Chapter 13

Ions in Aqueous Solutions and Colligative Properties

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Section 1  Compounds in Aqueous Solutions

Section 2  Colligative Properties
Lesson Starter

• Compare the composition and arrangement of particles in the solid crystals of CuSO$_4$$\cdot$5H$_2$O with those in the solution.
Objectives

• **Write** equations for the dissolution of soluble ionic compounds in water.

• **Predict** whether a precipitate will form when solutions of soluble ionic compounds are combined, and write net ionic equations for precipitation reactions.

• **Compare** dissociation of ionic compounds with ionization of molecular compounds.
Objectives, continued

• **Draw** the structure of the hydronium ion, and explain why it is used to represent the hydrogen ion in solution.

• **Distinguish** between strong electrolytes and weak electrolytes.
Dissociation

- **Dissociation** is separation of ions that occurs when an ionic compound dissolves.

\[
\text{NaCl}(s) \xrightarrow{H_2O} \text{Na}^+(aq) + \text{Cl}^- (aq)
\]

<table>
<thead>
<tr>
<th>1 mol</th>
<th>1 mol</th>
<th>1 mol</th>
</tr>
</thead>
</table>

\[
\text{CaCl}_2(s) \xrightarrow{H_2O} \text{Ca}^{2+}(aq) + 2\text{Cl}^- (aq)
\]

| 1 mol | 1 mol | 2 mol |
Dissociation of NaCl

A beaker labeled 250ml contains NaCl, and a close-up view shows the dissociation process, with Na\(^+\) and Cl\(^-\) ions surrounded by water molecules (H\(_2\)O).
Dissociation, *continued*

**Sample Problem A**

Write the equation for the dissolution of aluminum sulfate, $\text{Al}_2(\text{SO}_4)_3$, in water. How many moles of aluminum ions and sulfate ions are produced by dissolving 1 mol of aluminum sulfate? What is the total number of moles of ions produced by dissolving 1 mol of aluminum sulfate?
Dissociation, *continued*

Sample Problem A Solution

**Given:** amount of solute = 1 mol $\text{Al}_2(\text{SO}_4)_3$

solvent identity = water

**Unknown:**

a. moles of aluminum ions and sulfate ions

b. total number of moles of solute ions produced

**Solution:**

$$\text{Al}_2(\text{SO}_4)_3(s) \xrightleftharpoons{\text{H}_2\text{O}} 2\text{Al}^{3+}(aq) + 3\text{SO}_4^{2-}(aq)$$

a. $1\text{ mol } \text{Al}_2(\text{SO}_4)_3 \rightarrow 2\text{ mol } \text{Al}^{3+} + 3\text{ mol } \text{SO}_4^{2-}$

b. $2\text{ mol } \text{Al}^{3+} + 3\text{ mol } \text{SO}_4^{2-} = 5\text{ mol of solute ions}$
Dissociation, *continued*

**Precipitation Reactions**

- Although no ionic compound is completely insoluble, compounds of very low solubility can be considered insoluble for most practical purposes.
General Solubility Guidelines

1. Sodium, potassium, and ammonium compounds are soluble in water.

2. Nitrates, acetates, and chlorates are soluble.

3. Most chlorides are soluble, except those of silver, mercury(I), and lead. Lead(II) chloride is soluble in hot water.

4. Most sulfates are soluble, except those of barium, calcium, mercury, strontium, and lead.

5. Most carbonates, phosphates, and silicates are insoluble, except those of sodium, potassium, and ammonium.

6. Most sulfides are insoluble, except those of calcium, strontium, sodium, potassium, and ammonium.
Chapter 13

Rules for Solubility

Click below to watch the Visual Concept.

