**Name** _____**Chem 162 Section**: _____**Group Number:** _____

# *ALE 21. The Solvation Process*

(Reference: 13.1 – 13.2 *Silberberg 5th edition*)

## *How do intermolecular forces dictate whether compounds form a solution?*

## The Model: Solvent versus Solute

A solution is a **homogeneous mixture** of at least two components: a **solvent** and a **solute**. The solvent is the substance that dissolves and the solute is the substance that is dissolved (literally, is "loosened apart").

A *gas can dissolve in another gas* (e.g. air is a solution of $O_2$ and other gases "dissolved" in $N_2$) and *a gas can dissolve in a liquid* (e.g. carbonated water is $CO_2$ gas dissolved in water). A *liquid can dissolve in either another liquid* (e.g. a solution of hydrogen peroxide consists of liquid $H_20_2$ dissolved in water). And a *solid can dissolve in a liquid* (e.g. salt water is solid NaCl dissolved in water) and *a solid can dissolve in another solid* (e.g. brass is an alloy of copper and zinc). When deciding which component is the solvent and which is the solute, the **solvent** generally has the same phase as the solution. Also the **solvent** is generally the species with the greater number of particles within the solution.

### Key Questions

1. In each of the following solutions, determine which is the solute and which is the solvent.

a. Seawater: primarily a mixture of water and sodium chloride

**Solute:** _____ **Solvent:** _____

b. Dental amalgam: a mixture of mercury and silver

**Solute:** _____ **Solvent:** _____

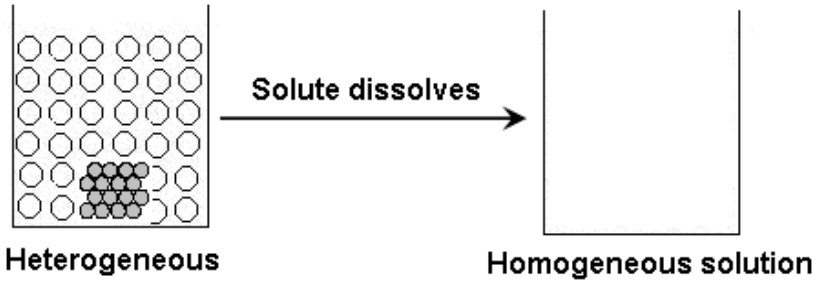
c. Air: a mixture of primarily nitrogen (~78% by volume) and oxygen (~21% by volume)

**Solute:** _____ **Solvent:** _____

d. Carbonated water: a mixture of carbon dioxide and water

**Solute:** _____ **Solvent:** _____

2. Suppose the figure below represents a "freeze frame" of a solid molecular compound (e.g. table sugar, where each dark sphere represents a sucrose molecule, $C_{12}H_{22}O_{11}$) that has been placed in a liquid solvent (e.g. water), but it has not yet been dissolved. (The solvent molecules are, of course, in constant random motion. This is, of course, just a "cartoon" as evidence by the exceptionally large size of the symbols representing the molecules.) On the right, sketch what the mixture might look like once it is made a solution. (You needn't worry about maintaining the same number of solvent molecules—it's only a sketch!)



3. Nature favors processes that maximize disorder—consider your bedroom if you do not put in some energy to keep it tidy! One of the reasons why a solution forms when two substances are mixed is that the system becomes more disordered—i.e. the formation of a solution results in an increase in ***entropy***—entropy is a measure of disorder. Refer to your sketch in Question 2 and explain how the solution is more disordered (i.e. is of *higher entropy*) than the segregated components.

4 a. What do dispersion forces and dipole-dipole forces have in common?

b. What is the difference between dispersion forces and dipole-dipole forces?

c. All molecular compounds have dispersion forces that hold the molecules together in the liquid (or solid) of that compound. When are molecules held together by dipole-dipole forces?

d. When are dipole-dipole forces referred to as "hydrogen bonds"?

5. Intermolecular forces must be broken in order to separate neighboring molecules from each other. When molecules are separated, is this an exothermic or an endothermic exchange of heat with the surroundings? (*Hint*: Think of evaporation of a liquid. Is this process exothermic or endothermic?) (*Circle your responses*.)
6. When molecules of solvent surround a molecule of solute, new intermolecular forces will be established. When molecules of solvent interact with a molecule of solute, is this an exothermic or an endothermic exchange of heat with the surroundings? *Explain your answer*.

