Solutions & Dissolution

Unit: Solutions

MA Curriculum Frameworks (2016): HS-PS2-7(MA)

Mastery Objective(s): (Students will be able to…)

- Describe how a solution forms.
- Explain the effect of temperature changes on solubility.

Success Criteria:

- Descriptions account for solvent-solute interactions.
- Descriptions account for intermolecular forces.
- Explanations of the effect of temperature are consistent with solubility curves.

Tier 2 Vocabulary: solution

Language Objectives:

- Explain how solutes dissolve in solvents.

Notes:

solute: a substance that is broken down and dissolved into another substance. Solutes can be solids, liquids, or gases.

solvent: a substance that contains a solute. Solvents can be solids or liquids.

solution: a mixture that consists of a solute dissolved in a solvent.

dissolution or solvation: the process of a solute dissolving in a solvent.

solubility: the amount of a solute that can dissolve in a solvent. Often expressed in $\frac{\text{mol}}{\text{L}}$ or $\frac{\text{g}}{\text{L}}$.

soluble: when a solute can dissolve in a solvent.

insoluble: when a solute cannot dissolve in a solvent. Common threshold values are that solutes with solubilities of less than $1\,\frac{\text{g}}{\text{L}}$ or less than $0.01\,\frac{\text{mol}}{\text{L}}$ in a given solvent are considered insoluble.

miscible: when two liquids can dissolve in (mix freely with) each other

dissociation: when ions split apart in a solution. *E.g.,* when NaCl dissolves, the Na^+ and Cl^- ions separate and dissolve separately.

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electrolyte: a solution that conducts electricity. Electrolytes are generally made when ionic compounds (salts) dissociate and dissolve, and the ions conduct electrons (electricity) through the solution.

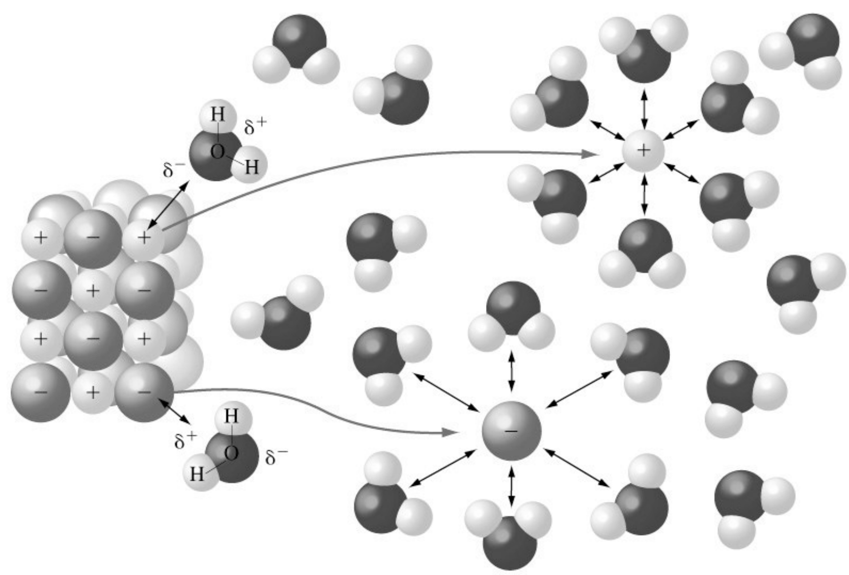
saturated solution: a solution that holds as much solute as the solvent is capable of dissolving at a given temperature.

unsaturated solution: a solution that contains less solute than is capable of dissolving in a solvent.

supersaturated solution: a solution that temporarily contains more solute than is capable of remaining dissolved in a solvent. Supersaturated solutions are unstable.

A solution forms when solute molecules are dissolved in solvent molecules. This process involves the following steps:

1. Solvent molecules are attracted to the surface of the solute.
2. Intermolecular bonds (*e.g.,* ion-dipole bonds, hydrogen bonds, *etc.*) between solvent and solute particles pull the solute particles (ions, molecules, *etc.*) apart and into the solvent.



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Enthalpy (Heat) of Solution

If a solute dissolves in a solvent, it is ***always*** the case that more energy had to be released when the solvent-solute intermolecular bonds are formed than it took to pull the solute particles apart. This means that the combined intermolecular forces between the solvent and solute particles are stronger than the intermolecular forces that had held the particles together in the solute.

If a solute does not dissolve, this means it would have taken more energy to pull the solute particles apart than the amount that would have been released by forming the solvent-solute intermolecular bonds. This means that the combined intermolecular forces between the solute particles are stronger than the combined intermolecular forces between solvent and solute particles.