Visual Concept
Ionic compounds can be soluble or insoluble in water. NiCl₂, KMnO₄, CuSO₄, and Pb(NO₃)₂ are soluble in water. AgCl and CdS are insoluble in water.
Particle Model for the Formation of a Precipitate

\[
\text{NaCl}(aq) \rightarrow \text{Na}^+(aq) + \text{Cl}^-(aq) \\
\text{Sodium chloride is a soluble salt that dissociates in water to form ions.}
\]

\[
\text{AgNO}_3(aq) \rightarrow \text{Ag}^+(aq) + \text{NO}_3^-(aq) \\
\text{Silver nitrate is a soluble salt that dissociates in water to form ions.}
\]

\[
\text{Ag}^+(aq) + \text{Cl}^-(aq) \rightarrow \text{AgCl(s)} \\
\text{Silver chloride is an insoluble salt that forms when Ag}^+ \text{ ions can react with Cl}^- \text{ ions.}
\]
Precipitation Reactions

Click below to watch the Visual Concept.
Dissociation, continued
Net Ionic Equations

• A net ionic equation includes only those compounds and ions that undergo a chemical change in a reaction in an aqueous solution.

• Ions that do not take part in a chemical reaction and are found in solution both before and after the reaction are spectator ions.
Dissociation, *continued*

Net Ionic Equations, *continued*

Overall ionic equation

\[
\text{Cd}^{2+}(aq) + 2\text{NO}_3^-(aq) + 2\text{NH}_4^+(aq) + S^{2\text{G}}(aq) \rightarrow \text{CdS}(s) + 2\text{NO}_3^-(aq) + 2\text{NH}_4^+(aq)
\]

Net ionic equation

\[
\text{Cd}^{2+}(aq) + S^{2\text{G}}(aq) \rightarrow \text{CdS}(s)
\]
Writing a Net Ionic Equation

Chemical equation:
\[ \text{K}_2\text{SO}_4(aq) + \text{Ba(NO}_3\text{)}_2(aq) \rightarrow 2\text{KNO}_3(aq) + \text{BaSO}_4(s) \]

Total ionic equation:
\[ 2\text{K}^+(aq) + \text{SO}_4^{2-}(aq) + \text{Ba}^{2+}(aq) + 2\text{NO}_3^-(aq) \rightarrow 2\text{K}^+(aq) + 2\text{NO}_3^-(aq) + \text{BaSO}_4(s) \]

Net ionic equation:
\[ \text{SO}_4^{2-}(aq) + \text{Ba}^{2+}(aq) \rightarrow \text{BaSO}_4(s) \]
Net Ionic Equation

QuickTime™ and a Sorenson Video 3 decompressor are needed to see this picture.
Dissociation, *continued*
Net Ionic Equations, *continued*

**Sample Problem B**

Identify the precipitate that forms when aqueous solutions of zinc nitrate and ammonium sulfide are combined. Write the equation for the possible double-displacement reaction. Then write the formula equation, overall ionic equation, and net ionic equation for the reaction.
Dissociation, continued
Net Ionic Equations, continued

Sample Problem B Solution

**Given:** identity of reactants: zinc nitrate and ammonium sulfide
reaction medium: aqueous solution

**Unknown:**

a. equation for the possible double-displacement reaction
b. identity of the precipitate
c. formula equation
d. overall ionic equation
e. net ionic equation
Dissociation, *continued*

Net Ionic Equations, *continued*

Sample Problem B Solution, *continued*

**Solution:**

a. Equation for the possible double-displacement reaction

\[ \text{Zn(NO}_3\text{)}_2(aq) + (\text{NH}_4\text{)}_2\text{S(aq)} \rightarrow \text{ZnS(?) + 2NH}_4\text{NO}_3(?) \]

b. Table 1 reveals that zinc sulfide is not a soluble sulfide and is therefore a precipitate. Ammonium nitrate is soluble according to the table.

c. The formula equation

\[ \text{Zn(NO}_3\text{)}_2(aq) + (\text{NH}_4\text{)}_2\text{S(aq)} \rightarrow \text{ZnS(s) + 2NH}_4\text{NO}_3(aq) \]
Dissociation, *continued*

**Net Ionic Equations, continued**

**Sample Problem B Solution, continued**

d. The overall ionic equation

\[
\text{Zn}^{2+}(aq) + \text{NO}_3^-(aq) + \text{NH}_4^+(aq) + S^{2-}(aq) \rightarrow \text{ZnS}(s) + \text{NH}_4^+(aq) + \text{NO}_3^-(aq)
\]

e. The ammonium and nitrate ions appear on both sides of the equation as spectator ions.

