Solutions (Concentration and Units)

Reading: Chapter 6: p 190-191, 194-197, 200-203, 206-207
Problems: (all Ch 6) 59, 61, 63, 65, 67, 69, 83, 85, 87, 89, 93, 99, 101a,b, 105, 117, 119, 121, 123, 129, 131

I. Introduction
A. Types of matter (Review from “Compounds”)
   1. Pure substances:
      Diamond (elemental form of C) is pure.
      Really clean water (molecular compound, H\textsubscript{2}O) is pure.
      Table salt (ionic compound, NaCl) is pure????? Depends!
   2. Mixtures
      a) heterogeneous (not the same all over, ex.: pepperoni pizza)
      b) homogeneous (same throughout, ex.: Kool-aid, sweet tea if every component is dissolved.)
      c) colloids (somewhere between hetero- and homogenous, chunk size, ex.: fog, dust motes in air)

B. Homogeneous mixture is a solution.
   Important to understand this!

C. We often think of solutions as liquids, but they can exist in other phases as well.
   Brass is a solution of copper and zinc.

II. Solutions (phases and definitions)
A. It is useful to define two components of a solution.
   1. The solvent is the component present in greater amount.
   2. The solute is the component present in lesser amount. There can be more than 1 solute.

B. Example: salt water. In a 5 % solution of NaCl, what is the solute & what is the solvent?

III. Characteristics of Solutions
A. Distribution of components is uniform.

B. Components do not settle on standing.

C. Components cannot be separate by filtration.

D. You can mix solute-solvent pairs in a continuous range of ratios.
   (Ex.: strong vs. weak coffee)

E. Aqueous solutions are “clear”. They do not scatter light. (opposite of cloudy)

F. Solutions can be separated by physical means.
IV. Concentration Units & Dilution

A. This is tremendously important when we apply solutions to life.

1. Examples:
   a) How strong do you like your coffee (tea)?
   b) Effective drug dose vs. overdose

   http://www.medpagetoday.com/Pediatrics/GeneralPediatrics/7469

2. All concentration units are some type of ratio, for us: quantity of solute/quantity of solution

B. Percent Concentration (nice for making solns.)

Definition of % is ratio to 100:
\[
\frac{\text{Part}}{\text{Whole}} = \frac{\%}{100} \quad \text{or} \quad \% = \frac{\text{part}}{\text{whole}} \times 100
\]

1. Percent weight/volume \(\% (w/v)\): solute weight to soln. volume

\[
\% \frac{w}{v} = \frac{\text{g of solute}}{\text{mL of solution}} \times 100
\]

Problem: Calculate the \( (w/v) \) of a soln. containing 351.0 g NaCl in a volume of 2.831 L.

2. Percent volume/volume \(\% (v/v)\): Solute volume to soln. volume (Alcohol in drinks)

\[
\% \frac{v}{v} = \frac{\text{mL of solute}}{\text{mL of solution}} \times 100
\]

3. Percent weight/weight \(\% (w/w)\): solute weight to soln. weight

\[
\% \frac{w}{w} = \frac{\text{g of solute}}{\text{g of solution}} \times 100
\]
C. Molarity (**chemists like molarity!**), abbreviated M

1. Definition: molarity = \( \frac{\text{moles of solute}}{\text{Liters of solution}} \)

2. Try using \( \frac{\text{mol}}{\text{L}} \) instead of M. It helps w/ cancelling, among other things.

Problem: Calculate the concentration in molarity of a solution whose volume is 855 mL that contains 4.500 g of KCl.

D. Parts per million (ppm) Ratio to \( 10^6 \), usually by wt.

Compare to %, (ratio to 100).

PPM is used in environmental & toxicity settings.

E. Dilution (like with concentrated orange juice?)

\[ M_1 V_1 = M_2 V_2 \]  
(where M = conc., V= volume, 1 = initial, 2 = final)

Problem: If you dilute 65.0 mL of 8.0 M HCl, to a final volume of 0.400 L, what will be the concentration of the diluted solution?

V. Solubility (usually has limits)

A. Solubility – meaning

1. Concerns the general process of a solute dissolving in a solvent.

2. Sometimes we may say the solubility is high (it is soluble) or low (not very soluble).

3. More specifically, it is the amount of solute that will dissolve in a solvent.

   a) Is there a max. amount that can dissolve? Y or N (sweet tea?)
b) When the max. is dissolved, the soln. is saturated.

c) A solution can be super-saturated for short periods of time. (Coke that “explodes” when bumped)
A super-saturated solution is not in equilibrium.
http://www.youtube.com/watch?v=XSGvy2FPICw
http://www.youtube.com/watch?v=cu9SXX6-hmc

4. Miscible is a related term.
   Two liquids that can dissolve in each other in any ratio are miscible.

B. Nature of Solute and Solvent
   1. “Like dissolves like”
   
   2. This usually focuses on polarity of the solvents.
   
   3. Does oil (non-polar) dissolve in water (polar)?
   
   4. Does sugar (polar) dissolve in water (polar)?

C. Temperature Effects on Solubility
   1. Often, for solids & liquids dissolving in a liquid,
      solubility ↑ as temperature ↑ (sugar/tea).
   