7. Exothermic processes *tend* to be spontaneous while endothermic processes tend to be nonspontaneous. We can think of the solvation process as occurring stepwise:

   Step ① Heat is added to separate the molecules of solute;

   Step ② Heat is added to separate the molecules of solvent; and

   Step ③ Solvent molecules and solute molecules "condense" and interact, releasing heat.

   If Step ③ is more exothermic than the sum of heats involved in Steps ① and ②, then the overall process is exothermic (Recall Hess's Law!) and the process tends to be spontaneous.

   a. Suppose the intermolecular forces within the solute are "strong". If the intermolecular forces between the solvent and the solute are "weak", will a solution likely form: Yes or No?

   b. Suppose the intermolecular forces within the solute are "weak". If the intermolecular forces between the solvent and the solute are "strong", will a solution likely form: Yes or No?

## *How can you predict if two substances will form a solution?*

## Model: Attractive forces between Solute and Solvent

For a solution to form between a solid and a liquid, the solute and solvent particles must be attracted to one another: **"Like Dissolves Like"** In general, for a solution to form, solute-solvent interparticle attractive forces must be greater than solvent-solvent and solute-solute interparticle attractive forces.

Hence, when predicting if a solution will form, in addition to considering entropy, the nature of the forces between solute and solvent particles must be considered. The major kinds of interparticle forces in solution are illustrated below in fig. 1, below.

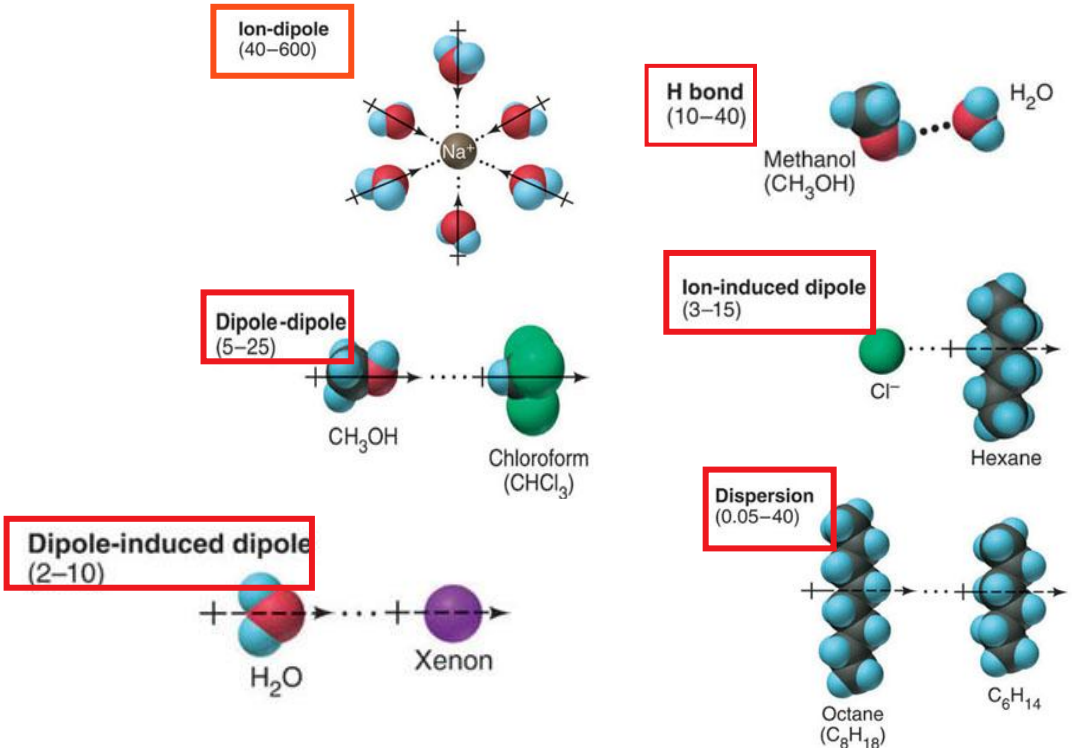



**Figure 1.** The major types of interparticle forces that exist between solute and solvent particles within a solution with the range of approximate bond energies in parentheses in kJ/mol.