The net ionic equation

\[
\text{Zn}^{2+}(aq) + S^{2-}(aq) \rightarrow \text{ZnS}(s)
\]
**Ionization**

- Ions are formed from solute molecules by the action of the solvent in a process called **ionization**.

- When a molecular compound dissolves and ionizes in a polar solvent, ions are formed where none existed in the undissolved compound.

- Hydrogen chloride, HCl, is a molecular compound that ionizes in aqueous solution.
  - HCl contains a highly polar bond.

\[
\text{HCl} \overset{\text{H}_2\text{O}}{\longrightarrow} \text{H}^+ (aq) + \text{Cl}^- (aq)
\]
Ionization

Click below to watch the Visual Concept.

Visual Concept
Comparing Dissociation and Ionization

Click below to watch the Visual Concept.
Ionization, continued
The Hydronium Ion

- Some molecular compounds ionize in an aqueous solution to release $H^+$. 
- The $H^+$ ion attracts other molecules or ions so strongly that it does not normally exist alone.

$$\text{HCl} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+(aq) + \text{Cl}^-(aq)$$

- The $\text{H}_3\text{O}^+$ ion is known as the hydronium ion.
Hydronium Ion

QuickTime™ and a Sorenson Video 3 decompressor are needed to see this picture.
Strong and Weak Electrolytes

• Electrolytes are substances that yield ions and conduct an electric current in solution.

• The strength with which substances conduct an electric current is related to their ability to form ions in solution.

• Strong and weak electrolytes differ in the degree of ionization or dissociation.
Models for Strong and Weak Electrolytes and Nonelectrolytes

**Strong Electrolyte**
- NaCl(aq)
- Na⁺, Cl⁻, H₂O

**Weak Electrolyte**
- HF(aq)
- H⁺, F⁻, H₂O

**Strong Electrolyte**
- AgCl(aq)
- Ag⁺, Cl⁻, H₂O

**Nonelectrolyte**
- C₁₂H₂₂O₁₁(aq)
- C₁₂H₂₂O₁₁, H₂O
Strong and Weak Electrolytes, continued

Strong Electrolytes

• A **strong electrolyte** is any compound whose dilute aqueous solutions conduct electricity well; this is due to the presence of all or almost all of the dissolved compound in the form of ions.

• To whatever extent they dissolve in water, they yield only ions.

  • HCl, HBr, HI
  • All soluble ionic compounds
Strong and Weak Electrolytes, continued

Weak Electrolytes

• A weak electrolyte is any compound whose dilute aqueous solutions conduct electricity poorly; this is due to the presence of a small amount of the dissolved compound in the form of ions.

• Some molecular compounds form aqueous solutions that contain not only dissolved ions but also some dissolved molecules that are not ionized.

\[ \text{HF} \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{F}^-\text{(aq)} \]

[HF] >> [H\(^+\)] and [F\(^-\)]
Lesson Starter

• Container A is filled with ice

• Container B is filled with ice + NaCl

• Will the ice in container A or in container B melt faster?
Objectives

• **List** four colligative properties, and explain why they are classified as colligative properties.

• **Calculate** freezing-point depression, boiling-point elevation, and solution molality of nonelectrolyte solutions.

• **Calculate** the expected changes in freezing point and boiling point of an electrolyte solution.

• **Discuss** causes of the differences between expected and experimentally observed colligative properties of electrolyte solutions.
Colligative Properties of Solutions

- Properties that depend on the concentration of solute particles but not on their identity are called **colligative properties**.

  - Vapor-Pressure Lowering
  - Freezing-Point Depression
  - Boiling-Point Elevation
  - Osmotic Pressure
Vapor-Pressure Lowering

- A **nonvolatile substance** is one that has little tendency to become a gas under existing conditions.
- The boiling point and freezing point of a solution differ from those of the pure solvent.
- A nonvolatile solute raises the boiling point and lowers the freezing point.
Comparing Volatile and Nonvolatile Liquids

Click below to watch the Visual Concept.