   2. For gases dissolving in liquids,
      solubility ↓ as T ↑  Example: CO$_2$ in soda pop

<table>
<thead>
<tr>
<th>Temperature ($^\circ$C)</th>
<th>Oxygen Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.1</td>
</tr>
<tr>
<td>5</td>
<td>12.7</td>
</tr>
<tr>
<td>20</td>
<td>9.0</td>
</tr>
<tr>
<td>30</td>
<td>7.5</td>
</tr>
<tr>
<td>40</td>
<td>6.4</td>
</tr>
</tbody>
</table>

3. The importance of 2 example: Thermal pollution by industrial heat sources.

D. Pressure
   1. Henry’s Law  (English Chemist) As pressure of a gas increases over a liquid, the gas solubility increases.
      So if pressure doubles, the solubility doubles.

   2. Applications:
      a) making soda pop

      b) hyperbaric O$_2$ chamber: gangrene, CO poisoning, tetanus, healing of skin grafts etc.
c) \( \text{N}_2 \) solubility, scuba diving and “the bends”


(results when previously dissolved gases come out of solution to form bubbles during depressurization.)

VI. Solutions with Water as a Solvent:

“Like dissolves Like”

A. First, see \( \text{H}_2\text{O} \) as a liquid: “Molecular Motion in Water:”

http://www.youtube.com/watch?v=t5ZFoU0S5iE&feature=related

At the start, “O” of water is purple, “H” is grey-blue.
As you move into the soln, the water molecules are whitish.
What do the yellow lines that form and disappear represent?
Draw molecules of water H-bonding in space on right.

B. How does water dissolve ionic compounds?
1. Draw a picture of a cation dissolved in \( \text{H}_2\text{O} \). (See animations for help.)

Animations:

http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/molvie1.swf

http://www.northland.cc.mn.us/biology/Biology1111/ go to animations, then dissolve.html

http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/thermochem/solutionSalt.html

2. To determine if a process (like dissolving) is favorable, compare initial & final states for all components using \( \Delta G = \Delta H - T \Delta S \)
   a) If substance dissolves readily, the sign for \( \Delta G \) for that process is . (Free energy)
   b) The \( \Delta H \) term in equation relates to forming/breaking interactions (for ex. H Bonding)
   c) The \( \Delta S \) term relates to whether randomness is increasing. It often dominates when dissolving substances in water.
   d) For ionic compounds that dissolve, stuff on right is more important than stuff on left.
      break some H-bonding of water form interaction between ion and water
      break ionic bonds increase randomness

C. Electrolytes
1. Compounds that dissociate in water to form charged particles.
2. Strong electrolytes, ex.: In water, NaCl falls apart completely to give Na\(^+\) & Cl\(^-\).
3. Weak electrolytes, ex.: In water, acetic acid (CH\(_3\)COOH) falls apart partially
D. How water dissolves covalent compounds
   1. Goal: Be able to draw a picture of ethanol, C\textsubscript{2}H\textsubscript{5}OH, dissolved in water.
   2. Compare dissolved state vs. two separate phases.
      a) Hydrogen bonds do form between ethanol and water

      b) During this hydrogen bond formation,
         are new Hydrogen Bonds being formed (which would contribute favorable to \( \Delta H \)),
         or
         are we just swapping one H Bond for another (which would give no net gain in \( \Delta H \))?
      c) Ethanol is so soluble in water because it has relatively small non-polar surface area.

Let's compare alcohols that have different non-polar surface area.

Identify the non-polar part of C\textsubscript{2}H\textsubscript{5}OH. Identify the non-polar part of C\textsubscript{6}H\textsubscript{13}OH.

Is C\textsubscript{6}H\textsubscript{13}OH more or less soluble in water than C\textsubscript{2}H\textsubscript{5}OH?
### Alcohol Chain Length: Water Solubility & Boiling Point

<table>
<thead>
<tr>
<th>Name</th>
<th>Structure</th>
<th>solubility in H₂O (g/100 mL)</th>
<th>b.p. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-propanol</td>
<td><img src="image" alt="Structure" /></td>
<td>completely miscible</td>
<td>101.6</td>
</tr>
<tr>
<td>1-butanol</td>
<td><img src="image" alt="Structure" /></td>
<td>7.4</td>
<td>~117.5</td>
</tr>
<tr>
<td>1-pentanol</td>
<td><img src="image" alt="Structure" /></td>
<td>2.7</td>
<td>135.5</td>
</tr>
<tr>
<td>1-hexanol</td>
<td><img src="image" alt="Structure" /></td>
<td>0.59</td>
<td>157</td>
</tr>
</tbody>
</table>

All values from the 10th edition of the Merck Index except for the solubility of 1-hexanol. That value is from: [http://www.inchem.org/documents/icsc/icsc/eics1084.htm](http://www.inchem.org/documents/icsc/icsc/eics1084.htm)

Based on the table above, is the non-polar surface area or Hydrogen Bonding (by the alcohol) more important in determining the solubility of organic alcohols in water?

Circle one: non-polar surface area          Hydrogen Bonding


Does gasoline dissolve in water?

\[ \text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3 \]

Use octane (C₈H₁₈) to represent gasoline.

a. A bit tricky, because it can’t be viewed strictly as bonding.
b. Relates to the ordering of $\text{H}_2\text{O}$ molecules into cage-like structures around non-polar solutes.

Let’s look at an animation:

“Hydration shell dynamics of a hydrophobic particle:”
http://www.youtube.com/watch?v=ETMmH2trTpM&feature=related

c. Is the formation of ordered structures inherently favorable? 

d. Draw pictures of the two states:

$\text{C}_8\text{H}_{18}$ and water as separate phases $\leftrightarrow$ $\text{C}_8\text{H}_{18}$ dissolved in water.

Which state has more favorable $\Delta H$ and $\Delta S$ terms?