# Energy Changes – Solution Formation

## ΔHsoln – Enthalpy of Solution Formation

Bond breaking: endothermic (ΔH > 0), requires energy

Bond formation: exothermic (ΔH < 0), releases energy.

Solution formation requires:

* Breaking the attractive forces between solute molecules or ions.
* Breaking some of the attractive interactions between solvent molecules
* Forming new attractive interactions between solute and solvent.

### Entropy: How can we account for + ΔHsoln?

* Enthalphy of solution formation can be calculated by adding together the enthalpy at each step in the process of solution formation. In general, if ΔHsoln is negative the solution forms. If it is positive the solution can form if there is a favorable increase in entropy due to mixing.
* NH4NO3 dissolved in water, the solution gets cold (positive enthalpy), yet NH4NO3 is very water soluble
* Another factor, entropy, accounts for the spontaneous dissolution of NH4NO3.
* Entropy is a measure of how dispersed or spread out energy is in a system.
* When a solution forms, entropy increases because there are more energy microstates in the system. The second law of thermodynamics states that entropy increases.

### Model 1: Like Dissolves Like

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| Class of Compounds | Structure | Water solubility | Hexane solubility |  |
| Alkanes | CH3(CH2)nCH3 | Insoluble | Very soluble |  |
| Alcohols |  |  |  |  |
|  | CH3CH2OH | Miscible | Miscible |  |
|  | CH3(CH2)3OH | Partially soluble | Partially soluble |  |
|  | CH3(CH2)7OH | Insoluble | Very soluble |  |
| NaCl |  | Very soluble | Insoluble |  |

Hexane:



### Questions

1. What happens to water solubility of alcohols as the number of carbons increase?

***Water solubility of alcohols decreases as the number of carbons increase.***

1. What happened to hexane solubility of alcohols as the number of carbons increase?

***Hexane solubility of alcohols decreases as the number of carbons increase.***

1. Are alkanes polar or nonpolar? ***Nonpolar***
2. How does the polarity of alkanes account for their solubility in hexane and lack of solubility in water?

***Hexane is nonpolar and will dissolve nonpolar alkanes. (Favorable London dispersion interactions can occur between the solvent and solute.) Water is very polar and cannot form favorable intermolecular interactions with nonpolar alkanes.***

1. What intermolecular interaction is formed between octane (C8H18) and hexane in solution?

***London dispersion (between nonpolar molecules of solvent and solute)***

1. All of the alcohols are capable of hydrogen bonding. What intermolecular force increases as the number of carbons (and hydrogens) in an alcohol increases? ***London dispersion***
2. How might your answer to question 7 explain the solubility trends of alcohols in water and in hexanes?

***For the smaller alcohols, the possibility of hydrogen bonding with water drives the solution process. When added to hexane, it is favorable for molecules of these compounds to hydrogen bond to other solute molecules. There is no strong intermolecular attraction between the smaller alcohols and nonpolar hexane.***

***As the London dispersion attractions increase, it becomes more difficult to break up the attractions between solute molecules and less favorable to form intermolecular attraction between solute and polar water. The increased London dispersion effects make it more favorable for the larger alcohols to form London dispersion interactions with nonpolar hexanes.***

1. Why is NaCl water soluble, but not soluble in hexane? (Explain in terms of intermolecular interactions between NaCl ions, between hexane molecules, and possible intermolecular interactions in solution.)

***NaCl can form ion dipole interactions with water, which is exothermic enough to drive the separation of ionic attraction between Na+ and Cl- and the separation of some hydrogen bonds between water molecules. NaCl has no strong intermolecular interaction with nonpolar hexane. The attraction between ions is strong and not compensated by an exothermic solution interaction.***

1. Predict the solubility of 1-aminopropane (H2NCH2CH2CH3) in water. Explain. (Go beyond “like dissolves like.”)

***1-aminopropane would be predicted to be water soluble. It contains N-H, capable of forming hydrogen bonds with water ( an exothermic process) and the London dispersion interactions between solute molecules are relative small for compounds with only 3 carbons.***

1. Predict the solubility of glucose in hexane. Explain. (Go beyond “like dissolves like.”)

***Glucose is predicted to be insoluble in hexane. Glucose molecules strongly hydrogen bond to each other. There is no strong intermolecular attraction between very polar glucose and nonpolar hexane to make the formation of solution favorable.***

### Take Home Exercises

1. Refer back to Activity 8. We found that ionic compounds between +1 cations and -1 anions are generally very water soluble, while compounds between +3 cations and -3 anions are insoluble. Which of the processes in forming solution is likely to become more endothermic for the +3/-3 ions? Explain.

***ΔH for separating the cations and anions from each other is likely to be more endothermic for the +3/-3 ions because the electrostatic attraction between ions increases with charge.***

1. Three bottles labeled A, B, and C are filled with different liquids, one of either propanol (CH3CH2CH2OH),pentane (CH3CH2CH2CH2CH3), or 1-octanol (CH3CH2CH2CH2CH2CH2CH2CH2OH). Label these compounds as polar or nonpolar. Use the following information on solubility properties to identify A, B, and C.

* When 10 drops of compound A are added to several milliliters of water, a thin layer of liquid A is observed on top of the water.
* When 10 drops of compound B are added to several milliliters of water, the first few drops dissolve completely, but the end result is a thin layer of liquid B on top of the water.
* When 10 drops of compound C are added to several milliliters of water, it dissolves completely.

***Propanol is polar and would be expected to be completely soluble in water (compound C)***

***Pentane is nonpolar and would be expected to be completely insoluble in water (compound A).***

***1-octanol, although it contains a polar OH group, contains a long C-H chain which makes it less polar. It is likely slightly water soluble (compound B)***

1. The molecular structure of three pesticides follow, along with their saturation concentration in water in mg/L. Using your knowledge of polarity and hydrogen bonding, explain the differences in the water solubility of these compounds.

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| ChemSpider 2D Image | Malathion | C10H19O6PS2 | ChemSpider 2D Image | CHLORDANE | C10H6Cl8 | ChemSpider 2D Image | 2,4-Dichlorophenoxyacetic acid | C8H6Cl2O3 |
| Malathion, 143 mg/L | Chlordane, 0.1 mg/L | 2,4-Dichlorophenoxyacetic acid, 682 mg/L |

**Note**: Problems 11 and 12 were taken from ChemConnections: Water Treatment: How Can We Make Our Water Safe to Drink? ©WW Norton 2004

***Chlordane is relatively nonpolar. It is not likely to form favorable intermolecular attractions with water.***

***Malathion is more polar and contains oxygen atoms. Water can form hydrogen bonds to these oxygens, so malathion is more soluble than chlordane.***

***2.4-dichlorophenoxyacetic acid contains an O-H group, so it can hydrogen bond to water. This makes it the most soluble of the pesticides.***