Visual Concept
**Chapter 13**

**Section 2 Colligative Properties of Solutions**

**Vapor Pressure vs. Temperature for a Pure Solvent and a Solution with a Nonvolatile Solute**

- **Solid**
- **Liquid**
- **Gas**

Temperature (°C)

Vapor pressure of solvent (atm)

- $t_f$ for solution
- $t_f$ for pure solvent
- $t_b$ for pure solvent
- $t_b$ for solution

$\Delta t_f$ for pure solvent

$\Delta t_b$ for solution

$\Delta P_{\text{solute}}$ at bp of pure solvent
Vapor Pressures of Pure Water and a Water Solution

The vapor pressure of water over pure water is greater than the vapor pressure of water over an aqueous solution containing a nonvolatile solute.

Pure water

Aqueous solution of nonvolatile solute

Used to represent C_{12}H_{22}O_{11}, sucrose

Used to represent H_{2}O, water
Freezing-Point Depression

- The **freezing-point depression**, $\Delta t_f$, is the difference between the freezing points of the pure solvent and a solution of a nonelectrolyte in that solvent, and it is directly proportional to the molal concentration of the solution.

- The **molal freezing-point constant** ($K_f$) is the freezing-point depression of the solvent in a 1-molal solution of a nonvolatile, nonelectrolyte solute.

\[ \Delta t_f = K_f m \]
## Freezing-Point Depression, *continued*

Molal Freezing-Point and Boiling-Point Constants

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Normal f.p. (°C)</th>
<th>Molal f.p. constant, $K_f$ (°C/m)</th>
<th>Normal b.p. (°C)</th>
<th>Molal b.p. constant, $K_b$ (°C/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>16.6</td>
<td>−3.90</td>
<td>117.9</td>
<td>3.07</td>
</tr>
<tr>
<td>Camphor</td>
<td>178.8</td>
<td>−39.7</td>
<td>207.4</td>
<td>5.61</td>
</tr>
<tr>
<td>Ether</td>
<td>−116.3</td>
<td>−1.79</td>
<td>34.6</td>
<td>2.02</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>80.2</td>
<td>−6.94</td>
<td>217.7</td>
<td>5.80</td>
</tr>
<tr>
<td>Phenol</td>
<td>40.9</td>
<td>−7.40</td>
<td>181.8</td>
<td>3.60</td>
</tr>
<tr>
<td>Water</td>
<td>0.00</td>
<td>−1.86</td>
<td>100.0</td>
<td>0.51</td>
</tr>
</tbody>
</table>
Freezing-Point Depression

Click below to watch the Visual Concept.
Freezing-Point Depression, continued

Sample Problem C
What is the freezing-point depression of water in a solution of 17.1 g of sucrose, \( \text{C}_{12}\text{H}_{22}\text{O}_{11} \), in 200. g of water? What is the actual freezing point of the solution?
Freezing-Point Depression, *continued*

Sample Problem C Solution

**Given:** solute mass and chemical formula = 17.1 g \(\text{C}_{12}\text{H}_{22}\text{O}_{11}\)

solvent mass and identity = 200. g water

**Unknown:**

a. freezing-point depression

b. freezing point of the solution

**Solution:**

\[
\text{mass of solute (g) } \times \frac{1 \text{ mol solute}}{\text{molar mass of solute (g)}} = \text{amount of solute (mol)}
\]
Freezing-Point Depression, continued

Sample Problem C Solution, continued

Solution:

\[
\frac{\text{amount of solute (mol)}}{\text{mass of solute (g)}} \times \frac{1000 \text{ g water}}{1 \text{ kg water}} = \text{molality}
\]

\[\Delta t_f = K_f m\]

f.p. solution = f.p. solvent + \(\Delta t_f\)
Freezing-Point Depression, *continued*

Sample Problem C Solution, *continued*

Solution:

\[
17.1 \text{ g } \text{C}_{12}\text{H}_{22}\text{O}_{11} \times \frac{1 \text{ mol solute}}{342.34 \text{ g } \text{C}_{12}\text{H}_{22}\text{O}_{11}} = 0.0500 \text{ mol } \text{C}_{12}\text{H}_{22}\text{O}_{11}
\]

\[
0.0500 \text{ mol } \text{C}_{12}\text{H}_{22}\text{O}_{11} \times \frac{1000 \text{ g water}}{200. \text{ g water}} \times \frac{1 \text{ kg water}}{1 \text{ kg water}} = 0.250 \text{ m}
\]
Freezing-Point Depression, continued