This energy can exist in two forms: enthalpy (heat) and entropy (how much the energy is spread out among the particles). Enthalpy and entropy are discussed in more detail in the chapter on "Thermochemistry (Heat)," starting on page 433.

If the solution gets hotter as the solute dissolves, this means energy was *released* in the form of enthalpy (heat).

If the solution gets colder as the solute dissolves, this means heat energy was *absorbed*. However, it still must be true that energy had to be released when the solute dissolved. (Otherwise it would not have done so.) This means that entropy must have increased, and that more energy was released in the form of entropy than was absorbed in the form of enthalpy (heat).

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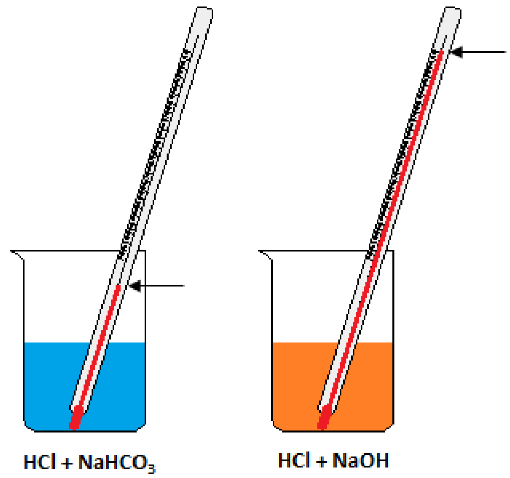
For example, if you mix a strong acid with sodium hydroxide (a strong base), the solution gets very hot. (In fact, it can get hot enough to boil!) However, if you mix a strong acid with sodium carbonate ("soda ash") or sodium hydrogen carbonate (baking soda), the solution gets cold, because it releases CO_2 gas. As the gas is released, its heat energy spreads out into the surroundings (the room), which is a large increase in entropy. This increase in entropy releases so much energy that it takes thermal energy (heat) away from the solution, cooling it off. This is why baking soda is a good choice for neutralizing strong acids, whereas sodium hydroxide would be a poor choice.



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Polar *vs.* Non-Polar Solvents

Whether a solute will dissolve in a solvent depends on the intermolecular forces between both the solvent and solute molecules. In both cases, the governing factor is the greater strength of ion-ion and dipole-dipole interactions as compared with London dispersion forces.

Polar Solvent

<u>polar or ionic solute</u>: polar or ionic solute particles are attracted to the positive and negative poles of the solvent molecules, which results in the solute dissolving.

<u>non-polar solute</u>: non-polar solute particles are not attracted to the solvent molecules. However, the solvent molecules are attracted to each other, and they exclude the solute.

Non-Polar Solvent

<u>polar or ionic solute</u>: polar or ionic solute particles are attracted to each other, but are not attracted to the solvent molecules, so they exclude the solvent and do not dissolve. (They form a precipitate, which means the solute falls (precipitates) to the bottom of the container.)

<u>non-polar solute</u>: neither the solute particles nor solvent molecules are strongly attracted to each other. (Both exhibit only London dispersion forces.) Because neither excludes the other, they spread out and intermingle freely.

A simple one-sentence statement of the above is *"<u>Like dissolves like.</u>"*

This statement applies to liquids as well as solids. Polar liquids are miscible with each other; non-polar liquids are miscible with each other; however, non-polar liquids are not miscible with polar liquids. This is why "oil and water do not mix."

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Factors that Affect the Rate of Dissolution

- temperature: solutes dissolve faster at higher temperatures because the molecules have more kinetic energy, which helps to pull the solute molecules apart.
- concentration: as the concentration increases, more and more solvent molecules are occupied with solute particles. The higher the concentration of the solute, the more slowly the solute will dissolve.
- surface area: because the solvent-solute interactions happen at the surface of the solute particles, the greater the surface area, the faster the solvent dissolves.
- pressure: for gases dissolving in liquids, increasing the pressure will force more gas molecules into the liquid, increasing the rate at which the gas dissolves.
- mixing: the faster a solution is mixed/stirred, the faster the solute will dissolve. This is because the mixing pulls dissolved solute particles away from each other, which is similar to lowering the concentration around the individual molecules.

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Homework Problems

For each solute given, indicate whether water (H_2O) or cyclohexane (a nonpolar molecule) would be a better solvent.

1. KNO_3

2. paraffin (long-chain hydrocarbons, such as $C_{20}H_{42}$ or $C_{40}H_{82}$)

3. ethyl alcohol (CH_3–CH_2–OH)

4. acetic acid ($HC_2H_3O_2$)

5. mineral oil

6. ammonia (NH_3)

7. gasoline (short-chain hydrocarbons such as octane, C_8H_{18})

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