Solubility and IMFs

Remember solubility rules? 😊 The bolded 3 at the beginning are the only ones you need to memorize, but there are lots and lots of solubility patterns we can observe.

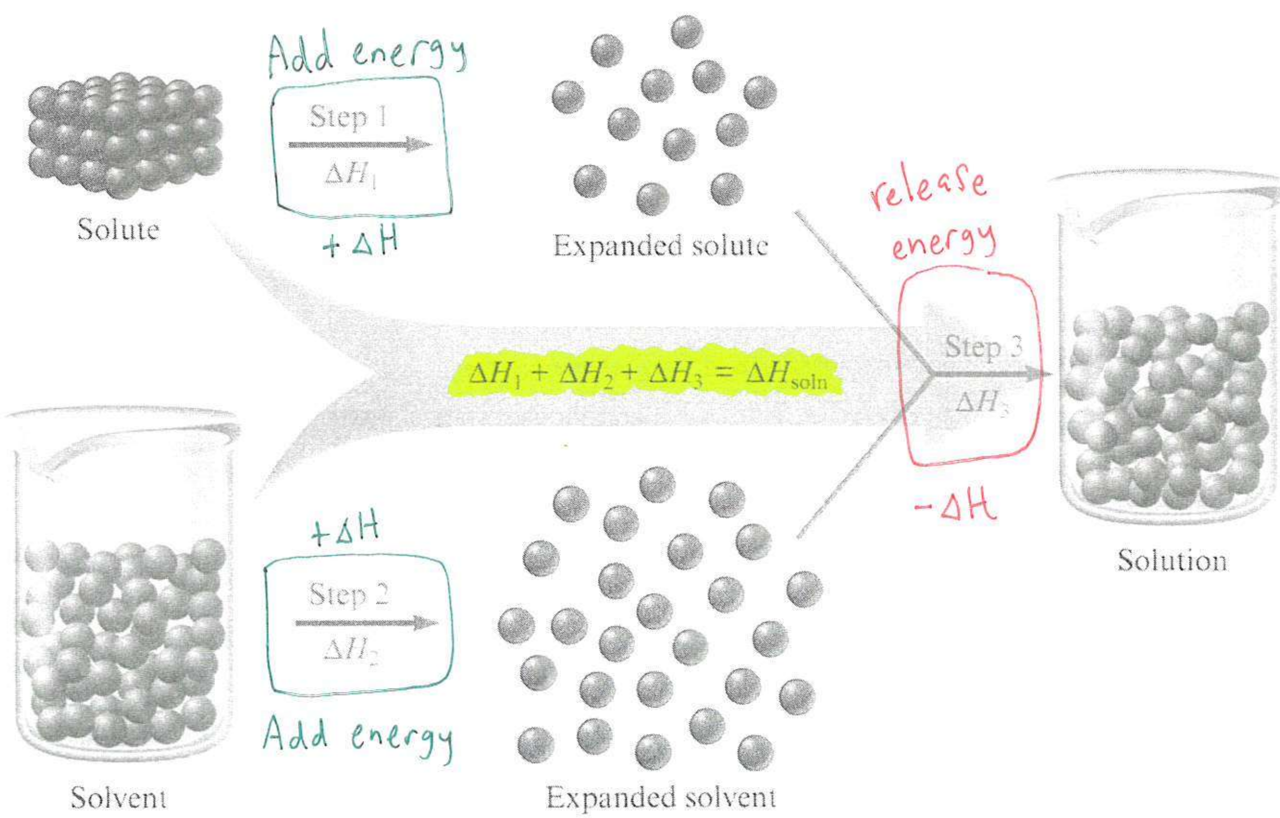
1. **Always soluble: alkali metal cations, NH_4^+, NO_3^-** (also ClO_3^-, ClO_4^-, $C_2H_3O_2^-$, HCO_3^-)
2. Generally soluble:
   a. Bromide, chloride, and iodide anions are soluble except when combined with Ag^+, Pb^{2+}, and Hg_2^{2+}.
   b. SO_4^{2-} is soluble except when combined with Sr^{2+}, Ba^{2+}, Pb^{2+}, and Hg_2^{2+}.
3. Generally insoluble:
   a. OH^- and S^{2-} are insoluble except when combined with Ca^{2+}, Sr^{2+}, Ba^{2+}, (and things from rule 1).
   b. CO_3^{2-}, PO_4^{3-}, SO_3^{2-}, and CrO_4^{2-} are insoluble except when combined with things from rule 1.