Sample Problem C Solution, continued

Solution:

a. \[ \Delta t_f = K_f m \]

\[ \Delta t_f = 0.250 \text{ m} \times (-1.86°C/m) = -0.465°C \]

b. \[ \text{f.p. solution} = \text{f.p. solvent} + \Delta t_f \]

\[ \text{f.p. solution} = 0.000°C + (-0.465°C) = -0.465°C \]
Boiling-Point Elevation

- The **boiling-point elevation**, $\Delta t_b$, is the difference between the boiling points of the pure solvent and a nonelectrolyte solution of that solvent, and it is directly proportional to the molal concentration of the solution.

- The **molal boiling-point constant** ($K_b$) is the boiling-point elevation of the solvent in a 1-molal solution of a nonvolatile, nonelectrolyte solute.

\[ \Delta t_b = K_b m \]
Boiling-Point Elevation and the Presence of Solutes

Click below to watch the Visual Concept.
Boiling-Point Elevation, *continued*

Sample Problem E

What is the boiling-point elevation of a solution made from 20.1 g of a nonelectrolyte solute and 400.0 g of water? The molar mass of the solute is 62.0 g.
Boiling-Point Elevation, *continued*

Sample Problem E Solution

**Given:**
- solute mass = 20.1 g
- solute molar mass = 62.0 g
- solvent mass and identity = 400.0 g of water

**Unknown:** boiling-point elevation

**Solution:**

\[
\text{mass of solute (g)} \times \frac{1 \text{ mol solute}}{\text{molar mass of solute (g)}} = \text{amount of solute (mol)}
\]
Boiling-Point Elevation, continued

Sample Problem E Solution, continued

Solution:

\[
\text{molality} = \frac{\text{amount of solute (mol)}}{\text{mass of solute (g)}} \times \frac{1000 \text{ g water}}{1 \text{ kg water}}
\]

\[
\Delta t_b = K_b m
\]

\[
\begin{align*}
20.1 \text{ g of solute} &\times \frac{1 \text{ mol solute}}{62.0 \text{ g of solute}} = 0.324 \text{ mol of solute} \\
0.324 \text{ mol of solute} &\times \frac{1000 \text{ g water}}{1 \text{ kg water}} = 0.810 \text{ mol solute/kg water} = 0.810 m
\end{align*}
\]
Boiling-Point Elevation, *continued*

Sample Problem E Solution, *continued*

Solution:

\[ \text{20.1 g of solute} \times \frac{1 \text{ mol solute}}{62.0 \text{ g of solute}} = 0.324 \text{ mol of solute} \]

\[ \frac{0.324 \text{ mol of solute}}{400.0 \text{ g water}} \times \frac{1000 \text{ g water}}{1 \text{ kg water}} = 0.810 \frac{\text{mol solute}}{\text{kg water}} = 0.810 \text{ m} \]

\[ \Delta t_b = 0.51^\circ\text{C}/m \times 0.810 \text{ m} = 0.41^\circ\text{C} \]
Osmotic Pressure

- A **semipermeable membrane** allows the passage of some particles while blocking the passage of others.

- The movement of solvent through a semipermeable membrane from the side of lower solute concentration to the side of higher solute concentration is **osmosis**.

- **Osmotic pressure** is the external pressure that must be applied to stop osmosis.
Semipermeable Membrane

QuickTime™ and a Sorenson Video 3 decompressor are needed to see this picture.
Chapter 13

Osmosis

QuickTime™ and a Sorenson Video 3 decompressor are needed to see this picture.
Osmotic Pressure

When pure water and an aqueous sucrose solution are separated by a semipermeable membrane, the net movement of water molecules through the membrane is from the pure water side into the aqueous solution.

The level of the solution rises until pressure exerted by the height of the solution equals the osmotic pressure, at which point no net movement of water molecules occurs.
Electrolytes and Colligative Properties

- Electrolytes depress the freezing point and elevate the boiling point of a solvent more than expected.

