Chapter 12.4
Colligative Properties of Solutions

Objectives

- List and define the colligative properties of solutions.
- Relate the values of colligative properties to the concentrations of solutions.
- Calculate the molar masses of solutes from measurements of colligative properties.
**Colligative property**: Any property of a solution that changes in proportion to the concentration of nonvolatile solute added to the solution.

- The identity of the particle has no influence on colligative property.
Adding a nonvolatile solute to a pure solvent causes:

higher boiling point
lower vapor pressure
lower freezing point
osmotic pressure
Boiling Point Elevation

**Adding a nonvolatile solute to a pure solvent causes:**

- higher boiling point
- lower vapor pressure
- lower freezing point
- osmotic pressure

\[ \Delta T = +k_b m_{\text{solute}} \]
Boiling Point Elevation

- The relationship between change in boiling point and solute concentration:
  - \( \Delta T_b = m k_b \) where \( m \) is the molal concentration of particles and \( k_b \) is the boiling point constant for the solvent

<table>
<thead>
<tr>
<th>Solvent</th>
<th>B.P. (°C)</th>
<th>( k_b ) (°C/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>117.90</td>
<td>3.07</td>
</tr>
<tr>
<td>Benzene</td>
<td>80.10</td>
<td>2.53</td>
</tr>
<tr>
<td>Water</td>
<td>100.00</td>
<td>0.512</td>
</tr>
</tbody>
</table>
In Class Example

Find the molecular weight of a solute if, when 1.33 g of the solute is dissolved in 25.0 g of benzene, the solution has a boiling point of 81.22 °C.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>B.P. (°C)</th>
<th>$k_b$ (°C/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>117.90</td>
<td>3.07</td>
</tr>
<tr>
<td>Benzene</td>
<td>80.10</td>
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</tr>
<tr>
<td>Water</td>
<td>100.00</td>
<td>0.512</td>
</tr>
</tbody>
</table>
Vapor Pressure Lowering

Adding a nonvolatile solute to a pure solvent causes:

- higher boiling point
  \[ \Delta T = +k_b m_{\text{solute}} \]
- lower vapor pressure
  \[ \Delta P = -P^o \chi_{\text{solute}} \]
- lower freezing point
- osmotic pressure
Vapor Pressure Lowering

- The vapor pressure of a solution that contains a nonvolatile solute is lower than pure solvent.
Vapor Pressure Lowering: Raoult’s Law

- **Raoult’s law**: The change in vapor pressure of solvent upon addition of a solute is equal to the mole fraction of the solvent times the vapor pressure of the pure solvent.

  \[ \Delta P = - \chi_{\text{solute}} P^0 \]
At 27.0 °C, the vapor pressure of benzene is 104 torr. What is the vapor pressure of a solution that has 0.200 mol of naphthalene dissolved in 9.90 mol of benzene?
Freezing Point Depression

Adding a nonvolatile solute to a pure solvent causes:

higher boiling point \[ \Delta T = +k_b m_{\text{solute}} \]

lower vapor pressure \[ \Delta P = -P^o \chi_{\text{solute}} \]

lower freezing point \[ \Delta T = -k_f m_{\text{solute}} \]

osmotic pressure
Freezing Point Depression

- Solute particles interfere with the ability of solvent particles to form a crystal and freeze. Thus, it takes a lower temperature to freeze solvent from a solution than from the pure solvent. This lowering is freezing point depression.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>F.P. (°C)</th>
<th>$k_f$ (°C/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>16.60</td>
<td>3.90</td>
</tr>
<tr>
<td>Benzene</td>
<td>5.51</td>
<td>4.90</td>
</tr>
<tr>
<td>Water</td>
<td>0.00</td>
<td>1.86</td>
</tr>
</tbody>
</table>
Benzophenone freezes at 48.1 °C. Adding 1.05 grams of urea, \((\text{NH}_2)_2\text{CO}\) (60.06 g/mol), to 30.0 g of benzophenone forms a solution that freezes at 42.4 °C. Calculate \(k_f\) for benzophenone.
Solution Concentration

