Chapter 14: Solutions

1. Solutions
2. Units of Concentration
3. Colligative Properties
4. Colloids
Is a Solution a Homogeneous or a Heterogeneous Mixture?

Is The Air a Solution?

Can You Have a Solution of Multiple Solids?

Brass = Alloy of Copper & Zinc
3 Types of Solutions

1. Gas Phase
2. Liquid Phase
3. Solid Phase
   - substitutional
   - interstitial
Solid Phase Solutions

A Brass, a substitutional alloy

B Carbon steel, an interstitial alloy
Hydrogen in Nobel Metals
Solutions

**Solvent** - substance present in greatest amount.

**Solute** - substance(s) dissolved in solvent

Solute Can Be:

1. **Liquid** (alcohol in the wine)
2. **Solid** (salt in the sea water)
3. **Gas** (oxygen in your blood)
Aqueous Solutions

Identify the solvent and solute.

Water is often called the universal solvent.
Aqueous Solvation Processes

Covalent Compounds Do Not Ionize

Ionic Compounds Ionize
Saturated Solutions

**Saturated Solution** - Contains the maximum amount of solute which can be in equilibrium with undissolved solute.

**Unsaturated Solution** - can dissolve more solute, has no solid present

**Super Saturated Solution** - has more dissolved solute than can exist with solid solute
Liquid/Liquid Solutions

**Miscible** - Soluble in all proportions

**Immiscible** - Insoluble liquids, do not mix
Predicting Miscibility

How Do We Predict If 2 Liquids Will Mix?

LIKE DISSOLVES LIKE

-polar in polar
-nonpolar in nonpolar
Separation of Pentane & Octane

Distillation

-Pentane, being lighter, has a lower boiling pt, and boils while the octane is still a liquid. It is then condensed by the cold water.
Heat of Solution

Determine Heat of Solution for the Solvation of KOH at 25°C from Standard Enthalpies of Formation

\[ \Delta H^0_f \text{ KOH}(s) = -424.764 \]
\[ \Delta H^0_f \text{ KOH}(aq) = -482.37 \]

Is this endothermic or exothermic
Aqueous Solvation Process of Ionic Compounds

Requires energy to overcome solvent/solvent and solute/solute attractions (endothermic process)

Releases energy through solute/solvent attractions
Heat of Solution

Heat of dissolution is classified into endothermic and exothermic types.

1. **Endothermic**
   - Separation of solute molecules
   - $\Delta H_1$: Separation of solute molecules

2. **Endothermic**
   - Separation of solvent molecules
   - $\Delta H_2$: Separation of solvent molecules

3. **Exothermic**
   - Formation of solute-solvent interactions
   - $\Delta H_3$: Formation of solute-solvent interactions
Heat of Solution

Exothermic

Endothermic
Ways of Expressing Concentration

1. Molarity
2. Molality
3. Mole Fraction
4. Mass Fraction
5. PPM
6. PPB
Molarity

\[ M = \text{molarity} = \frac{\text{moles solute}}{\text{volume solution}} \]

What are the Units of molarity? M (mol/L)

Why is Molarity so Important in Solution Stoichiometric Calculations?

Because solutes are typically reactants and we can measure the solution volume, this gives us the moles solute for the stoichiometric eqs.
Calculate the Molarity of a Solution if 2.00 g NaCl is diluted to 250.0 ml with water.

\[(2 \text{ g NaCl})(\frac{\text{mol NaCl}}{58.5 \text{ g}})(\frac{1}{.250 \text{ L}}) = .137 M\]

How much NaOH would you need to make 500.0 mL of .70M NaOH?

\[.5 \text{ L}(\frac{.7 \text{ mol NaOH}}{\text{L}})(\frac{40 \text{ g NaOH}}{\text{mol}}) = 14 \text{ g}\]
Molality

\[ m = \text{molality} = \frac{\text{moles solute}}{\text{kg solvent}} \]

What are the Units of molality? \( m(\text{mol/kg}) \)

When is Molality Important?

