Phenomena: Different masses of solute were added to 1 kg of either H₂O or C₆H₆. The boiling and freezing points of the solutions were then measured. Examine the data to determine patterns in how these variables affect the boiling and freezing points of the solutions.

H₂O

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Solute</th>
<th>Mass of Solute</th>
<th>Moles of Solute</th>
<th>Boiling Point</th>
<th>Freezing Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>0.0 g</td>
<td>0.00 mol</td>
<td>100.0 °C</td>
<td>0.0 °C</td>
</tr>
<tr>
<td>2</td>
<td>NaCl</td>
<td>50.0 g</td>
<td>0.85 mol</td>
<td>100.9 °C</td>
<td>-3.2 °C</td>
</tr>
<tr>
<td>3</td>
<td>NaCl</td>
<td>100.0 g</td>
<td>1.71 mol</td>
<td>101.7 °C</td>
<td>-6.4 °C</td>
</tr>
<tr>
<td>4</td>
<td>K₂O</td>
<td>50.0 g</td>
<td>0.53 mol</td>
<td>100.8 °C</td>
<td>-3.0 °C</td>
</tr>
<tr>
<td>5</td>
<td>K₂O</td>
<td>107.0 g</td>
<td>1.14 mol</td>
<td>101.7 °C</td>
<td>-6.3 °C</td>
</tr>
<tr>
<td>6</td>
<td>C₁₂H₂₂O₁₁</td>
<td>1169.0 g</td>
<td>3.42 mol</td>
<td>101.7 °C</td>
<td>-6.4 °C</td>
</tr>
<tr>
<td>7</td>
<td>NaHCO₃</td>
<td>71.7 g</td>
<td>0.85 mol</td>
<td>100.9 °C</td>
<td>-3.2 °C</td>
</tr>
<tr>
<td>8</td>
<td>C₆H₁₂O₆</td>
<td>616.1 g</td>
<td>3.42 mol</td>
<td>101.7 °C</td>
<td>-6.4 °C</td>
</tr>
</tbody>
</table>

C₆H₆

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Solute</th>
<th>Mass of Solute</th>
<th>Moles of Solute</th>
<th>Boiling Point</th>
<th>Freezing Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>0.0 g</td>
<td>0.00 mol</td>
<td>80.1 °C</td>
<td>5.5 °C</td>
</tr>
<tr>
<td>2</td>
<td>NaCl</td>
<td>50.0 g</td>
<td>0.85 mol</td>
<td>84.4 °C</td>
<td>-3.2 °C</td>
</tr>
<tr>
<td>3</td>
<td>NaCl</td>
<td>100.0 g</td>
<td>1.71 mol</td>
<td>88.7 °C</td>
<td>-12.0 °C</td>
</tr>
<tr>
<td>4</td>
<td>K₂O</td>
<td>50.0 g</td>
<td>0.53 mol</td>
<td>84.1 °C</td>
<td>-2.7 °C</td>
</tr>
<tr>
<td>5</td>
<td>K₂O</td>
<td>107.0 g</td>
<td>1.14 mol</td>
<td>88.7 °C</td>
<td>-11.9 °C</td>
</tr>
<tr>
<td>6</td>
<td>C₁₂H₂₂O₁₁</td>
<td>1169.0 g</td>
<td>3.42 mol</td>
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<td>C₆H₁₂O₆</td>
<td>616.1 g</td>
<td>3.42 mol</td>
<td>88.8 °C</td>
<td>-12.0 °C</td>
</tr>
</tbody>
</table>

Big Idea: Liquids will mix together if both liquids are polar or both are nonpolar. The presence of a solute changes the physical properties of the system. For nonvolatile solutes the vapor pressure, boiling point, freezing point, and osmotic pressure are only dependent on the number of ions/particles.
**Types of Solutions**

- **Solution**: A homogeneous mixture. Solutions are made up of at least two parts.
- **Solvent**: The most abundant component of a solution.
- **Solute**: A dissolved substance.

<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: Natural gas</td>
</tr>
<tr>
<td>Liquid</td>
<td>Liquid</td>
<td>Liquid</td>
<td>Tequila: Antifreeze</td>
</tr>
<tr>
<td>Liquid</td>
<td>Liquid</td>
<td>Gas</td>
<td>Soda water: Sugar water</td>
</tr>
<tr>
<td>Solid</td>
<td>Solid</td>
<td>Solid</td>
<td>Sea water: Sugar water</td>
</tr>
<tr>
<td>Solid</td>
<td>Solid</td>
<td>Gas</td>
<td>Alloys (Steel or brass)</td>
</tr>
<tr>
<td>Solid</td>
<td>Solid</td>
<td>Gas</td>
<td>Hydrogen in platinum</td>
</tr>
</tbody>
</table>

**Student Question**

The density of a 40.0% by weight aqueous solution of NaOH is 1.432 \( \text{g/mL} \). What is the molality of NaOH?

