

CHEMISTRY The Central Science

Chapter 13 Properties of Solutions

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Solutions

- Homogeneous mixtures
 - composition may vary from one sample to another
 - appears to be one substance, though really contains multiple materials
- Most homogeneous materials we encounter are actually solutions
 - e.g., air and seawater



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Examples of Solutions

State of Solute	State of Solvent	Example
Gas	Gas	Air (O ₂ in N ₂)
Gas	Liquid	Club Soda $(CO_2 \text{ in } H_2O)$
Gas	Solid	Catalytic Converter (CO into Pt)
Liquid	Gas	Water Vapor in Air
Liquid	Liquid	Vodka (ethyl alcohol in H ₂ O)
Liquid	Solid	Dental Amalgams (Hg in Ag and other metals)
Solid	Gas	Naphthalene in Air
Solid	Liquid	Seawater
Solid	Solid	Brass or other alloys (Zn in Cu)

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How Does a Solution Form?

- As a solution forms, the solvent pulls solute particles apart and surrounds, or solvates, them.
- When water is the solvent, the process is called specifically *hydration*.





Intermolecular Forces and the Solution Process

- Energy changes in the formation of most solutions also involve differences in attractive forces between the particles
- For the solvent and solute to mix you must overcome
 - 1. all of the solute–solute attractive forces
 - 2. some of the solvent–solvent attractive forces
 - both processes are endothermic
- At least some of the energy to do this comes from making new solute–solvent attractions
 - which is exothermic



Intermolecular Attractions





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Solution Interactions





Solution



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Heat of Solution

- When some compounds, such as NaOH, dissolve in water, a lot of heat is released
 - the container gets hot
- When other compounds, such as NH₄NO₃, dissolve in water, heat is absorbed from the surroundings
 - the container gets cold
- Why is this?



Energetics of Solution Formation: the Enthalpy of Solution

- To make a solution you must
- 1. overcome all attractions between the solute particles; therefore ΔH_{solute} is **endothermic**
- 2. overcome some attractions between solvent molecules; therefore $\Delta H_{solvent}$ is **endothermic**
- 3. form new attractions between solute particles and solvent molecules; therefore ΔH_{mix} is **exothermic**
- The overall ΔH for making a solution depends on the relative sizes of the ΔH for these three processes $\Delta H_{sol'n} = \Delta H_{solute} + \Delta H_{solvent} + \Delta H_{mix}$



Solution Process



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1. Add energy in to overcome all solute-solute attractions 2. Add Energy in 80 Uters8 Ment attractions for the solute attractions



Energetics of Solution Formation

If the total energy cost for breaking attractions between particles in the pure solute and pure solvent is besateran the endergy mend a sete as ed in making the new attractions between the solute and solvent, the overall process will be endothermicic



Solution Equilibrium

NaCl(s)

When sodium chloride is first added to water, sodium and chloride ions begin to dissolve into the water.



$$NaCl(s) \longrightarrow Na^+(aq) + Cl^-(aq)$$

As the solution becomes more concentrated, some of the sodium and chloride ions can begin to recrystallize as solid sodium chloride.



(b) Dissolving

$$NaCl(s) \implies Na^+(aq) + Cl^-(aq)$$

When the rate of dissolution equals the rate of recrystallization, dynamic equilibrium has been reached.



Rate of dissolution = Rate of recrystallization (c) Dynamic equilibrium



(a) Initial

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Attention!



- Just because a substance disappears when it comes in contact with a solvent, it doesn't mean the substance dissolved.
- Dissolution is a physical change you can get back the original solute by evaporating the solvent.
- If you can't, the substance didn't dissolve, it reacted.



Solutions

- **Dissolve:** solute + solvent \rightarrow solution.
- Crystallization: solution \rightarrow solute + solvent.
- Saturation: crystallization and dissolution are in equilibrium.
- Solubility: amount of solute required to form a saturated solution.
- Supersaturated: a solution formed when more solute is dissolved than in a saturated solution.



Factors Affecting Solubility

1. Nature of Solute / Solvent.

2. Temperature -

i) Solids/Liquids- Solubility increases with Temperature

Increase K.E. increases motion and collision between solute / solvent.

ii) gas - Solubility decreases with Temperature

Increase K.E. result in gas escaping to atmosphere.

3. Pressure Factor -

i) Solids/Liquids - Very little effect

Solids and Liquids are already close together, extra pressure will not increase solubility.

ii) gas - Solubility increases with Pressure.

Increase pressure squeezes gas solute into solvent.





"like dissolves like"

Two substances with similar *intermolecular* forces are likely to be soluble in each other.