When describing how a solute effects a solvent's physical properties

What is the molality of all ions in a solution made by adding 1 g of CaCl\(_2\) to 50 mL water
CaCl$_2$(s) + H$_2$O $\rightarrow$ Ca$^{+2}$(aq) + 2Cl$^{-}$(aq)

$1\text{gCaCl}_2 \times \left( \frac{\text{mole CaCl}_2}{112\text{g}} \right) = 0.00895 \text{ moles CaCl}_2$

0.00895 moles CaCl$_2$ = 0.0269 moles of all ions

molality$_{\text{all ions}} = \frac{0.0269\text{ moles}}{0.05\text{kg H}_2\text{O}} = 0.537\text{m}$
Mole Fraction

\[ X_A = \text{mole fraction} = \frac{n_a}{\sum n_i} \]

What are the Units of \( X_A \)? unitless

What does the sum of the mole fraction of all species equal? 1
Mass Percent

\[ \text{Mass}\% = \left(\frac{\text{Mass Solute}}{\text{Mass Solution}}\right)(100) \]

Note, Mass Solution = Mass Solvent + the Mass of All the Solutes Present

Calculate Mass % of Sodium Chloride If 5.00 Grams Table Salt Is Mixed in a Liter of Water.

\[ \%\text{NaCl} = \left(\frac{5.00\text{g}}{1005\text{g}}\right)\text{NaCl} \times \frac{100}{\text{Total}} = 0.498\% \]
PPM

ppm = parts per million

$g \text{ solute}/10^6 \ g \text{ solvent}$

Often used in very Dilute Solutions

$ppm = \text{mg solute}/L \text{ water}$
PPM

Calculate the PPM of a 1.00 x 10^{-5} M KMnO_4 solution

(FW=158g/mol)

\[
\frac{1.00 \times 10^{-5} \text{ mol KMnO}_4}{L} \left( \frac{158 \text{ g KMnO}_4}{\text{ mol}} \right) \left( \frac{1000 \text{ mg}}{\text{ g}} \right) = 1.58 \text{ PPM KMnO}_4
\]
PPB

\[ \text{ppb} = \text{parts per billion} \]
\[ \text{g solute}/10^9 \text{ g solvent} \]

Often Used in Very Very Dilute Solutions

\[ \text{ppb} = \mu\text{g solute}/\text{L water} \]
What is the molarity of a solution which is 25 ppb in arsenic?

\[
25 \text{ ppb } As = \frac{25 \times 10^{-6} \text{ g As}}{L} \left( \frac{\text{mol As}}{74.9 \text{ g}} \right) = 3.3 \times 10^{-7} \text{ M As}
\]
Factors Affecting Solubility

Temperature

Pressure (gas phase solute)
Solubility of Gases

Solubility (M) \( S_g = k_H P_g \)

Henry’s Law Constant

Partial Pressure of gas (mmHg)

Explain the solubility of gases in terms of surface transport across the gas/liquid boundary and gas partial pressure
Solubility of Gases
Temperature Effects on Solubility of Various Salts
Colligative Properties

-Solvent Properties Which Are Affected by a Solute
-Independent on the Nature of the Solute

-Vapor Pressure
-Boiling Point
-Freezing Point
-Osmosis
How does the vapor pressure of a solution compare to that of a pure solvent?

It depends on whether the solute is volatile or not.

Case 1: Nonvolatile Solute
Case 2: Volatile Solute
Non Volatile Solutes

Solutes That Do Not Have an Appreciable Vapor Pressure of Their Own
Raoult’s Law

Vapor pressure over a fluid is proportional to the number of solvent molecules near the surface.

\[ P_{\text{solvent}} = kX_{\text{solvent}} \]

For Pure Solvent (X=1):

\[ P_{\text{solvent}} = k \]

\[ P_{\text{solvent}} = P_{\text{solvent}} \cdot X_{\text{solvent}} \]
Raoult’s Law

Vapor pressure over a fluid is proportional to the number of solvent molecules near the surface.

\[ P_{\text{solvent}} = P^o_{\text{solvent}} \times X_{\text{solvent}} \]

- \( P_{\text{solvent}} \) is reduced by solute molecules.
- \( X_{\text{solvent}} \) = mole fraction of the solvent.
- \( P^o_{\text{solvent}} \) = vapor pressure of pure solvent.
Raoult’s Law