**Helpful Information**: \( \text{M}_{\text{NaOH}} = 40.00 \text{ g/L} \)

1. 12.9 m
2. 14.3 m
3. 16.7 m
4. 13.8 m
5. None of the above

**Solubility**

- **Exothermic**
- **Endothermic**

**Student Question**

Which one of the following substances would be the most soluble in \( \text{CCl}_4 \)?

1. \( \text{CH}_3\text{CH}_2\text{OH} \)
2. \( \text{C}_{10}\text{H}_{22} \)
3. \( \text{H}_2\text{O} \)
4. \( \text{NaCl} \)
5. \( \text{NH}_3 \)

**Solubility**

- **Hydration**: The reaction of a substance with water.
  
  **Note**: For molecules, the extent of hydration increases as polarity increases.
  
  **Note**: For ions, the extent of hydration increases as charge density (charge per volume) increases. In general, the smaller the size, the larger the charge density and the larger the charge, the larger the charge density.

- **Saturated Solution**: A solution that holds the maximum amount of solute.
- **Unsaturated Solution**: A solution that holds less than the maximum amount of solute.
- **Supersaturated Solution**: A solution that holds more than the maximum amount of solute.

If a solution is supersaturated any small disturbance can cause the solute to recrystallize.
Chapter 17: Properties of Solutions

Solubility

The graph shows the saturation level of different solutions at a given temperature. If a solution has a solubility that results in a point above the line, then the solution is considered to be supersaturated. However, if a solution has a solubility that results in a point under the line, then the solution is considered unsaturated.

Colligative Properties

- **Colligative Properties**: Physical properties of solutions that depend on the number of solute particles present but not the type of solute particles.

  - **Examples of Colligative Properties**:
    - Vapor Pressure (non volatile solutes)
    - Freezing Point
    - Boiling Point
    - Osmotic Pressure

Vapor Pressure

- **Vapor Pressure**: The pressure exerted by the vapor of a liquid or solid.
- **Volatile**: Having a high vapor pressure at ordinary temperatures (evaporates easily).
- **Nonvolatile**: Having a low vapor pressure at ordinary temperatures (does not evaporate easily).

**Nonvolatile Solute**

- **Raoult’s Law**

\[ P_{\text{sol}} = P_{\text{sol}}^{\text{ideal}} X_{\text{sol}} \]

Note: Where \( x \) is the mole fraction of the gas dissolved in solution.

Note: An alternate form of Henry’s Law is \( P = k \chi \) where \( c \) is the molarity.

Student Question

Which of the following aqueous solutions containing nonvolatile solutes should have the highest boiling point?

- a) 0.02 M C₆H₁₂O₆
- b) 0.02 M (NH₄)₂SO₄
- c) 0.02 M NaCl
- d) 0.02 M Ce(NO₃)₄
- e) All have the same boiling point

Vapor Pressure

- **Ideal Solution (Obeys Raoult’s Law)**

Which substance (A or B) has the higher boiling point?
Student Question

What is the vapor pressure of a solution of 50.0 g of CCl₄ and 50.0 g of CHCl₃ at 25°C. The vapor pressures at 25°C for pure CCl₄ and CHCl₃ are 98.3 torr and 172.0 torr respectively.

Helpful Information: \( M_{CCl_4} = 119.37 \text{ g/mol} \) and \( M_{CHCl_3} = 153.81 \text{ g/mol} \)

a) 131 torr
b) 140 torr
c) 149 torr
d) 126 torr
e) None of the Above

Boiling and Freezing Points

- **Freezing Point Depression**: The decrease in the freezing point of a solvent caused by the presence of a solute.
- **Boiling Point Elevation**: The increase in the boiling point of a solution caused by the presence of a solute.

### Freezing Point Depression

When a solute is added to a solvent, the freezing point of the solution will be lower than that of the pure solvent.

- The presence of a nonvolatile solute lowers the vapor pressure of the solution, therefore, a higher temperature must be present in order for the vapor pressure of the solution to reach 1 atm (normal boiling point).

### Boiling Point Elevation

- At the freezing point, the solid and the liquid are in equilibrium.