- Electrolytes produce more than 1 mol of solute particles for each mole of compound dissolved.

\[
\begin{align*}
C_{12}H_{22}O_{11} & \xrightarrow{H_2O} C_{12}H_{22}O_{11}(aq) & 1 \\
\text{CaCl}_2(s) & \xrightarrow{H_2O} \text{Ca}^{2+}(aq) + 2\text{Cl}^{-}(aq) & 2 \\
\text{NaCl}(s) & \xrightarrow{H_2O} \text{Na}^{+}(aq) + \text{Cl}^{-}(aq) & 3
\end{align*}
\]
Electrolytes and Colligative Properties, continued

Calculated Values for Electrolyte Solutions

- Colligative properties depend on the total concentration of solute particles.

- The changes in colligative properties caused by electrolytes will be proportional to the total molality of all dissolved particles, not to formula units.

- For the same molal concentrations of sucrose and sodium chloride, you would expect the effect on colligative properties to be twice as large for sodium chloride as for sucrose.
Electrolytes and Colligative Properties, continued

Sample Problem F

What is the expected change in the freezing point of water in a solution of 62.5 g of barium nitrate, \( \text{Ba(NO}_3\text{)}_2 \), in 1.00 kg of water?
Sample Problem F Solution

**Given:** solute mass and formula = 62.5 g Ba(NO$_3$)$_2$

solvent mass and identity = 1.00 kg water

$\Delta t_f = K_f m$

**Unknown:** expected freezing-point depression

**Solution:**

\[
\text{molality of solute} \left( \frac{\text{mol}}{\text{kg}} \right) = \frac{\text{mass of solute (g)}}{\text{mass of solvent (kg)}} \times \frac{1 \text{ mol solute}}{\text{molar mass solute (g)}}
\]
Sample Problem F Solution, continued

Solution:

\[
\frac{\text{molality of solute (mol)}}{\text{kg (kg)}} \times \frac{\text{molality conversion (mol ions/mol)}}{\text{mol}} \times K_f \left( \frac{\circ C \text{ gkg H}_2\text{O}}{\text{mol ions}} \right) = \text{expected freezing-point depression (\circ C)}
\]

\[
\frac{62.5 \text{ g Ba(NO}_3\text{)}_2}{1.00 \text{ kg H}_2\text{O}} \times \frac{\text{mol Ba(NO}_3\text{)}_2}{261.35 \text{ g Ba(NO}_3\text{)}_2} = \frac{0.239 \text{ mol Ba(NO}_3\text{)}_2}{\text{kg H}_2\text{O}}
\]
Electrolytes and Colligative Properties, continued

Sample Problem F Solution, continued

Solution:

\[ \text{Ba(NO}_3\text{)}_2(s) \xrightarrow{\text{H}_2\text{O}} \text{Ba}^{2+}(aq) + 2\text{NO}_3^-(aq) \]

Each formula unit of barium nitrate yields three ions in solution.

\[
\frac{0.239 \text{ mol Ba(NO}_3\text{)}_2}{\text{kg H}_2\text{O}} \times \frac{3 \text{ mol ions}}{\text{mol Ba(NO}_3\text{)}_2} \times \frac{-1.86^\circ \text{C g kg H}_2\text{O}}{\text{mol ions}} = -1.33^\circ \text{C}
\]
Electrolytes and Colligative Properties, *continued*

Actual Values for Electrolyte Solutions

<table>
<thead>
<tr>
<th>Solute</th>
<th>Concentration (m)</th>
<th>$\Delta t_f$, observed ($^\circ$C)</th>
<th>$\Delta t_f$, nonelectrolyte solution ($^\circ$C)</th>
<th>$\Delta t_f$, observed $\Delta t_f$, nonelectrolyte solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>KCl</td>
<td>0.1</td>
<td>−0.345</td>
<td>−0.186</td>
<td>1.85</td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td>−0.0361</td>
<td>−0.0186</td>
<td>1.94</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>−0.00366</td>
<td>−0.00186</td>
<td>1.97</td>
</tr>
<tr>
<td>MgSO$_4$</td>
<td>0.1</td>
<td>−0.225</td>
<td>−0.186</td>
<td>1.21</td>
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<tr>
<td></td>
<td>0.01</td>
<td>−0.0285</td>
<td>−0.0186</td>
<td>1.53</td>
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<tr>
<td></td>
<td>0.001</td>
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<tr>
<td>BaCl$_2$</td>
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<tr>
<td></td>
<td>0.01</td>
<td>−0.0503</td>
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<tr>
<td></td>
<td>0.001</td>
<td>−0.00530</td>
<td>−0.00186</td>
<td>2.84</td>
</tr>
</tbody>
</table>

- The actual values of the colligative properties for all strong electrolytes are almost what would be expected based on the number of particles they produce in solution.
Electrolytes and Colligative Properties, continued

Actual Values for Electrolyte Solutions

- The differences between the expected and calculated values are caused by the attractive forces that exist between dissociated ions in aqueous solution.