Determine $\Delta P$ due to added solute

$\Delta P = P_{\text{solvent}} - P^o_{\text{solvent}}$

$\Delta P = X_{\text{solvent}} P^o_{\text{solvent}} - P^o_{\text{solvent}}$

$\Delta P = -P^o_{\text{solvent}} (1 - X_{\text{solvent}})$

Noting the sum of the mole fractions $= 1$

$X_{\text{solute}} + X_{\text{solvent}} = 1$

$\Delta P = -P^o_{\text{solvent}} X_{\text{solute}}$

From Raoult’s Law:

$P_{\text{solution}} = X_{\text{solvent}} P_{\text{solvent}}$

substituting:

$X_{\text{solute}} = 1 - X_{\text{solvent}}$
Raoult’s Law-Summary

1. The Pressure due to a volatile Solvent in a Solution is:

\[ P_{\text{solvent}} = X_{\text{solvent}} P^o_{\text{solvent}} \]

2. The Decrease in Pressure due to the addition of a non-volatile solute is:

\[ \Delta P = -X_{\text{solute}} P^o_{\text{solvent}} \]
Raoult’s Law: Non Volatile Solute

\[ P = X_{\text{solute}} P^o_{\text{solvent}} \]

\[ \Delta P = -X_{\text{solute}} P^o_{\text{solvent}} \]
Raoult’s Law

Ideal Solution - Obeys Raoult’s Law
-Properties Are Independent of Solute/Solvent Interactions

2 Types of Non Ideal Solutions

a. Solvent Solute Interactions > Solvent/Solvent
   -lowers vapor pressure

b. Solvent Solute Interactions < Solvent/Solvent
   -raises vapor pressure
Raoult’s Law: Non Ideal Solutions

**Ideal Solution**
- Obeys Raoult’s Law; Properties Are Independent of Solute/Solvent Interactions

**Solvent Solute Interactions**
- Solvent/Solvent raises vapor pressure
- Solvent/Solute Interactions lowers vapor pressure

\[ P_{\text{solute}} \quad P_{\text{solvent}} \quad X_{\text{solvent}} \quad 0 \quad 1.0 \]

**Ideal Solution** - Obeys Raoult’s Law; Properties Are Independent of Solute/Solvent Interactions
Boiling Pt Elevation

For Ideal Solution:
\[ \Delta T_{bp} = i k_{bp} m_{solute} \]

\( i = \text{Van’t Hoff Factor} \)
- \( i = 1 \) for nonelectrolyte
- \( i = \text{approx} \# \text{ ions electrolyte dissociates into} \)

\( K_{bp} = \text{Boiling Point Elevation Constant} \)
\( M = \text{molality} \)
Molar Mass Determination & Colligative Properties

What is the Molar Mass of Adrenaline if 0.64g of Adrenaline in 36.0g of CCl₄ causes a Boiling Pt. Elevation of 0.49 °C.

\[ k_b(CCl_4) = 5.02(°C/m) \]

given: \( \Delta T = ik_b m \), \( m = \frac{n_{solute}}{kg_{solvent}} \), \( fw = \text{formula weight} = \frac{\text{mass}(g)}{n(\text{mole})} \), \( i = 1 \)

\[ n = m(kg_{solvent}) = \frac{\Delta T}{k_b}(kg_{solvent}) \]

\[ fw = \text{mass} \frac{k_b}{\Delta T(kg_{solvent})} = \frac{.64g \left(5.02^\circ C \frac{kg_{solvent}}{mole_{solute}}\right)}{0.49^\circ C \left(0.036kg_{solvent}\right)} \]

\[ fw = 182g/mol \]
Freezing Point Depression

\[ \Delta T_{fp} = -ik_{fp}m_{\text{solute}} \]

or

\[ \Delta T_{fp} = ik_{fp}m_{\text{solute}} \]

\( \Delta T_{fp} \) is always negative.