**Both Beakers are at 0°C**

- **Pure H₂O**: Ice and Water at Equilibrium
- **H₂O and Nonvolatile Solute**: Ice and Water not at Equilibrium
Boiling and Freezing Points

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Boiling Point (°C)</th>
<th>Kb (°C·mol⁻¹·kg⁻¹)</th>
<th>Freezing Point (°C)</th>
<th>Kf (°C·mol⁻¹·kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>100.0</td>
<td>0.51</td>
<td>0.0</td>
<td>1.86</td>
</tr>
<tr>
<td>CCl₄</td>
<td>76.5</td>
<td>5.03</td>
<td>-22.99</td>
<td>30.0</td>
</tr>
<tr>
<td>CHCl₃</td>
<td>61.2</td>
<td>3.63</td>
<td>-63.5</td>
<td>4.70</td>
</tr>
<tr>
<td>C₆H₅</td>
<td>80.1</td>
<td>2.53</td>
<td>5.5</td>
<td>5.12</td>
</tr>
<tr>
<td>CS₂</td>
<td>46.2</td>
<td>2.34</td>
<td>-111.5</td>
<td>3.83</td>
</tr>
<tr>
<td>C₄H₁₀O</td>
<td>34.5</td>
<td>2.02</td>
<td>-116.2</td>
<td>1.79</td>
</tr>
<tr>
<td>C₁₀H₁₆O</td>
<td>208.0</td>
<td>2.95</td>
<td>179.8</td>
<td>40.0</td>
</tr>
</tbody>
</table>

Boiling and Freezing Points

Student Question

A solution of 0.640 g of azulene in 100.0 g of benzene boils at 80.230 ˚C. The boiling point of benzene is 80.100 ˚C; the Kb is 2.53 ˚C·mol⁻¹·kg⁻¹. What is the molecular weight of azulene?

a) 108  g
b) 117  g
c) 134  g
d) 99  g
e) None of the Above

Osmotic Pressure

- Osmosis: The flow of solvent from a lower concentration solution through a semipermeable membrane to a higher concentration solution.
- Osmotic Pressure: The pressure needed to stop the flow of solvent through a semipermeable membrane.

Take Away From Chapter 17

- Big Idea: Liquid will mix together if both liquids are polar or both are nonpolar. The presence of a solute changes the physical properties of the system. For non-volatile solutes the vapor pressure, boiling point, freezing points, and osmotic pressure are only dependent on the number of ions/particles.
- Types of Solutions
  - Know the difference between homogeneous and heterogeneous mixtures
  - Homogeneous Mixtures: Uniformly mixed (air)
  - Heterogeneous Mixtures: Not uniformly mixed (chocolate chip cookie)
**Take Away From Chapter 17**

### Solubility
- Be able to predict whether two substances are soluble (33, 34)
  - Like dissolves like
  - Two polar substances are soluble with each other
  - Two nonpolar substances are soluble with each other
  - A nonpolar and a polar substance are not soluble with each other
- Be able to predict the extent of hydration (32)
  - The more polar the ion/molecule, the greater the hydration
  - The greater the charge density, the greater the hydration (in general, the smaller the ion/molecule, the greater the hydration and the larger the charge, the greater the hydration)
- Know the effects of temperature on solubility
  - In general, the greater the temperature, the higher the solubility of a solid in a liquid
  - The greater the temperature, the lower the solubility of a gas in a liquid
- Know the effects of pressure on the solubility of a gas (39)
  - $P = k_T \Delta T$

### Colligative Properties

#### Vapor Pressure
- Be able to calculate the vapor pressure of a solvent and a nonvolatile solute (42, 44, 47, 79)
  - $P_{solvent} = \text{saturation vapor pressure}$
- Be able to calculate the vapor pressure of solvent and volatile solute (49, 51)
- Be able to construct mole fraction vs. vapor pressure plots (52, 53, 54, 55, 57)
- Know what a positive deviation to Raoult’s Law implies
  - $\Delta H > 0$: solute/solvent interactions are weaker than solute/solute interactions or solvent/solvent interactions
- Know what a negative deviation of Raoult’s Law implies
  - $\Delta H < 0$: solute/solvent interaction are stronger than solute/solute interactions or solvent/solvent interactions

### Boiling and Freezing Points
- Be able to determine the van’t Hoff factor ($i$) and know how this factor effects colligative properties (13, 81, 82)
- Be able to calculate freezing point and boiling point of a solution (62, 63, 70, 74, 124)
  - $T_f = T_f^0 - \Delta T_f$ or $T_b = T_b^0 + \Delta T_b$
  - $\Delta T_f = i k_f m$ or $\Delta T_b = i k_m m$

### Osmotic Pressure
- Be able to calculate osmotic pressure (71, 117)
  - $\pi = i \mu_{osm}$