- According to Debye and Hückel a cluster of hydrated ions can act as a single unit rather than as individual ions, causing the effective total concentration to be less than expected.

- Ions of higher charge have lower effective concentrations than ions with smaller charge.
End of Chapter 13 Show
Multiple Choice

1. Acetic acid is a weak electrolyte because it

A. is miscible with water.
B. forms hydronium and hydroxide ions in aqueous solution.
C. lowers the freezing point of water.
D. ionizes only slightly in aqueous solution.
Multiple Choice

1. Acetic acid is a weak electrolyte because it

A. is miscible with water.

B. forms hydronium and hydroxide ions in aqueous solution.

C. lowers the freezing point of water.

D. ionizes only slightly in aqueous solution.
Multiple Choice

2. Which of the following solutions would contain the highest concentration of hydronium ions, $H_3O^+$?

A. 0.10 M HCl
B. 0.10 M HF
C. 0.10 M CH$_3$COOH
D. 0.10 M NaCl
Multiple Choice

2. Which of the following solutions would contain the highest concentration of hydronium ions, $\text{H}_3\text{O}^+$?

A. 0.10 M HCl
B. 0.10 M HF
C. 0.10 M CH$_3$COOH
D. 0.10 M NaCl
Multiple Choice

3. Which of the following is the best representation of the precipitation reaction that occurs when aqueous solutions of sodium carbonate and calcium chloride are mixed?

A. \( \text{Na}^+(aq) + \text{Cl}^-(aq) \rightarrow 2\text{NaCl}(s) \)

B. \( 2\text{Na}^+(aq) + \text{CO}_3^{2-}(aq) + \text{Ca}^{2+}(aq) + 2\text{Cl}^-(aq) \rightarrow \text{CaCO}_3(s) + 2\text{NaCl}(s) \)

C. \( \text{CO}_3^{2-}(aq) + \text{Ca}^{2+}(aq) \rightarrow \text{CaCO}_3(s) \)

D. No precipitation reaction occurs.
Multiple Choice

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C. \( \text{CO}_3^{2-} (aq) + \text{Ca}^{2+} (aq) \rightarrow \text{CaCO}_3 (s) \)

D. No precipitation reaction occurs.
Multiple Choice

4. Which of the following is not a colligative property?

A. molality
B. vapor-pressure lowering
C. boiling-point elevation
D. osmotic pressure
Multiple Choice

4. Which of the following is *not* a colligative property?

A. molality
B. vapor-pressure lowering
C. boiling-point elevation
D. osmotic pressure
5. Solution A contains 0.1 mol of sucrose, \( \text{C}_{12}\text{H}_{22}\text{O}_{11} \), dissolved in 500 g of water. Solution B contains 0.1 mol of sodium chloride, NaCl, in 500 g of water. Which of the following statements about these solutions is true?

A. Both solutions have the same vapor pressure.
B. Solution A would boil at a higher temperature than solution B would.
C. Solution A would freeze at a higher temperature than solution B would.
D. Both solutions would boil at the same temperature.
Multiple Choice

5. Solution A contains 0.1 mol of sucrose, $C_{12}H_{22}O_{11}$, dissolved in 500 g of water. Solution B contains 0.1 mol of sodium chloride, NaCl, in 500 g of water. Which of the following statements about these solutions is true?

A. Both solutions have the same vapor pressure.
B. Solution A would boil at a higher temperature than solution B would.
C. Solution A would freeze at a higher temperature than solution B would.
D. Both solutions would boil at the same temperature.
Multiple Choice

The table below shows the freezing points of solutions of three nonvolatile solutes, X, Y, and Z, in water. Refer to the table to answer items 6 and 7. The $K_f$ for water is $-1.86^\circ \text{C}/m$.