IMFs help explain these patterns of solubility!

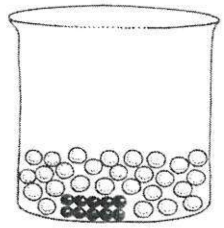
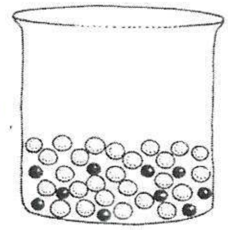
Dissolution depends on the forces of attraction between Solute and Solvent particles

In order to dissolve a substance, you must:

1. Add energy: Overcome attractions (requires energy = endothermic) *"endo-ing" an attraction is endothermic!*
   a. Solute-solute IMFs (or ion-ion electrostatic attraction, if ionic)
   b. Solvent-solvent IMFs
2. Release energy: Form solute-solvent attractive forces upon mixing (releases energy = exothermic)

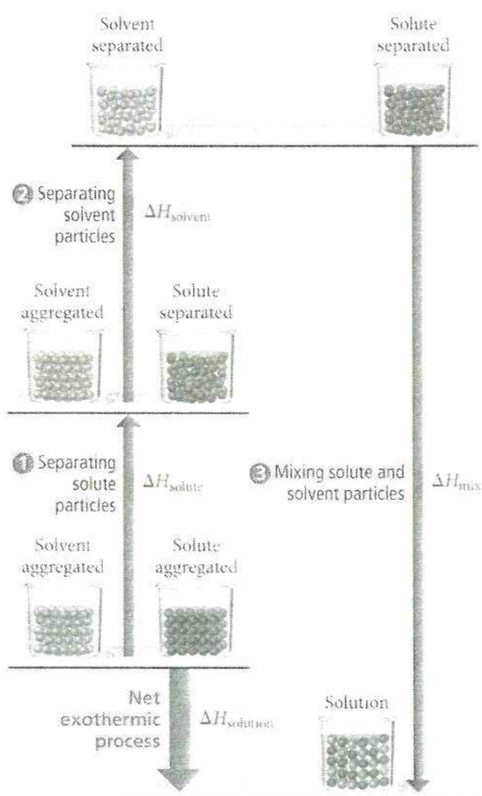
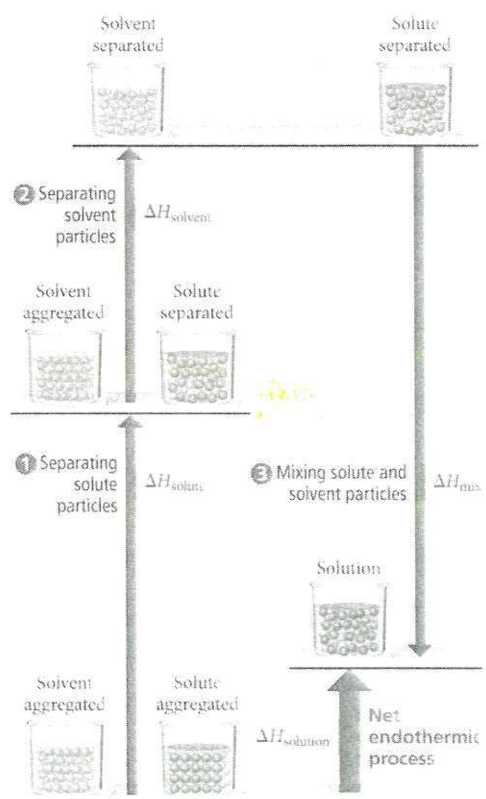


Soluble or Insoluble?

Soluble	Insoluble
Higher solute-solvent attractions	Lower solute-solvent attractions
 Soluble (miscible)	Backwards pictures! oops...  Insoluble (immiscible)

Notice, in general, the solute particles that are **INSOLUBLE** have ___larger___ ion charges, which means they have a greater attraction to other solute particles: go, Coulomb's Law, go!