Be aware! Sometimes \( k_{fp} \) is recorded as a negative value and sometimes as a positive value. Use appropriate eq that gives negative \( \Delta T \).
van’t Hoff factor

For Ionic Solutes Colligative Effect is Predicted by Total # of Ionic Particles

\[ i = \frac{\Delta t_{fp, measured}}{\Delta t_{fp, calculated}} \]

\[ \Delta T_{fp} = i k_{fp} m_{solute} \]

van’t Hoff factor (i) is roughly the number of ions the salt dissociates into
van’t Hoff factor

<table>
<thead>
<tr>
<th>Mass % NaCl</th>
<th>M (mol/kg) NaCl</th>
<th>( \frac{\Delta T_{fp, measured}}{\Delta T_{fp, calculated}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00700</td>
<td>0.0120</td>
<td>1.94</td>
</tr>
<tr>
<td>0.500</td>
<td>0.0860</td>
<td>1.87</td>
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<td>1.00</td>
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</tr>
<tr>
<td>2.00</td>
<td>0.349</td>
<td>1.83</td>
</tr>
</tbody>
</table>
Osmosis

\[ \Pi = MRT \]
Osmosis

What is the osmotic pressure of 145mL aqueous solution containing 2.02g of urea ((NH₂)₂CO at 20 °C?

\[
\Pi = MRT = \frac{2.02\, g\,(NH_2)_2\, CO \left(\frac{mol\,(NH_2)_2\, CO}{60\, g}\right)}{0.145\, L} \left(\frac{0.08206\, L\cdot atm}{K\cdot mol}\right)293.15K
\]

\[
\Pi = 5.58\, atm
\]

**hypertonic solution** - has a higher osmotic pressure than a comparison solution (blood)

**Hypotonic solution** - has a lower osmotic pressure than a comparison solution (blood)

**Isotonic solution** - has the same osmotic pressure as a comparison solution (blood)
Quiz question

In a Mountainous region the boiling pt. of pure water is 95.0°C. How many grams of table salt must be added to 1.00 kg of water to bring the boiling pt. to 100.°C, \( k_b = 0.5121 \text{oC/m} \)?

Step 1. Find moles solute required to raise temp to 100°C.

\[
\Delta T = i k_b m \Rightarrow m = \frac{\Delta T}{i k_b} = \frac{5 \text{oC}}{(2).5121 \text{oC/m}} = 4.8819m
\]

\[
m = \frac{n_{\text{solute}}}{k g_{\text{solvent}}} \Rightarrow n_{\text{solute}} = m(kg_{\text{solvent}}) = 4.8819 \left( \frac{mole_{\text{solute}}}{kg_{\text{solvent}}} \right)(1kg_{\text{solvent}}) = 4.8819mol
\]
Step 2: Calculate Mass from moles and molar mass. Note, $m$ is molality of all solute particles, that is, $i = 2$ in the first step.

\[
Molar \ Mass = \frac{mass(g)}{n(mole)} \Rightarrow mass = (Molar \ Mass) (n)
\]

\[
mass_{solute} = 58.45 \left(\frac{g}{mol}\right)[4.8819mol] = 285g
\]
Colloids

Colloidal Dispersions (Colloids) Represent a State Between a Suspension & a Solution

**Aerosol** - liquid/solid dispersed in gas

**Foam** - gas dispersed in liquid or solid

**Emulsion** - 1 liquid dispersed in another

**Sol** - solid dispersed in liquid or solid

**Gel** - liquid dispersed in solid
Colloids

Hydrophobic Colloids (Water Fearing)

Hydrophilic Colloids (Water Loving)

• AgCl(s) often forms colloidal suspensions during precipitation reactions and sort of “Floats”.

• Results if a lot of Ag$^+$ is present
  
  • several surround the Cl$^-$ giving a positively charged colloidal particle

  • Attracts a secondary layer of negative anions

• Repulsions between like charged colloids prevents ions from coming together and forming large precipitates.
Colloids

Hydrophobic Colloids (Water Fearing)

Hydrophilic Colloids (Water Loving)

Coagulation - aggregation of dispersed phase

Micelle - colloidal sized particle created by the association of hydrophilic & hydrophobic particles (like parts attract each other while
Soaps - Emulsifying Agents