1.0 atm pressure. If the partial pressure of the acetylene is increased to 12 atm, what is its solubility in acetone?

Colligative Properties of a solution are properties that depend on the concentration of solute molecules or ions in solution but not on the chemical identity of the solute. 

Molarity = \( \frac{\text{(moles of solute)}}{\text{(L of solution)}} \)

Mass % of Solute - the % by mass of the solute contained in a solution.

\[
\text{Mass \% of Solute} = \left( \frac{\text{(mass of solute)}}{\text{(mass of solution)}} \right) \times 100 
\]

Example: An experiment asks for 35.0 g of \( \text{HCl}_{(aq)} \) that is 20.2 % \( \text{HCl} \) by mass. How many grams of \( \text{HCl} \) is this? How many grams of water?
**Molality** is the moles of solute per kilogram of solvent

Molality = (moles of solute) / (kg of solvent)

Example:

Toluene, C₆H₅CH₃, is a liquid compound similar to benzene, C₆H₆. It is the starting material for other substances, including trinitrotoluene. Find the molality of toluene in a solution that contains 35.6 g of toluene and 125 g of benzene.

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The **mole fraction** of a component substance A (X_A) in a solution is defined as the moles of component substance divided by the total moles of the solution.

\[ X_A = \frac{\text{moles of substance A}}{\text{total moles of solution}} \]

Example: What are the mole fractions of glucose and water in a solution containing 5.67 g of glucose, C₆H₁₂O₆, dissolved in 25.2 g of water?
Vapor Pressure of a Solution

Vapor pressure of a volatile solvent is lowered by addition of a nonvolatile solute, this is called vapor - pressure lowering, a colligative property.

**Vapor pressure lowering =**

(\text{the vapor pressure of the pure solvent}) - (\text{the vapor pressure of the solution})

Francois Raoult observed that the partial vapor pressure of solvent over a solution of a nonelectrolyte solute depends on the mole fraction of solvent in the solution.

**Raoult's Law** states that partial pressure of solvent $P_A$, over a solution equals the vapor pressure of the pure solvent $P_A^\circ$ times the mole fraction of solvent $X_A$, in the solution.

$$P_A = P_A^\circ X_A$$

If the solute is nonvolatile, $P_A$, is the total vapor pressure of the solution.

Example: Calculate the vapor pressure lowering of water when 5.67 g of glucose, $C_6H_{12}O_6$, is dissolved in 25.2g of water at 25°C. The vapor pressure of water at 25°C is 23.8 mmHg. What is the vapor pressure of the solution?

Suppose you need to boil a water based solution at a temperature lower than a 100°C. What kind of liquid could you add to the water to make this happen?
Another colligative property, **boiling point elevation**, \( \Delta T_b = \)

\[
\frac{\text{the boiling point of the solution}}{\text{the boiling point of the pure solvent}}
\]

\[\Delta T_b = K_b c_m\]

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Formula</th>
<th>Boiling Point (°C)</th>
<th>Freezing Point (°C)</th>
<th>(K_b) (°C/m)</th>
<th>(K_f) (°C/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>HC(_2)H(_5)O(_2)</td>
<td>118.5</td>
<td>16.60</td>
<td>3.08</td>
<td>3.59</td>
</tr>
<tr>
<td>Benzene</td>
<td>C(_6)H(_6)</td>
<td>80.2</td>
<td>5.455</td>
<td>2.61</td>
<td>5.065</td>
</tr>
<tr>
<td>Camphor</td>
<td>C(<em>{10})H(</em>{16})O</td>
<td>—</td>
<td>179.5</td>
<td>—</td>
<td>40</td>
</tr>
<tr>
<td>Carbon disulfide</td>
<td>CS(_2)</td>
<td>46.3</td>
<td>—</td>
<td>2.40</td>
<td>—</td>
</tr>
<tr>
<td>Cyclohexane</td>
<td>C(<em>6)H(</em>{12})</td>
<td>80.74</td>
<td>6.55</td>
<td>2.79</td>
<td>20.0</td>
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<tr>
<td>Ethanol</td>
<td>C(_2)H(_5)OH</td>
<td>78.3</td>
<td>—</td>
<td>1.07</td>
<td>—</td>
</tr>
<tr>
<td>Water</td>
<td>H(_2)O</td>
<td>100.000</td>
<td>0.000</td>
<td>0.512</td>
<td>1.858</td>
</tr>
</tbody>
</table>


**Freezing point depression** =

\[
\Delta T_f = K_f c_m
\]

Example: How many grams of ethylene glycol, CH\(_2\)OHCH\(_2\)OH, must be added to 37.8 grams of water to give a freezing point of -0.150°C ?

Colligative properties are also used to obtain molecular masses.

Example: A solution is prepared by dissolving 0.131 g of a substance in 25.4 g of water. The molality of the solution is determined by freezing point depression to be 0.056 m. What is the molecular mass of the substance?
Osmosis

The phenomenon of solvent flow through a semi-permeable membrane to equalize the solute concentrations on both sides of the membrane.

A concentrated glucose solution is placed in an inverted funnel whose mouth is sealed with a semipermeable membrane. The funnel is then placed in a beaker of pure water. As water flows from the beaker through the membrane into the funnel, the liquid level rises in the stem of the funnel. The glucose solution continues to rise up the funnel stem until the downward pressure exerted by the solution above the membrane stops the upward flow of the solvent (water).

Osmotic pressure (\(\pi\)), a colligative property of a solution, is equal to the pressure that, when applied to the solution, just stops osmosis.

\[ \pi = \text{MRT} \]

where \( R \) = the gas constant, \( T \) = absolute temperature \( M \) = molar concentration

Example: The formula for low molecular mass starch (\(\text{C}_6\text{H}_{10}\text{O}_5\))\(_n\), where \( n \) averages \( 2.00 \times 10^2 \). When 0.798 g of starch is dissolved in 100.0 mL of water solution, what is the osmotic pressure, in mmHg, at 25ºC?
Colligative Properties of Ionic Solutions

Concentration of ions in solutions must be considered rather than the concentration of the ionic solution.

For a freezing point lowering the equation then becomes

\[ \Delta T_f = i \ K_f \ c_m \]

where \( i \) = the number of ions resulting from each formula unit

\( c_m \) is the molality computed on the basis of the formula of the ionic compound

The value of \( i = \Delta T_f / K_f c_m \) is called the van Hoff factor, where the salt is ionized completely in solution but that the activities, or effective concentration of the ions are less than their actual concentrations as a result of electrical interactions of the ions in solution.

A **Colloid** is a dispersion of particles of one substance (the dispersed phase) throughout another substance or solution (the continuous phase).

A Colloidal solution can be distinguished from a true solution by its ability to scatter light, known as the Tynsdlall effect.

Colloids in which the continuous phase is water can be divided into two major classes:

- Hydrophilic colloid
- Hydrophobic colloid
Micelle is a colloidal-sized particle formed in water by the association of molecules or ions that each have a hydrophobic end and a hydrophilic end.

Iron (III) hydroxide solution can be made to aggregate by the addition of an ionic solution, particularly if the solution contains anions with multiple charges. **Coagulation** is the process by which the dispersed phase of a colloid is made to aggregate and thereby separate from the continuous phase.

The greater the magnitude of the negative charge, the more compact is the layer of the charge. If the ion layer is gathered close to the colloidal particle, the overall charge is effectively neutralized.