**Adding a nonvolatile solute to a pure solvent causes:**

- Higher boiling point: \( \Delta T = +k_b m_{\text{solute}} \)
- Lower vapor pressure: \( \Delta P = - P^\circ \chi_{\text{solute}} \)
- Lower freezing point: \( \Delta T = - k_f m_{\text{solute}} \)
- Osmotic pressure: \( \Pi = RTM_{\text{solute}} \)
Osmotic Pressure

**Osmosis** is the diffusion of a liquid through a semipermeable membrane.

- Semipermeable membranes allow small molecules like water to pass through them.
Osmotic pressure is a colligative property, and can be calculated by the equation:

$$\Pi = MRT$$

where:

$$\Pi = \text{osmotic pressure}$$

$$M = \text{molar concentration of solute}$$

$$R = \text{ideal gas law constant}$$

$$T = \text{temperature in Kelvins}$$
A 5.70 mg sample of protein is dissolved in water to give 1.00 mL of solution. Calculate the molecular weight of the protein if the solution has an osmotic pressure of $8.58 \times 10^{-3}$ atm at 20 °C.
## Summary of Colligative Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Symbol</th>
<th>Concentration Unit</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease in vapor pressure</td>
<td>$\Delta P$</td>
<td>Mole fraction</td>
<td>$P^o$</td>
</tr>
<tr>
<td>Boiling point elevation</td>
<td>$\Delta T_b$</td>
<td>Molal</td>
<td>$k_b$</td>
</tr>
<tr>
<td>Freezing point depression</td>
<td>$\Delta T_f$</td>
<td>Molal</td>
<td>$k_f$</td>
</tr>
<tr>
<td>Osmotic pressure</td>
<td>$\Pi$</td>
<td>Molar</td>
<td>$RT$</td>
</tr>
</tbody>
</table>
Chapter 12.5
Colligative Properties of Electrolyte Solutions

Objectives

• Predict the ideal van’t Hoff factor of ionic solutes
• Calculate the colligative properties for solutions of electrolytes
• Explain why colligative properties of ionic solutions vary from the predicted properties
Electrolyte (Salt Containing) Solutions

- The colligative properties of electrolyte solutions are more pronounced because electrolytes separate into ions in solution and if you remember from last lecture, ions have very strong interactions in solutions.

- The **van’t Hoff factor**, $i$, is the multiple that determines the number of ions formed when a formula unit of an ionic compound dissolves.

- $n_{\text{ions}} = i \times n_{\text{formula unit}}$

- Non-electrolyte solutions have a van’t Hoff factor equal to 1.0.
Summary of Colligative Properties

- In non-saturated solutions, the van’t Hoff factor for salts is the number of ions produced by one formula unit of the substance.

- The greater number on ions, \( n_{ions} \), the greater impact the electrolyte has on colligative properties

  - \( \text{NaCl} \rightarrow \text{Na}^+(aq) + \text{Cl}^-(aq) \quad i=2 \)
  - \( \text{MgBr}_2 \rightarrow \text{Mg}^{2+}(aq) + 2 \text{Br}^-(aq) \quad i=3 \)
Arrange the following aqueous solutions in order of increasing boiling points by finding $n_{ions}$:

0.03 molal urea(s) (a nonelectrolyte)
0.01 molal NaOH
0.02 molal BaCl$_2$
0.01 molal Fe(NO$_3$)$_3$
In Class Example

Increasing Boiling Point

<table>
<thead>
<tr>
<th>Concentration</th>
<th>$n_{ions}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02 molal BaCl$_2$</td>
<td>0.06</td>
</tr>
<tr>
<td>0.01 molal Fe(NO$_3$)$_3$</td>
<td>0.04</td>
</tr>
<tr>
<td>0.03 molal urea(s) (a nonelectrolyte)</td>
<td>0.03</td>
</tr>
<tr>
<td>0.01 molal NaOH</td>
<td>0.02</td>
</tr>
</tbody>
</table>