The Thermodynamics of Dissolution

Exothermic Dissolution ($-\Delta H_{soln}$)	Endothermic Dissolution ($+\Delta H_{soln}$)
• Heat released when salt dissolve • Feels warm to the touch	• Heat absorbed when salt dissolve • Feels cold to the touch
Always thermodynamically favorable ($-\Delta G$) because entropy will always increase $-\Delta H$, $+\Delta S$	**Thermodynamically favorable at warmer temperatures**, depending on increase in entropy $+\Delta H$, $+\Delta S$
	

Handy rule of thumb: **"Like dissolves like"**

Great multiple choice trick but does not count as explanation on free response!

1. Polar solvents dissolve polar solutes
   - Hydrophilic (polar) groups to watch for: OH, CHO, C=O, COOH, NH_2, and Cl.
2. Non-polar solvents dissolve non-polar solutes
   - Hydrophobic (non-polar) groups to watch for: C – H and C – C.

Many molecules have both hydrophilic and hydrophobic parts; solubility in water becomes a Competition between the attraction of the polar groups for water and the attraction of the nonpolar groups for their own kind.

Never use "like dissolves like" to explain a FR on the AP exam: instead, EXPLAIN in terms of structure, IMFs, and energy!

So… how *do* you explain solubility for free response questions?

1. **Identify solute-solvent IMFS**

Type of Substance	Dominant Interaction with Water	Dominant Interaction with a Non-polar Solvent
Ionic	ion-dipole	ion-induced dipole (nope)
Polar + FON	hydrogen bonds	dipole-induced dipole
Polar	dipole-dipole	dipole-induced dipole
Non-polar	dipole-induced dipole	induced dipole-induced dipole (London dispersion forces)

2. **Are solute–solvent attractions greater than solute–solute (or solvent–solvent) attractions?**
   - Explain: strong interactions BETWEEN solvent and solute → yes, solute will dissolve!
3. **Solute–solvent attractions weaker than solute–solute (or solvent–solvent) attractions?**
   - Explain: weak solute–solvent interactions are not as strong as existing solvent–solvent (or solute-solute) attractions, thus solute will NOT dissolve.

Of course, you must be Specific! ☺! Identify **BOTH** solute and solvent by name or formula.

*Note: you do NOT have to explain WHY a given compound can form specific IMFS; it is enough to state them.

Example #1: Can CH_3OH dissolve in water? Why or why not?

Too much "CH_3OH can form hydrogen bonds with water because it has a hydrogen which is covalently bonded to an oxygen, so it will form strong IMFs with water and thus will be able to dissolve in water."

Just right "CH_3OH can form strong hydrogen bonds with water, so it will be able to dissolve."

Not enough "CH_3OH can form strong hydrogen bonds, so it will be able to dissolve in water."

Example #2: Can benzene, C_6H_6, dissolve in water? Why or why not?

Too much "C_6H_6 is non-polar with has a dipole moment of zero, and so it can only form weak dipole-induced dipole interactions with water, which are not as strong as the hydrogen bonds that already exist between water molecules, so C_6H_6 won't dissolve in water."

Just right "C_6H_6 is non-polar and can only form weak intermolecular attractions with water, which are not as strong as the hydrogen bonds that already exist between water molecules, so C_6H_6 won't dissolve in water."

Not enough "C_6H_6 is non-polar, so it won't dissolve in a polar substance like water."

polar + FON   non-polar

Example FR question: Which is more likely to be soluble in water, liquid methanol (CH_3OH) or liquid hexane (C_6H_{14})? Justify your answer.

- CH_3OH is more likely to be soluble in H_2O than C_6H_{14}
- CH_3OH is polar + can form strong hydrogen bonds with water
- C_6H_{14} is non-polar + can only form weak dipole-induced dipole attractions with water

Free Response Practice!

Directions: Use principles of atomic structure, bonding, and intermolecular forces to answer the following questions. Your responses must include specific information about all substances referred to in each part.

1. Ammonia, NH_3, is very soluble in water, whereas phosphine, PH_3, is only moderately soluble in water. Explain.

- NH_3 can form strong hydrogen bonds w/ water ⇒ highly soluble in H_2O
- PH_3 can form dipole-dipole attractions w/ water, which are not as strong as the hydrogen bonds that already exist between H_2O molecules, ⇒ only moderately soluble in H_2O