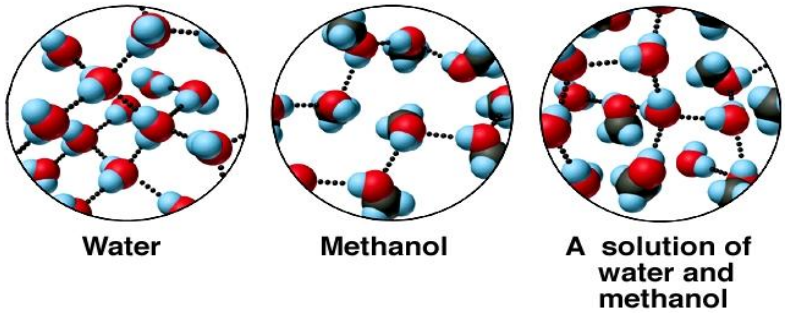



**Figure 2.** Illustrations of the major interparticle attractive forces in water, methanol and a solution between water and methanol.

**Key Questions**

8. Why does a solution form between water and methanol? *Hint*: Address the kinds of kind(s) of interparticle bonds involved and the role played by entropy.

9. Why do all nonpolar liquids mix to form solutions? *Give an example or two to support your response*.

10. Identify the *strongest* type of interparticle force between solute and solvent in each of the following:

    a.) $Cu_{(s)}$ in $Ag_{(s)}$ _____

    b.) $CH_3F_{(g)}$ in $CH_3OCH_{3\,(g)}$ _____

    c.) $CH_3CH_{3(g)}$ in $CH_3CH_2CH_2NH_{2\,(l)}$ _____

    d.) $NaCl_{(aq)}$ _____

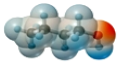
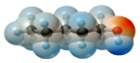
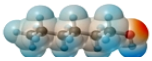
    e.) $HCl_{(aq)}$ _____

11. Circle the member of each pair that you would predict to be *more soluble in water* and *briefly explain your reasoning*.

    a.) $CH_3CH_2OCH_2CH_{3(l)}$ or $CH_3CH_2OCH_{3(g)}$

    b.) $CH_2Cl_{2(l)}$ or $CCl_{4(l)}$

**Table 1.** Solubility of alcohols in water and hexane. Solubility is expressed in mol alcohol/100g solvent at 20 °C)

| Alcohol | Model | Water | Hexane |
|---|---|---|---|
| $CH_3OH$ (methanol) |  | ∞ | 0.12 |
| $CH_3CH_2OH$ (ethanol) |  | ∞ | ∞ |
| $CH_3(CH_2)_2OH$ (propanol) |  | ∞ | ∞ |
| $CH_3(CH_2)_3OH$ (butanol) |  | 0.11 | ∞ |
| $CH_3(CH_2)_4OH$ (pentanol) |  | 0.030 | ∞ |
| $CH_3(CH_2)_5OH$ (hexanol) |  | 0.0058 | ∞ |

**Refer to Table 1, above, to answer the following two questions.**

12. a. Compared to butanol, pentanol and hexanol, the solubility of methanol, ethanol and propanol in water is extremely: *high* *low* (Circle your response.)
    b. Explain why the solubility of methanol, ethanol and propanol in water is quite different from that of butanol, pentanol and hexanol.

13. a. Compared to the other five alcohols listed in table 1, above, the solubility of methanol in hexane is relatively: *high* *low* (Circle your response.)
    b. Explain why methanol's solubility in hexane is different from the other five alcohols in table 1.

14. Chemical cold packs used by athletic trainers are activated by the dissolving of ammonium nitrate ($NH_4NO_3$) in water, a highly endothermic process—i.e. ammonium nitrate has an endothermic heat of solution ($\Delta H_{soln}$). What is the driving force behind ammonium nitrate's solubility in water? Circle the correct response and *explain your reasoning*.

    a.) Entropy  b.) Endothermic $\Delta H_{soln}$  c.) Entropy and Endothermic $\Delta H_{soln}$

15. Would you expect NaCl to be soluble in hexane? *Yes* or *No* (Circle your response and *explain below*.)