<table>
<thead>
<tr>
<th>Solute</th>
<th>Solute (mol)</th>
<th>Water (g)</th>
<th>Freezing point ($^\circ \text{C}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>1.00</td>
<td>1000</td>
<td>$-5.58$</td>
</tr>
<tr>
<td>Y</td>
<td>1.00</td>
<td>1000</td>
<td>$-1.86$</td>
</tr>
<tr>
<td>Z</td>
<td>1.00</td>
<td>1000</td>
<td>$-3.72$</td>
</tr>
</tbody>
</table>
Multiple Choice

6. Which of the following statements is *not* true?

A. All three solutes are nonelectrolytes.
B. Solute X could be Ca(NO$_3$)$_2$.
C. Solute Y could be sucrose.
D. Solute Z could be KCl.
Multiple Choice

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A. All three solutes are nonelectrolytes.
B. Solute X could be Ca(NO$_3$)$_2$.
C. Solute Y could be sucrose.
D. Solute Z could be KCl.
Multiple Choice

7. Which of the solutions described in the table would have the highest boiling point?

A. the solution of solute X
B. the solution of solute Y
C. the solution of solute Z
D. All three solutions would have the same boiling point.
Which of the solutions described in the table would have the highest boiling point?

A. the solution of solute X
B. the solution of solute Y
C. the solution of solute Z
D. All three solutions would have the same boiling point.
8. An aqueous solution of an unknown quantity of a nonelectrolyte solute is found to have a freezing point of \(-0.58^\circ\text{C}\). What is the molal concentration of the solution?
8. An aqueous solution of an unknown quantity of a nonelectrolyte solute is found to have a freezing point of $-0.58^\circ\text{C}$. What is the molal concentration of the solution?

**Answer:** 0.31 m
9. Give the names and formulas of two strong electrolytes.
Short Answer

9. Give the names and formulas of two strong electrolytes.

**Answer:** Answers will vary. Any strong acid, any strong base, or any soluble ionic compound is an acceptable answer. Weak acids, weak bases, or insoluble ionic compounds are not acceptable.
Short Answer

10. Write the formula equation, the overall ionic equation, and the net ionic equation for the precipitation reaction that occurs when solutions of zinc chloride, ZnCl$_2$, and sodium sulfide, Na$_2$S, are mixed.
10. Write the formula equation, the overall ionic equation, and the net ionic equation for the precipitation reaction that occurs when solutions of zinc chloride, ZnCl₂, and sodium sulfide, Na₂S, are mixed.

**Answer:**

**Formula:** \( ZnCl_2(aq) + Na_2S(aq) \rightarrow ZnS(s) + 2NaCl(aq) \)

**Overall Ionic:** \( Zn^{2+}(aq) + 2Cl^-(aq) + 2Na^+(aq) + S^{2-}(aq) \rightarrow ZnS(s) + 2Na^+(aq) + 2Cl^-(aq) \)

**Net Ionic:** \( Zn^{2+}(aq) + S^{2-}(aq) \rightarrow ZnS(s) \)
11. Distinguish between dissociation and ionization. Write one chemical equation to illustrate each of these terms.
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**Answer:** Dissociation is the separation of ions that occurs when an ionic compound dissolves. Examples will vary. Two possibilities are

\[ \text{Na}_2\text{SO}_4 (s) \xrightarrow{\text{H}_2\text{O}} 2\text{Na}^+ (aq) + \text{SO}_4^{2-} (aq) \]

\[ \text{CrCl}_3 (s) \xrightarrow{\text{H}_2\text{O}} \text{Cr}^{3+} (aq) + 3\text{Cl}^{-} (aq) \]
11. Distinguish between dissociation and ionization. Write one chemical equation to illustrate each of these terms.

**Answer, continued:** Ionization is the creation of ions from solute molecules by the action of the solvent. Examples will vary. Two possibilities are

\[
\text{HCl}(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{Cl}^- (aq)
\]

\[
\text{HF}(g) + \text{H}_2\text{O}(l) \leftrightarrow \text{H}_3\text{O}^+(aq) + \text{F}^- (aq)
\]