- non-polar molecules are soluble in non-polar solvents CCl_4 in C_6H_6
- polar molecules are soluble in polar solvents C_2H_5OH in H_2O
- ionic compounds are more soluble in polar solvents NaCl in H_2O or $NH_3(l)$



Factors Affecting Solubility

- Polar substances tend to dissolve in polar solvents.
- Nonpolar substances tend to dissolve in nonpolar solvents.
- The more similar the intermolecular attractions, the more likely one substance is to be soluble in another.

TABLE 13.3 Solubilities of Some Alcohols in Water and in Hexane*			
Alcohol	Solubility in H ₂ O	Solubility in C ₆ H ₁₄	
CH_3OH (methanol)	∞	0.12	
CH_3CH_2OH (ethanol)	∞	∞	
CH ₃ CH ₂ CH ₂ OH (propanol)	∞	∞	
CH ₃ CH ₂ CH ₂ CH ₂ OH (butanol)	0.11	∞	
CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ OH (pentanol)	0.030	∞	
CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ OH (hexanol)	0.0058	∞	
CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ OH (heptanol)	0.0008	∞	

*Expressed in mol alcohol/100 g solvent at 20°C. The infinity symbol indicates that the alcohol is completely miscible with the solvent.



Factors Affecting Solubility

- Vitamin A is soluble in nonpolar compounds (like fats).
- Vitamin C is soluble in water.





Gases in Solution

- In general, the solubility of gases in water increases with increasing mass.
- Larger molecules have stronger dispersion forces.

in Water at 20°C, with 1 atm Gases Pressure		
Gas	Solubility (<i>M</i>)	
N ₂ CO O ₂ Ar Kr	0.69×10^{-3} 1.04×10^{-3} 1.38×10^{-3} 1.50×10^{-3} 2.79×10^{-3}	



0.008 Solubility, g in 100 g water 0.007 0.006 0.005 • N2 0.004 **O2** 0.003 0.002 0.001 0 10 0 20 30 40 50 60 70 80 90 100 110 Temperature, °C

Solubility of Gases in Water at Various Temperatures



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Temperature

- The opposite is true of gases:
 - Carbonated soft drinks are more "bubbly" if stored in the refrigerator.
 - ➢ Warm lakes have less
 dissolved O₂ in them than
 cool lakes.



Pressure





- The solubility of liquids and solids does not change significantly with pressure.
- The solubility of a gas in a liquid is directly proportional to its pressure.



Henry's Law

$$S_g = kP_g$$

where

- S_g is the solubility of the gas;
- *k* is the Henry's law constant for that gas in that solvent;
- P_g is the partial pressure of the gas above the liquid.





Henry's Law

TABLE 12.4 Henry's LawConstants for Several Gasesin Water at 25 °C

Gas	k_H (M∕atm)
02	$1.3 imes10^{-3}$
N ₂	$6.1 imes 10^{-4}$
CO ₂	$3.4 imes10^{-2}$
NH_3	$5.8 imes 10^1$
He	$3.7 imes10^{-4}$

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Factors Affecting Solubility

Pressure Effects

- Carbonated beverages are bottled with a partial pressure of $CO_2 > 1$ atm.
- As the bottle is opened, the partial pressure of CO₂ decreases and the solubility of CO₂ decreases.
- Therefore, bubbles of CO₂ escape from solution.





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Henry's Law

The effect of partial pressure on solubility of gases

At pressure of few atmosphere or less, solubility of gas solute follows Henry Law which states that the amount of solute gas dissolved in solution is directly proportional to the amount of pressure above the solution.

 $\mathbf{c} = \mathbf{k} \mathbf{P}$

c = solubility of the gas (M)k = Henry's Law ConstantP = partial pressure of gas

Henry's Law Constants (25°C), k

- N₂ 8.42 •10⁻⁷ M/mmHg
- O₂ 1.66 •10⁻⁶ M/mmHg
- CO₂ 4.48•10⁻⁵ M/mmHg



Lowering the Pressure Above the Solution (by opening bottle) Decreases Gas Solubility

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Effervescence of a Soft Drink



Henry's Law of Gas Solubility

Problem: The lowest level of oxygen gas dissolved in water that will support life is $\sim 1.3 \times 10^{-4}$ mol/L. At the normal atmospheric pressure of oxygen is there adaquate oxygen to support life?

Plan: We will use Henry's law and the Henry's law constant for oxygen in water with the partial pressure of O_2 in the air to calculate the amount.

Temperature



Generally, the solubility in liquid solvents increases with increasing temperature (solid solutes).



Practice – Decide if each of the following solutions is saturated, unsaturated, or supersaturated

50 g KNO₃ in 100 g H₂O @ 34 °C saturated

50 g KNO₃ in 100 g H₂O @ 50 °C unsaturated

50 g KNO₃ in 50 g H₂O @ 50 °C supersaturated

100 g NH₄Cl in 200 g H₂O @ 70 °C unsaturated

100 g NH₄Cl in 150 g H₂O @ 50 °C supersaturated

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Solubility of Some Salts in Water

