**SOLUTIONS**

CHEM 1212K / Chapter 11

**Solutions** are homogenous mixtures of two or more substances. A solution contains one or more solutes dissolved in a solvent. If the solvent is water, it is an aqueous solution.

**DISSOLUTION & SOLUBILITY**

A solution is formed by the dissolution of a solute(s) in a solvent. The dissolution process is favored when there is a decrease in energy (exothermic) and an increase in the disorder or randomness (entropy) of the system. The heat of solution, $\Delta H_{sol}$, is the change in energy during dissolution. An ideal solution is formed if $\Delta H_{sol} = 0$.

Intermolecular forces are responsible for dissolution. First, intermolecular forces between solute particles must be overcome by absorption of energy (endothermic) to dissolve the solute. Next, intermolecular forces between solvent particles must also be overcome by absorption of energy (endothermic). Lastly, solute and solvent particles mix to form a solution and release energy (exothermic). The formation of solutions is favored when the process is exothermic, however there are instances in which solutions will form endothermically. In solutions formed by endothermic dissolution there is a large increase in disorder that overcomes the endothermicity.

Often the formation of a solution involves the dissolution of a solid solute in liquid solvent. However, liquids and gases can also be solutes. Miscibility is the ability of liquids to dissolve in other liquids. Gases capable of hydrogen bonding and ionization dissolve in water. The solubility of compounds generally follows the rule “like dissolves like”. Polar solvents dissolve polar solutes, and nonpolar solvents dissolve nonpolar solutes.

**CHARACTERISTICS OF SOLUTIONS**

The **molality**, $m$, is the concentration of a solution expressed as the number of moles of solute per kilogram of solvent.

$$\text{molality} = \frac{\text{moles solute}}{\text{kilograms solvent}}$$

The **mole fraction** of a solution component is the ratio of its moles to the total number of moles of all components in the solution.

$$X_a = \frac{n_A}{n_{\text{total}}}$$

**Nonelectrolytes** are solutions composed of covalent solutes that do not ionize or dissociate. Ionic compounds dissociate 100% in aqueous solution to produce ions, a solution known as an **electrolyte**. Therefore, electrolytes produce more particles in solution than nonelectrolytes. The extent of ionization or dissociation of an electrolyte in water is called the **van’t Hoff factor**, $i$. Since nonelectrolytes do not ionize or dissociate, their van’t Hoff factors $= 1$. Electrolytes such as sodium chloride dissociate in aqueous solution producing a 1:1 ratio of sodium to chloride ions. One mole of sodium chloride dissociates into two moles of particles, so the van’t Hoff factor $= 2$.

The van’t Hoff factor can be found by determining the number of ions that are produced by dissociation of an ionic compound. Alternatively, it can also be calculated using equations introduced below for specific colligative properties.
The van’t Hoff factor multiplied by the molality of a solution is referred to as the **effective molality**, which affects colligative properties of solutions.

### COLLIGATIVE PROPERTIES

**Colligative properties** of solutions depend on the number of solute particles in solution, not the kind of solute. Four colligative properties are discussed below.

#### Vapor Pressure Lowering
The vapor pressure of a solution is lower than the vapor pressure of the pure solvent. Vapor pressure lowering is dependent on the number of particles in solution. Solutions that obey the following relationship are called ideal solutions (no net energy change), and are made with non-volatile solutes. Non-volatile solutes stay in solution; only the vapor of the solvent is above the solution.

$$ P_{\text{solution}} = X_{\text{solvent}} P^0_{\text{solvent}} $$

- $P_{\text{solution}}$ = vapor pressure of solution
- $X_{\text{solvent}}$ = mole fraction of solvent
- $P^0_{\text{solvent}}$ = vapor pressure of pure solvent

Ideal solutions made of volatile components behave differently than those containing non-volatile solutes. Volatile solutes are present in the vapor above the solution, so each component of the solution contributes to the lowering of the vapor pressure. The vapor pressure of volatile solutions is calculated using Raoult’s Law and Dalton’s Law of Partial Pressures.

$$ P_{\text{solution}} = X_A P^0_A + X_B P^0_B $$

#### Freezing Point Depression
The freezing point of a solution is lower than the freezing point of the pure solvent. The new freezing point of a solution is found by subtracting $\Delta T_f$ from the freezing point of the pure solvent. Freezing point depression of a solvent is proportional to the number of particles in solution.

$$ \Delta T_f = i K_f m $$

- $\Delta T_f$ = freezing point depression (°C)
- $i$ = van’t Hoff factor
- $K_f$ = freezing point depression constant or cryoscopic constant (°C/m)
- $m$ = molality (mol/kg)

#### Boiling Point Elevation
The boiling point of a solution is higher than the boiling point of the pure solvent. The new boiling point of a solution is found by adding $\Delta T_b$ to the boiling point of the pure solvent. Boiling point elevation of a solvent is proportional to the number of particles in solution.

$$ \Delta T_b = i K_b m $$

- $\Delta T_b$ = boiling point elevation (°C)
- $i$ = van’t Hoff factor
\( K_f \) = boiling point elevation constant or ebullioscopic constant (°C/m)
\( m \) = molality (mol/kg)

**Osmotic Pressure**

Osmotic pressure is the minimum pressure required to prevent the movement of a pure solvent across a semipermeable membrane into a solution.

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\pi = iMRT
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\( \pi \) = osmotic pressure (atm)
\( i \) = van’t Hoff factor
\( M \) = molarity (mol/L)
\( R \) = gas constant, 0.08206 L atm/mol K
\( T \) = temperature (K)